06 – Renewable Energy Sources

Energetic characteristics and assessment of the potential of an area

Brussels, 27th October 2015

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MECA H417 / MECA H530 – Sustainable energy
A. General overview

http://atm.ulb.ac.be

Lesson plan

Content

1. Sun
2. Wind
3. River
4. Ocean (currents, tides, waves, salinity)
5. Natural heat flows and reservoirs
6. Biomass
7. Synthesis

a. Form and origin (why, where)
b. Power
c. Measurements
d. Annual energy
e. Variability (short term, daily, seasonal)
f. Energetic conversion precautions

General learning outcome

You are able :

- To describe renewable energy sources and their energy conversion aspects

Specific learning outcomes

- To describe the presented concept (ie look at the content)
- To give the main energetic features of each RES (Origin and form, Power, Annual energy, Variability (short term, daily, Seasonal), Measurements, Energetic conversion precautions)
- Assess energy potential of an area
- OoM: Belgian annual energy per area and variability: Sun, Wind, Hydro, Natural heat, Biomass

Bibliography extract

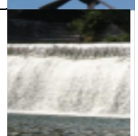
EVERETT

HERMANS

MACKAY
- 1

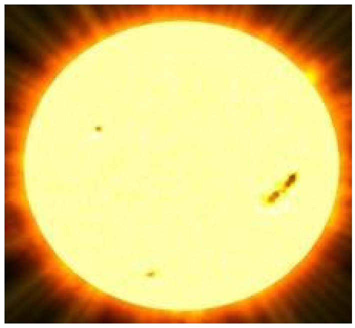
Other material
- 1

Identification of the renewable energy sources (RES)

RES		Form	
Wind		**Kinetic energy** (sensible)	
Watercourses **Tides - Current - Waves** **Salinity gradient**		**Gravitational energy** (potential) **Gravitational energy** and/or **Kinetic energy** (sensible) **Electrochemical energy** (potential)	
Sun		**Radiation** (sensible)	
Biomass	**Food** **Combustible** **Biogas** **Biofuel**	**Chemical energy** (potential)	
« Natural » Heat Flow/Reservoir (geothermal, oceanic or indirect solar heat)		**Heat** (sensible)	

(Others : Lightning, …)

SUN



a. Form (radiation) and origin (black body moving)
b. Power
c. Measurements (power, energy, shadows)
d. Annual and monthly energy
e. Day, seasonal, clouds variability
f. Energetic conversion precautions

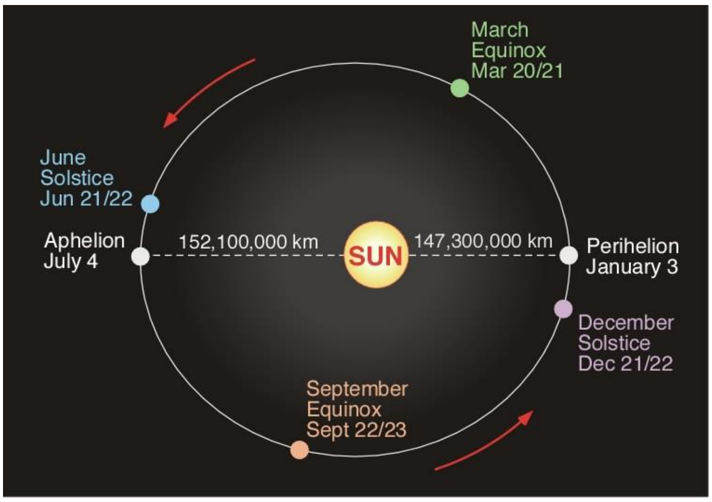
References :

- Renewable energy – G. Boyle – RE Boyle : Chapter 2 (p21-50); Chapter 3 (p 70)
- Photovoltaic Systems - Planning and Installing - A guide for installers, architects and engineers - Deutsche Gesellschaft Fur Sonnenenergie Dgs

1.a. Sun

Form = Radiation from the sun (Heat transfer from sun to earth through the void and atmosphere)

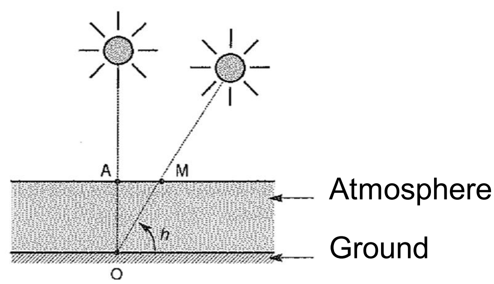
Sun – Earth distance : 147-152 million km -> Ray route time : 500 s



Path in the atmosphere

Air Mass (AM)

AM0 : outside earth's atmosphere AM0



AM = 1 / sin h

h: incidence

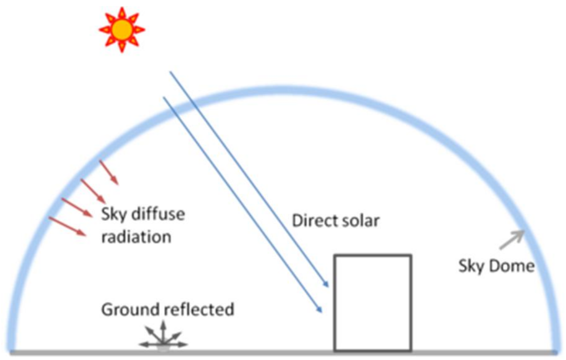
Incidence 90° -> AM = 1
Incidence 62° -> AM 1.1
Incidence 41.8° -> AM 1.5
Incidence 30° -> AM 2
Incidence 14.5° -> AM 4

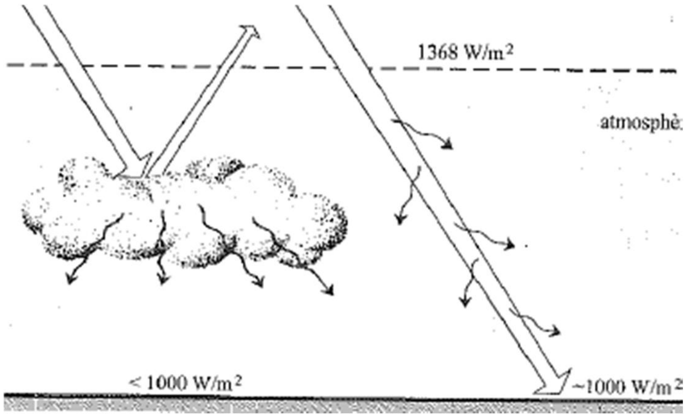
1.a. Sun radiation

When the sun's rays hit the atmosphere light is scattered depending on the AM, the cloud cover and the air clearness.

Sun radiation = diffuse + direct radiations
Diffuse radiation : blue from atmosphere nitrogen, white from clouds or dust).
Direct radiation : light that appears straight from the sun and/or reflected by reflective surfaces (ground, snow, water, white cloud)

Only direct radiation can be concentrated.





1.a. Solar spectra

Sun = 5,780 °K black body -> Radiation emission following a spectrum, that is a lot of ray with wavelengths from 0.2 to 2.5 µm with a defined power distribution : **Solar spectrum.**
At sea level, there are different spectra depending on the crossed atmosphere (AM, clearness and absorption wavebands (O_3, O_2, CO_2, H_2O)).

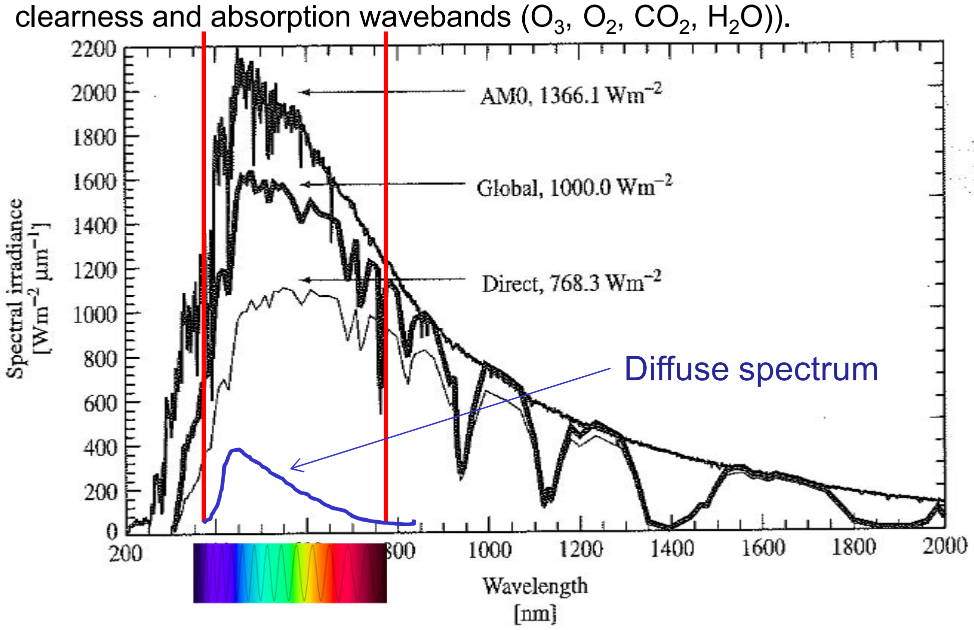
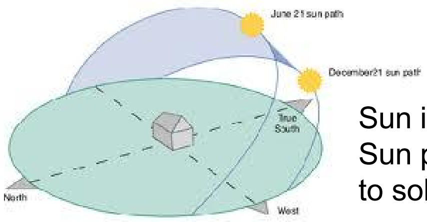


Figure 16.1 Global, Direct, and AM0 reference spectra listed in Tables 16.2 and 16.3. Adapted with permission from the Annual Book of ASTM Standards, Copyright ASTM [10, 12, 13]
Ref : Handbook of photovoltaic science and engineering

<u>Energy distribution</u>
AM0
UV : 6,4 %
Visible : 48,0%
IR : 45,6 %

AM1,5
UV : 3 %
Visible : 42 %
IR : 55 %



1.a. Sun path diagram - Belgium

Sun is a moving resource (referring to Earth centrum)
Sun paths diagram gives sun position (height and azimuth) in relation to solar time.

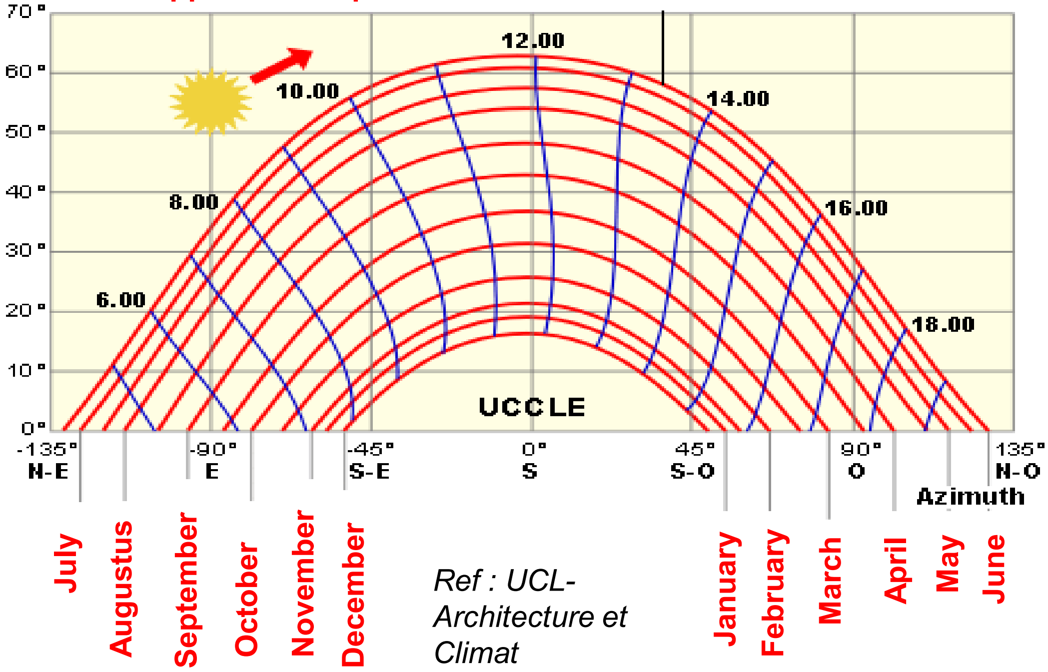
Latitude 50,8°

Apparent sun path for each month based on the time

Remarks :
Solar time is not local time.

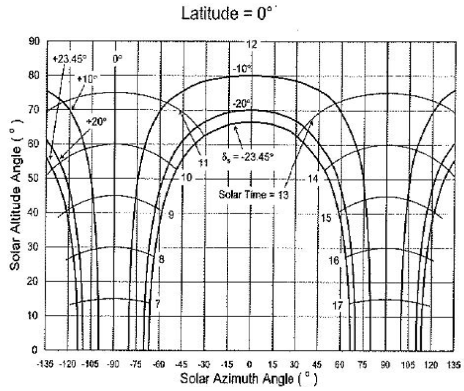
Approximately 12:00 Summer solar time = 14h00 clock time

Winter solar time 12:00 = 13:00 clock time

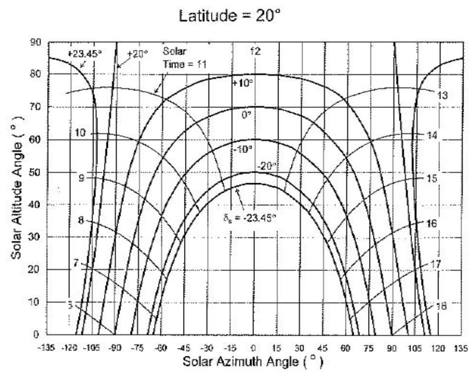


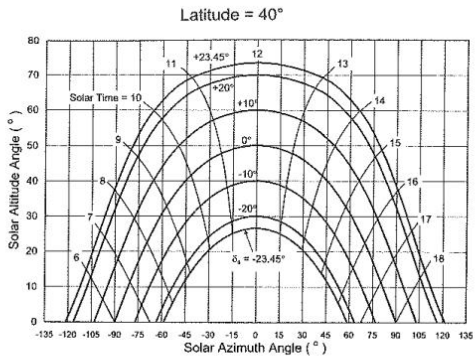
Ref : UCL-Architecture et Climat

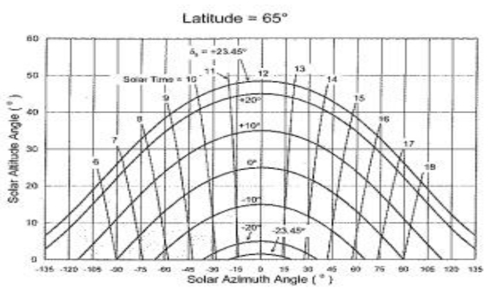
1.a. Sun path diagrams change with latitude



Solar energy pocket - ISES

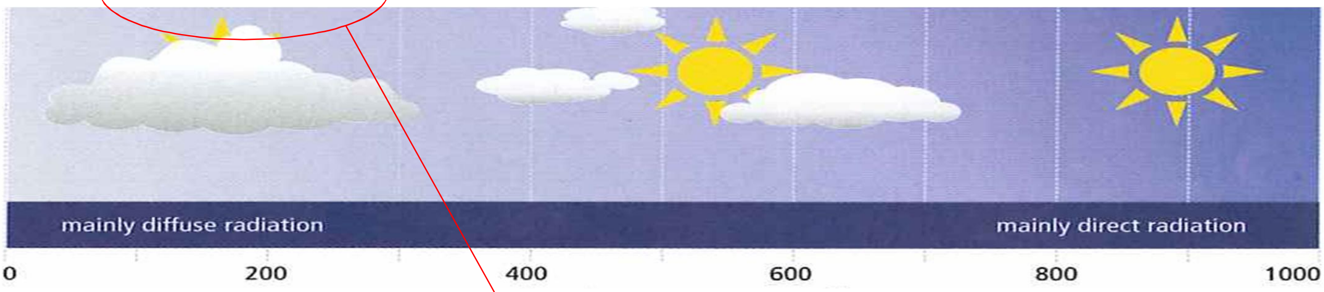




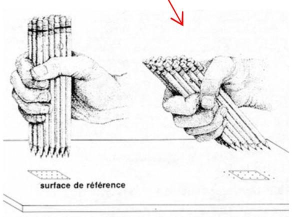


1.b. Radiation power

Global AM 0 : 1,368 W/m²
Global AM 1.5 : 1,000 W/m²
Actual : 0 to 1,000 W/m² depending on sun incidence, clouds cover, atmosphere clearness and surface tilt and orientation.



Clear sky at noon : 1,000 W/m²
Little mist in summer : 800 W/m² and 400 W/m² in winter
Without direct radiation, less than 200 W/m².
Fog : less than 80 W/m²



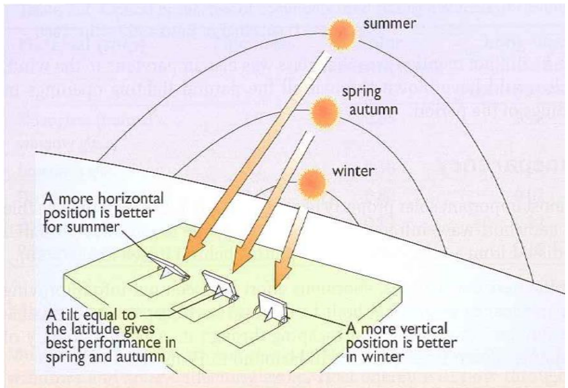
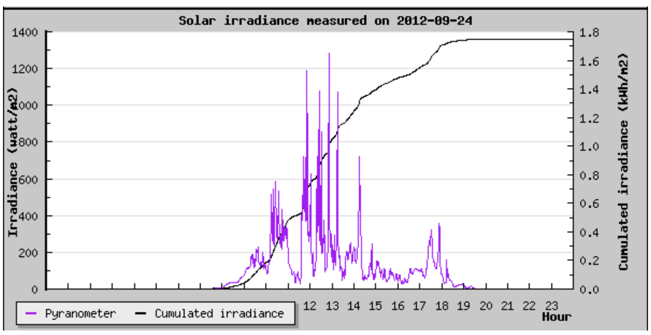


Figure 2.12 Optimizing the tilt for different seasons

1.c. Power measurement

Measuring device :
- Solarimeter
- *Piranometer*

Online Meteo data
- http://www.eausolaire.eu - located in Louvain-la-Neuve, Belgium (longitude: 4° 36'; latitude: 50° 40' 6)
  Azimuth : South –Tilt 40°



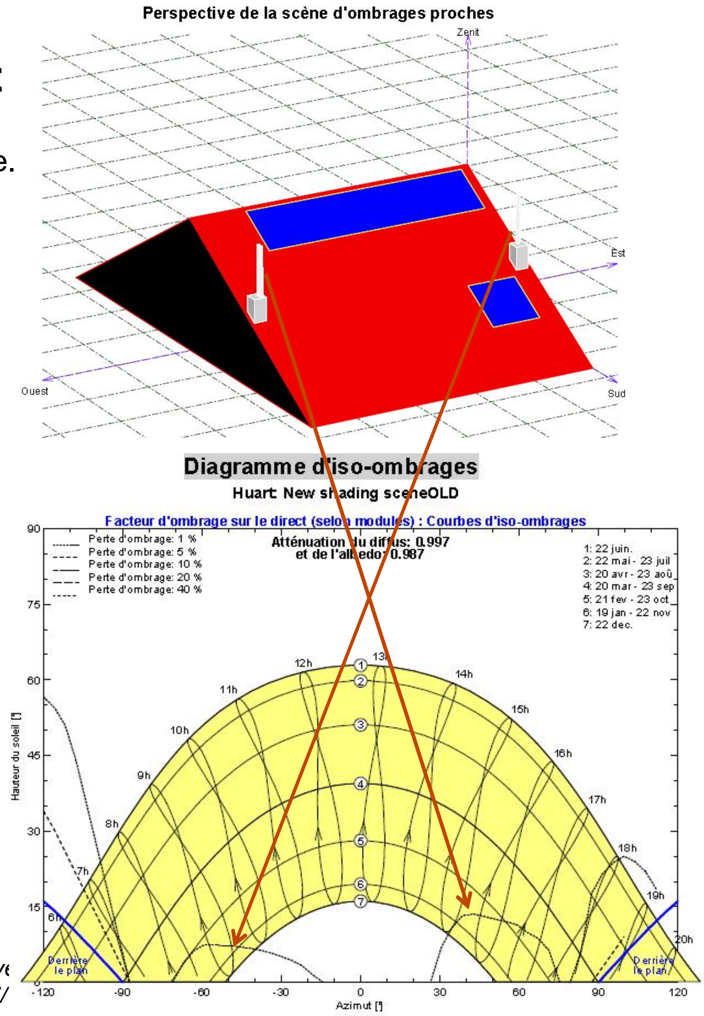
1.c. Skyline measurement

<u>Measurement of shadows on a surface</u> (i.e. roof)

Skyline = Draw the shadows on the sky path diagram

- Manual method

Using : Compass + tilt meter + camera



1.c. Skyline with suneye

Solar site analysis – Skyline i.e. (1/2

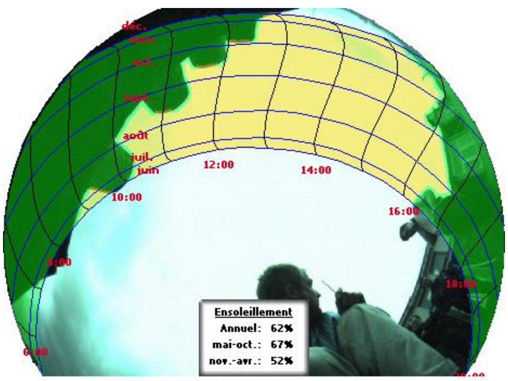
Input : Picture with round view camera

(Tilt : horizontal – Orientation : South)

Sunpath integrated

Output : Skyline

Sun Eye



Données par Solmetric SunEye™ -- www.solmetric.com

1.d. Annual Belgian solar irradiation

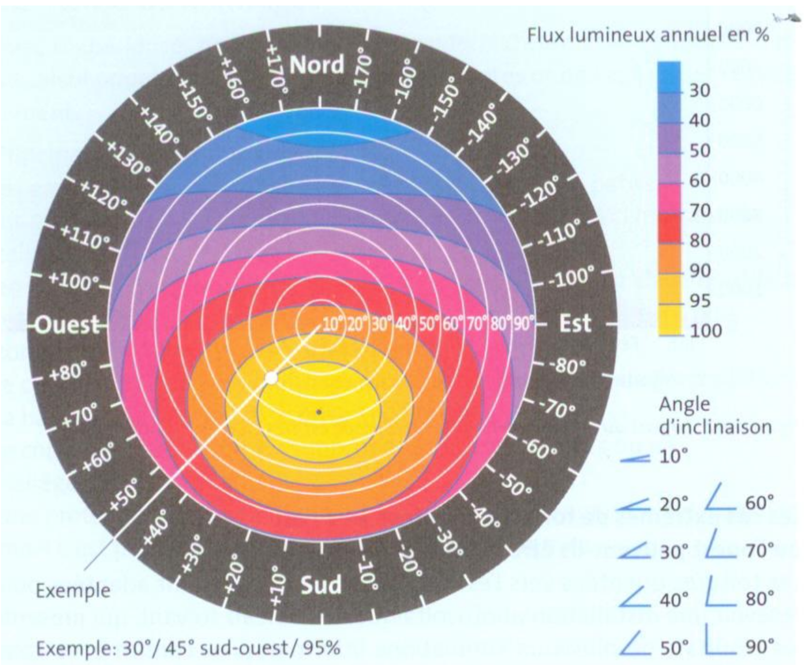
Brussels (IRM)	Global kWh/m² y (horizontal)	Direct / Global	Annual sunshine hours (h)	Solar PV production (kWh/kWp) South - 35°
Source	IRM		IRM	energizAIR
Norm	980	40%	1 546	971
Norm 2014	1 014	47%	1 575	977
2002	990	44%		ND
2003	1 151	52%		ND
2004	1 034	44%		ND
2005	1 056	47%		ND
2006	1 040	47%	1 510	ND
2007	998	45%	1 472	ND
2008	1 023	45%	1 487	ND
2009	1 087	47%	1 699	985
2010	1 056	47%	1 556	923
2011	1 087	49%	1 782	1 032
2012	1 041	45%	1 529	964
2013	1 037	44%	1 510	953
2014	1 067	45%	1 634	1 003

Year horizontal figure Uccle – IRM - Renouvelle n°67

Order of magnitude
1 m² horizontal **1.000 kWh/y** (2.8 kWh/d)

Optimal yearly exposure
Tilt 35° – South: 1.136 kWh/y (1,000/0.88)

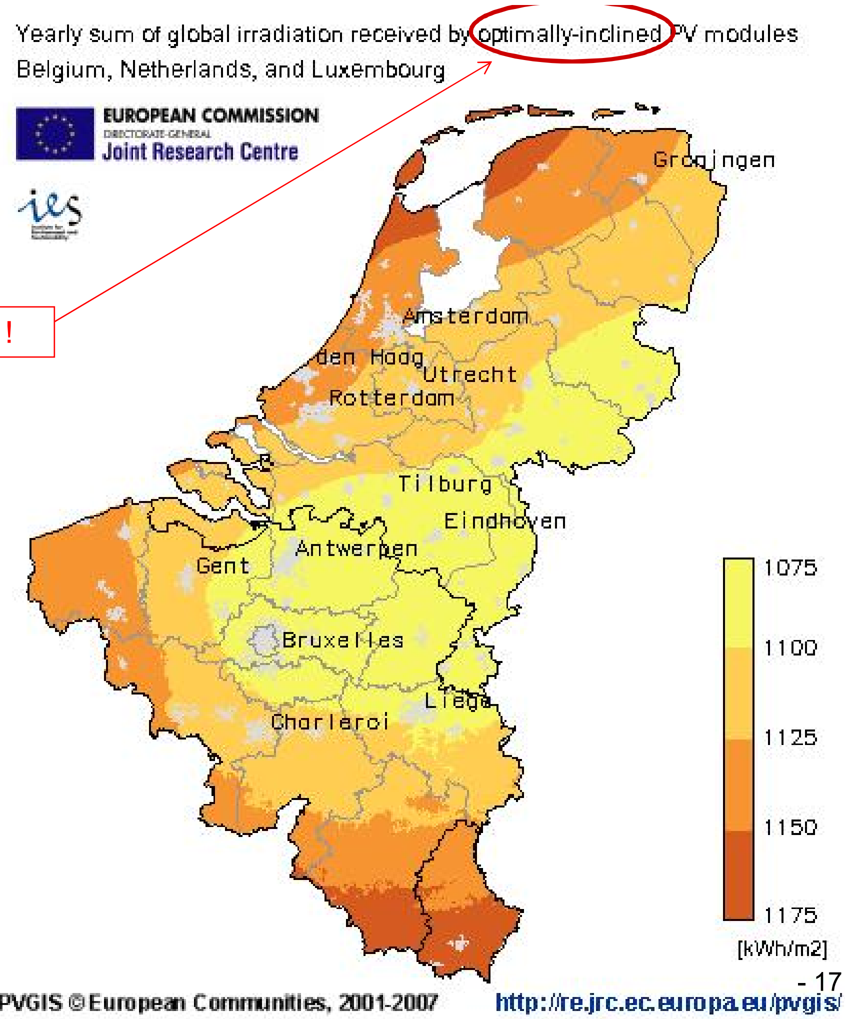
1.d. Tilt and orientation effect on annual energy Belgium



Azimuth
North: 0°
East : 90°
South : 180°
West: 270°

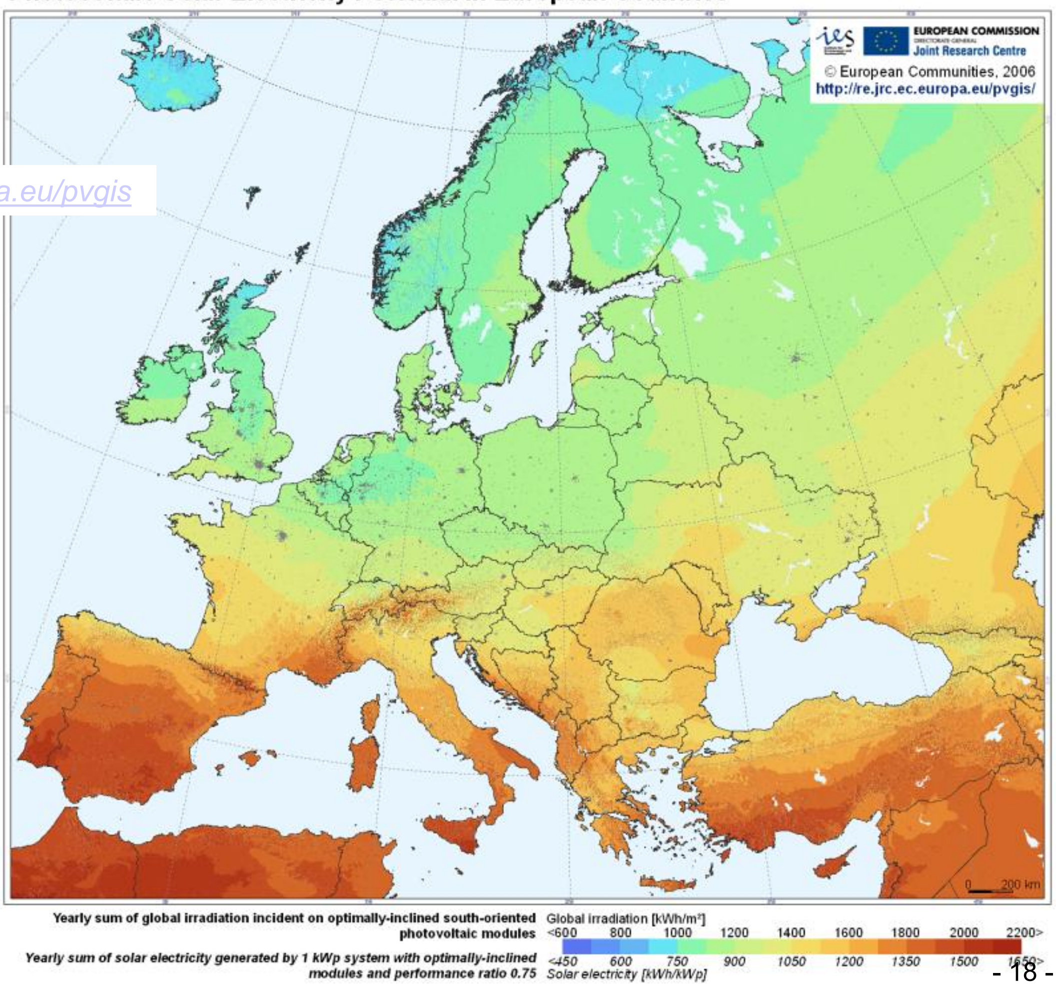
orientation	inclinaison (°)						
	0	15	25	35	50	70	90
est	88%	87%	85%	83%	77%	65%	50%
sud-est	88%	93%	95%	95%	92%	81%	64%
sud	88%	96%	99%	max 100%	98%	87%	68%
sud-ouest	88%	93%	95%	95%	92%	81%	64%
ouest	88%	87%	85%	82%	76%	65%	50

1.d. Annual Global irradiation - Benelux

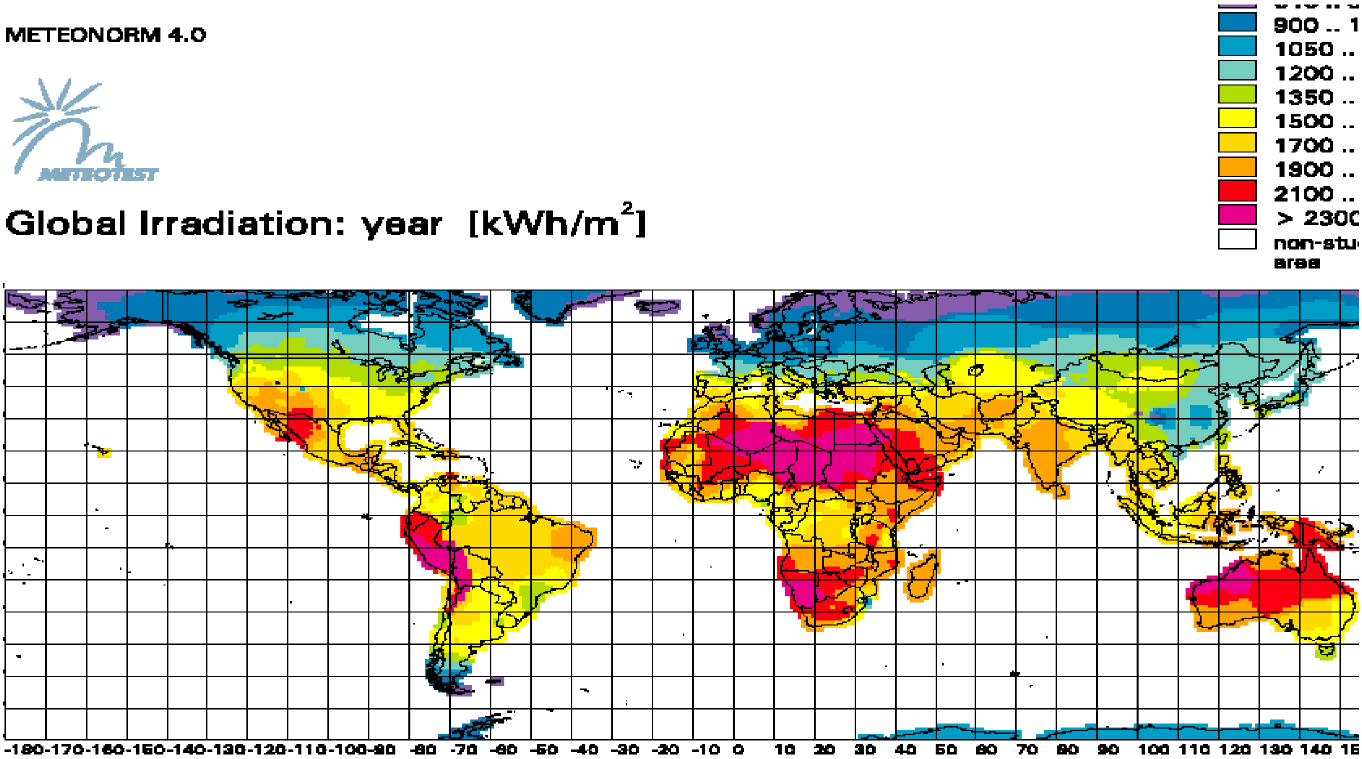


Be carefull !

Photovoltaic Solar Electricity Potential in European Countries



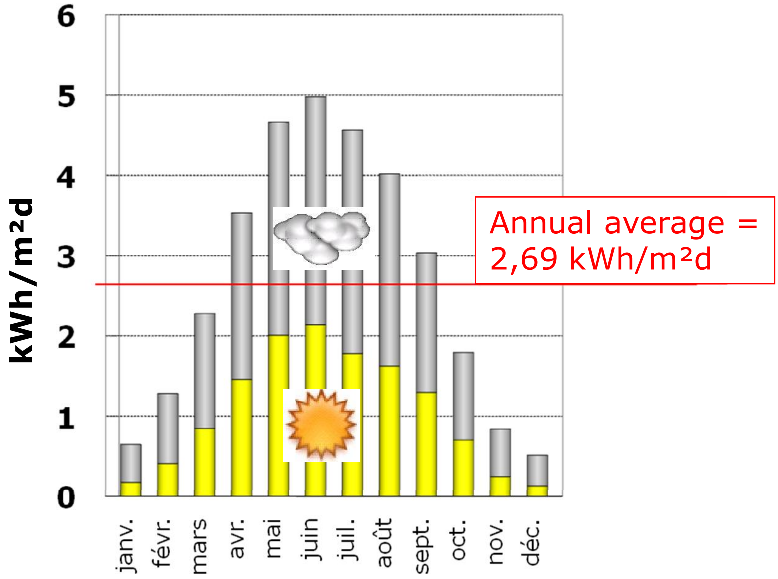
http://re.jrc.ec.europa.eu/pvgis



1.e. Monthly variability – Belgium - Normal

Unequally year distribution
Horizontal tilt, 8 times more in June than in December.

Figures change with tilt and orientation.

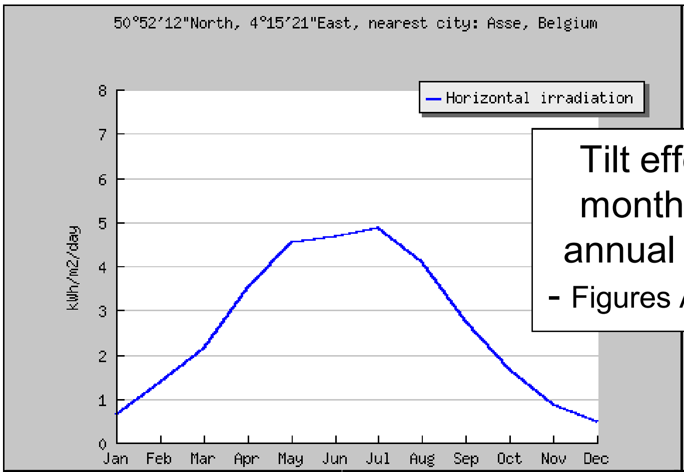


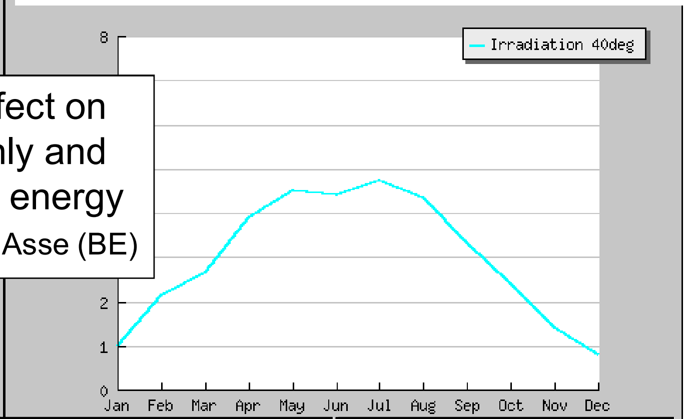
	janv.	févr.	mars	avr.	mai	juin	juil.	août	sept.	oct.	nov.	déc.
--------Diffuse--------	0,48	0,87	1,43	2,07	2,65	2,84	2,78	2,39	1,74	1,09	0,60	0,38
--------Direct---------	0,18	0,41	0,85	1,46	2,01	2,14	1,78	1,63	1,30	0,71	0,25	0,13

Normal monthly radiation on an horizontal area – Brussels (Belgium) - IRM

Tilt effect on monthly and annual energy - Figures Asse (BE)

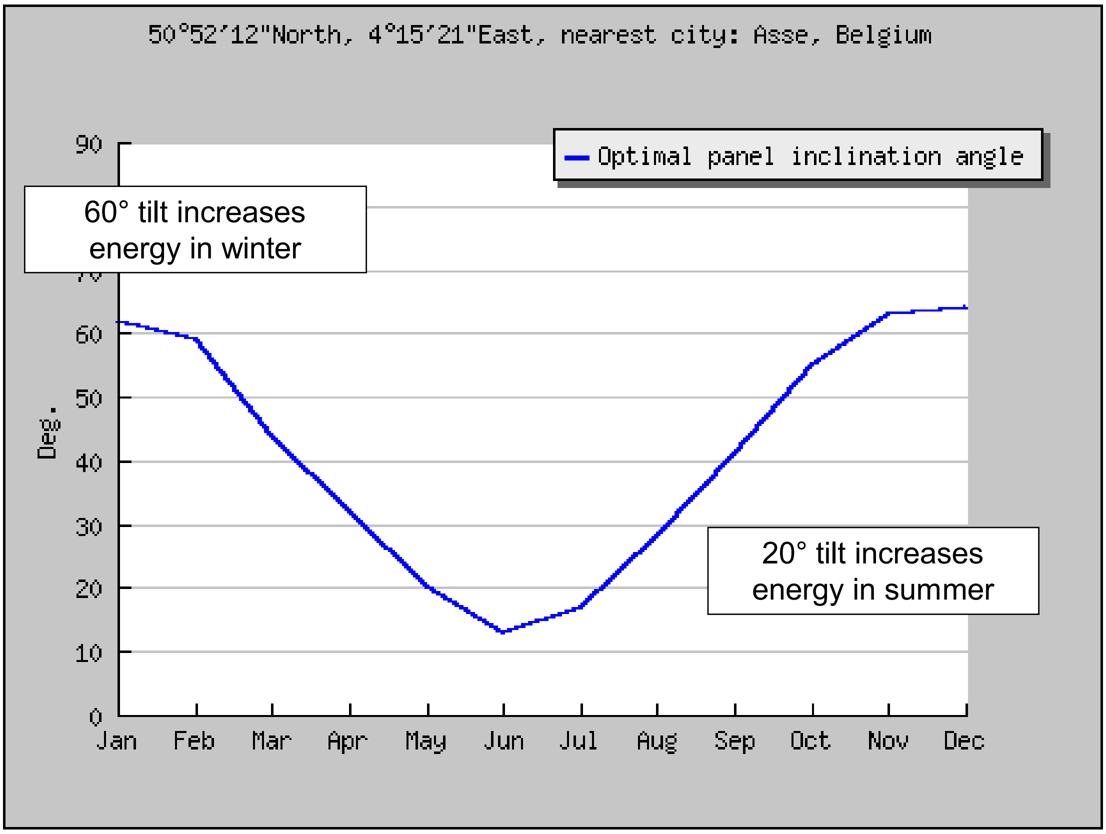
http://re.jrc.ec.europa.eu/solarec





Irradiation at inclination:		Irradiation at inclination:		Irradiation at inclination:		Irradiation at inclination:	
0 deg.	Wh/m²/j	25 deg.	Wh/m²/j	40 deg.	Wh/m²/j	90 deg.	Wh/m²/j
Jan	636	Jan	891	Jan	992	Jan	961
Feb	1386	Feb	1926	Feb	2131	Feb	1983
Mar	2157	Mar	2564	Mar	2659	Mar	2081
Apr	3526	Apr	3910	Apr	3907	Apr	2611
May	4534	May	4693	May	4521	May	2605
Jun	4660	Jun	4663	Jun	4413	Jun	2393
Jul	4864	Jul	4959	Jul	4737	Jul	2615
Aug	4099	Aug	4426	Aug	4358	Aug	2738
Sep	2755	Sep	3245	Sep	3342	Sep	2500
Oct	1675	Oct	2203	Oct	2384	Oct	2093
Nov	862	Nov	1244	Nov	1398	Nov	1365
Dec	494	Dec	700	Dec	784	Dec	773
Year	2644	Year	2957	Year	2973	Year	2059
kWh/m²/an	965	kWh/m²/an	1079	kWh/m²/an	1085	kWh/m²/an	752

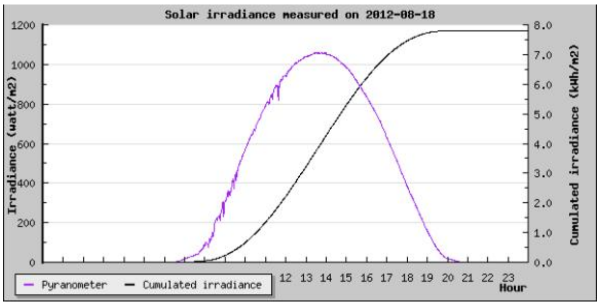
1.e. Monthly optimal panel tilt



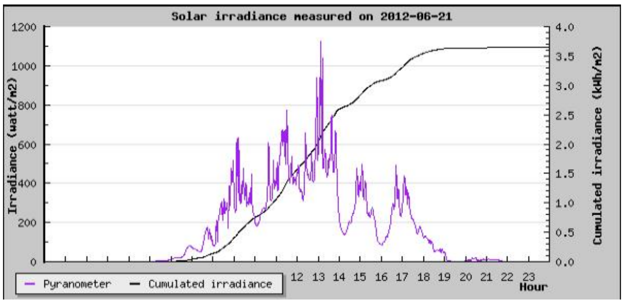
1.e. Variability of irradiation

- Day and night variation
- Seasonal variation
- Clouds effect

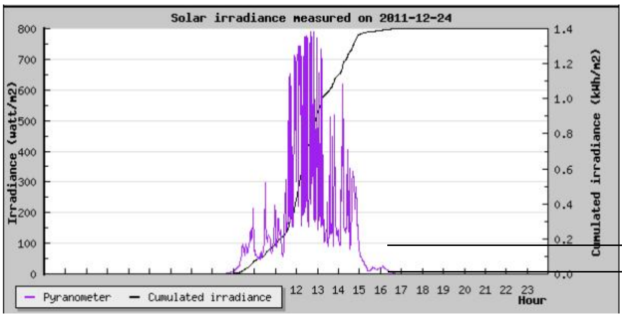
http://www.eausolaire.eu - *located in Louvain-la-Neuve, Belgium (longitude: 4° 36'; latitude: 50° 40' 6)*
Azimuth : South –Tilt 40°



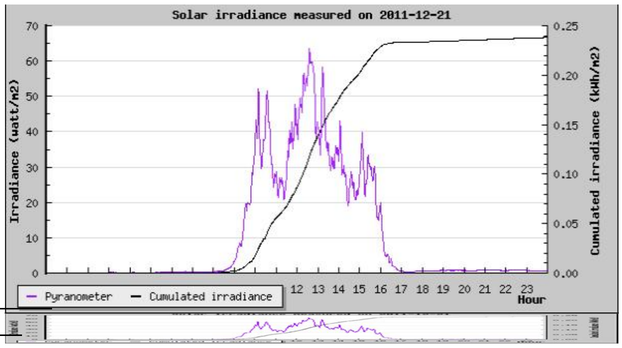
Summer clear day



Summer variable day

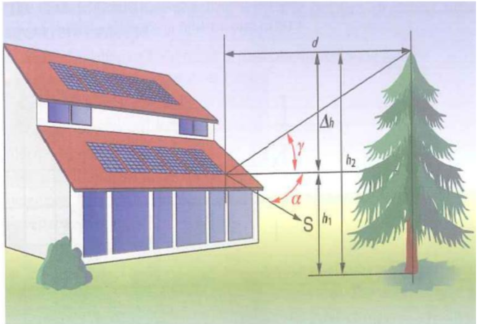


Winter variable day



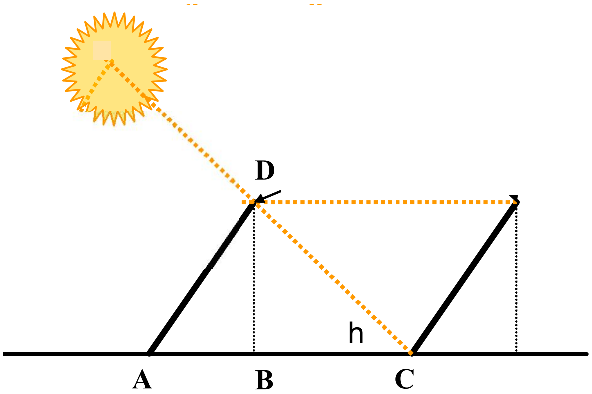
Winter cloudy day

1.f. Precaution - Avoid shadows (Direct radiation)



Particular attention should be paid to chimneys, antennae, offset building structure, surrounding trees, …

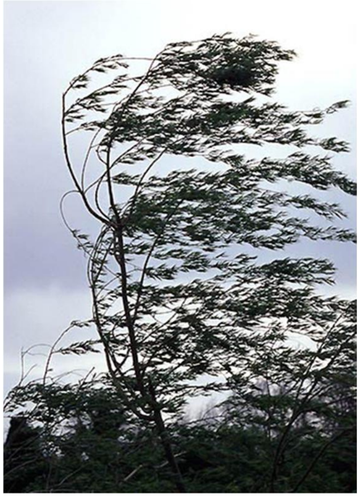
If solar panels are set out in several rows one behind one another, the distance between the rows must be greater enough so that no shading or as little as possible



BC = DB / tg(h)
h = Height in °

ie. DB=0,5
h = 21°
BC = 1,3 m
AD = 1 m tilt 30°

2. WIND



a. Form (kinetic) and origin (why air movement?)
b. Power
c. Measurements
d. Annual energy
e. Variability (minute, hour, day, week, season, year)
f. Energetic conversion precautions

References :

- Renewable Energy in Power Systems - Leon Freris - David Infield – Chapter Wind power p. 27-36
- Renewable energy – G. Boyle – Chapter 7 – p 244-249

2.a. Wind

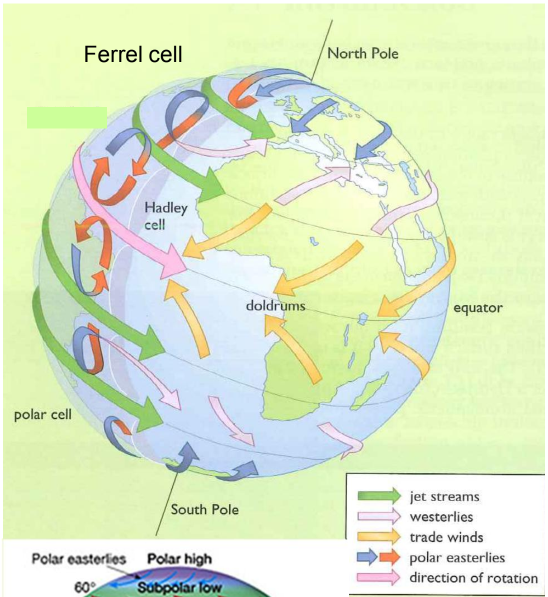
Form = Kinetic energy

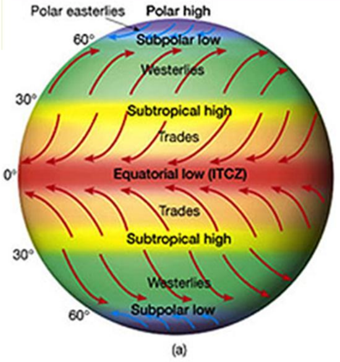
Wind is air mass movement driven by pressure variations due to thermal conditions on the earth.

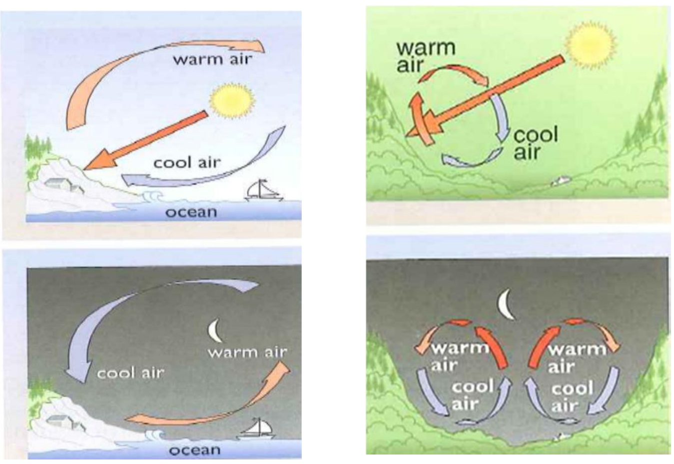
There are two different kind of wind:

- **Global earth wind systems** resulting from global air circulation (Hadley, Ferrel and Polar cells and Jet streams) and generating on the ground westerlies, trade winds, polar easterlies and cyclones.

- **Local wind patterns** (Sea breezes, Mountain valley winds)

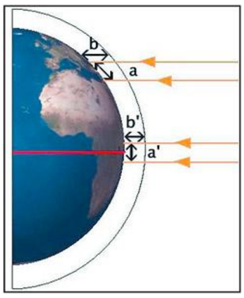






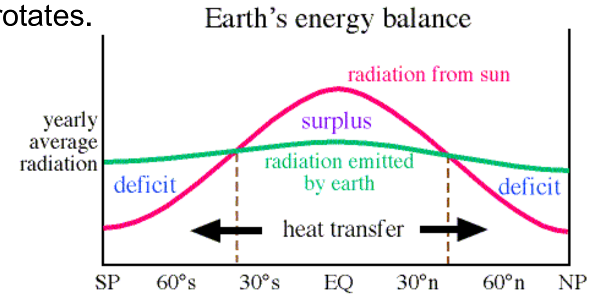
http://apollo.lsc.vsc.edu

2.a. Global earth wind systems - Origin



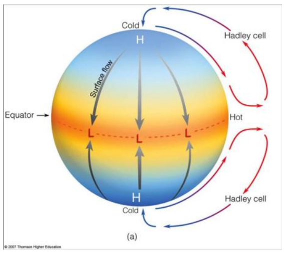
In low altitude atmosphere (troposphere), these movements of air are created on a global scale primarily by differential solar heating of the earth's atmosphere. Air in the equatorial regions is heated more strongly than at other latitudes, causing it to become lighter and less dense. This warm air rises to high altitudes and then flows northward and southward towards the poles where the air near the surface is cooler.

This movement ceases at about 30°, because earth rotates.



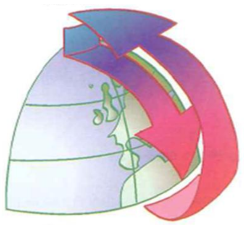
If you assume:
- earth is uniformly covered with water
- sun is directly over equator
- no rotation

you will end up with a single-cell pattern -->> warm air rises at the equator, cold air sinks at the poles

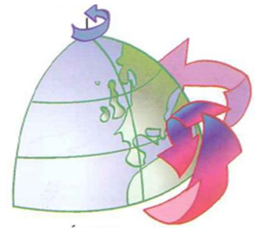


http://apollo.lsc.vsc.edu

If the Earth was not rotating



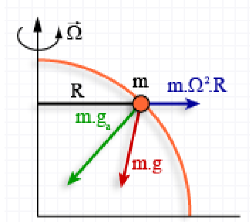
But it rotates !



2.a. Global earth wind systems

Afterwards, global earth wind systems are subjected to the effect of earth rotating.

Rotation speed at equator = 1,670 km/h
Rotation speed at 30° latitude ≈ 1,450 km/h
Rotation speed at x latitude ≈ 1,670 cos(x)



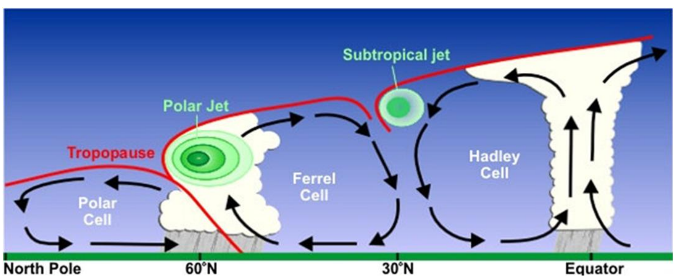
Centrifugal force

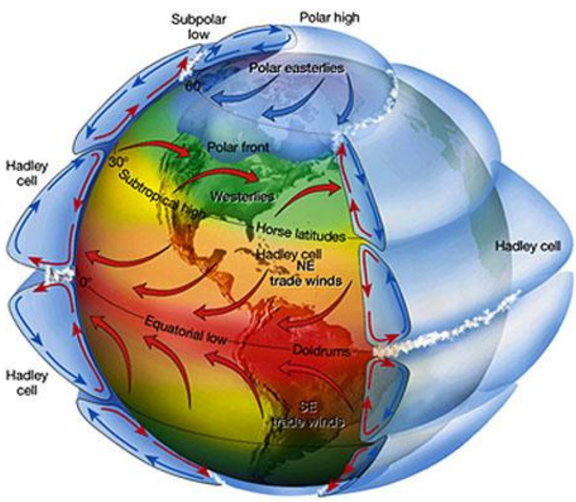
Hadley cell : Air mass motion to the Pole is subjected to the reduction of centrifugal force (go down) and Coriolis effect (acceleration to West).

Polar cell: Air mass motion from the Pole is subjected to the increase of centrifugal force (go up) and Coriolis effect (acceleration to East).

Ferrel cells : Cells between Hadley and Polar cells.

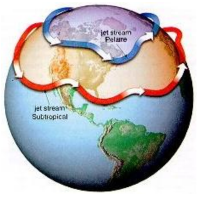
In low altitude, it creates Trade winds, Westerlies and polar easterlies.

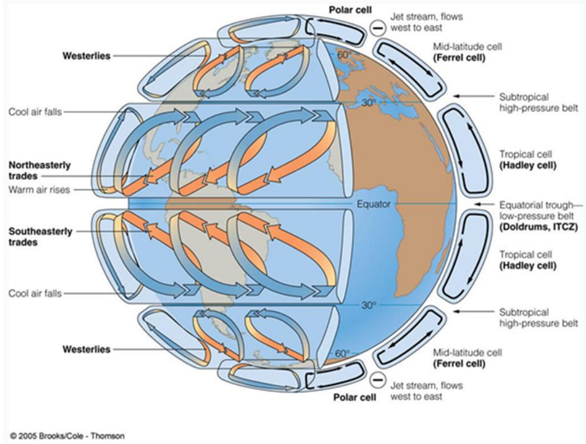




http://apollo.lsc.vsc.edu

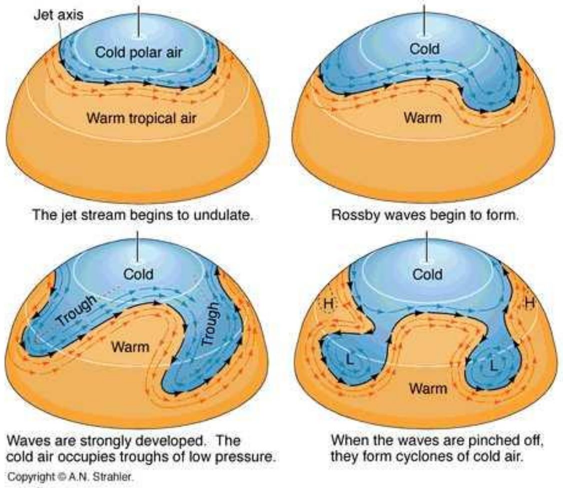
In the high troposphere, **Jet streams** are fast flowing (25 – 100 m/s), narrow (hundred km large and 1-5 km thickness) air currents located in the high troposphere. Like a snake chasing its own tail, these westerly winds undulate around the globe tracing the trajectory of the Jet Stream.
Jet streams belt is not stable: Ondulations are observed which creates regularly depression cyclones and high pressure cyclone.





In the low troposphere, **Westerlies**, are prevailing winds in the latitudes between 30 and 60 degrees, blowing from the high pressure area in the horse latitudes towards the poles.
These prevailing winds blow from the west to the east and steer extratropical cyclones in this general manner.

In Belgium, it's a 8 days cycle (HP – LP – HP) of this synoptic motion. More frequently in autumn, winter and spring than summer (Vanderhoven).



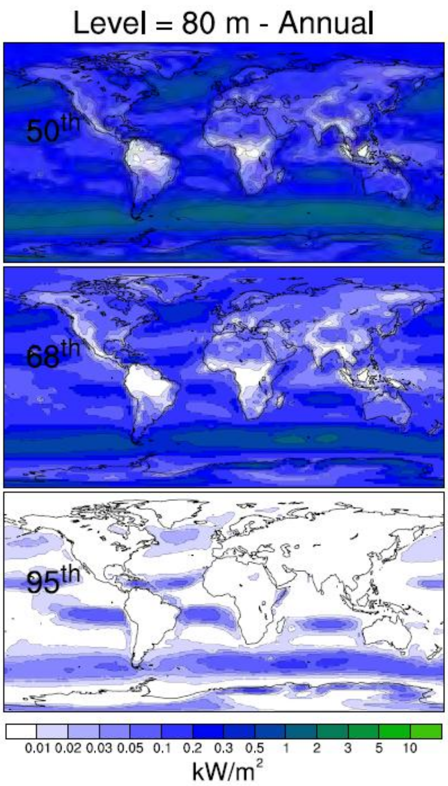
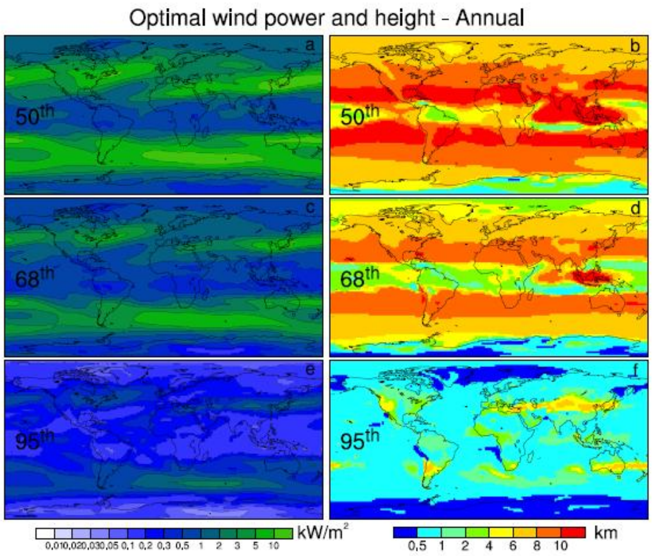


Figure 1.1: Wind power density (kW/m²) that was exceeded 50%, 68%, and 95% of the times at 80 m during years in 1979-2006 from the NCEP/DOE reanalyses.
4

Optimal power

Optimal height



Achieved 50% time

Achieved 68% time

Achieved 95% time

Figure 2.1: Optimal wind power density (kW/m², left panels) and optimal height (km, right panels) that was exceeded 50%, 68%, and 95% of the times during years in 1979-2006 from the NCEP/DOE reanalyses.

Atlas of high altitude wind power

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Ken Caldeira

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Carnegie Institute for Science
260 Panama Street
Stanford, CA 94305

16 June 2008

2.b. Wind (Power)

Wind = moving air mass
Laminar flow + turbulent flow

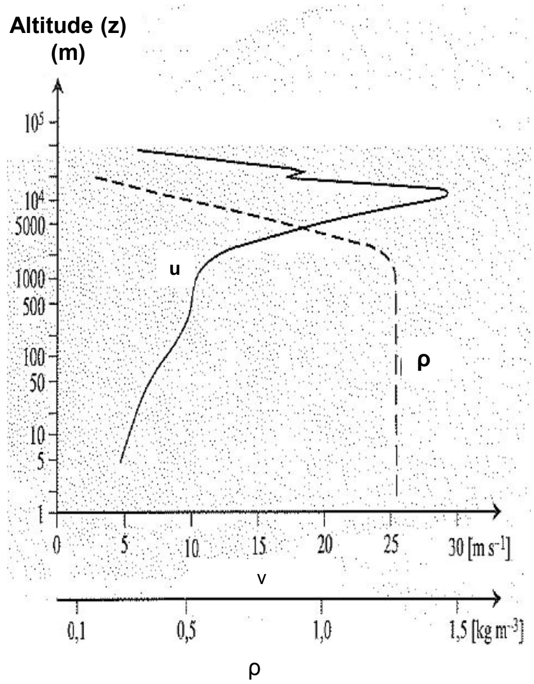
P (W) = ½ ρ S u³ [*kg/m³ m² m³/s³*]

[+ turbulences]

ρ : Air density
- Temperature
- Pressure

(Until 2000 m of altitude
ρ is ≈ constant)

t°	Density [kg/m³]
-25	1,423
0	1,292
5	1,269
10	1,247
15	1,225
20	1,204
25	1,184
30	1,165
35	1,146
40	1,127

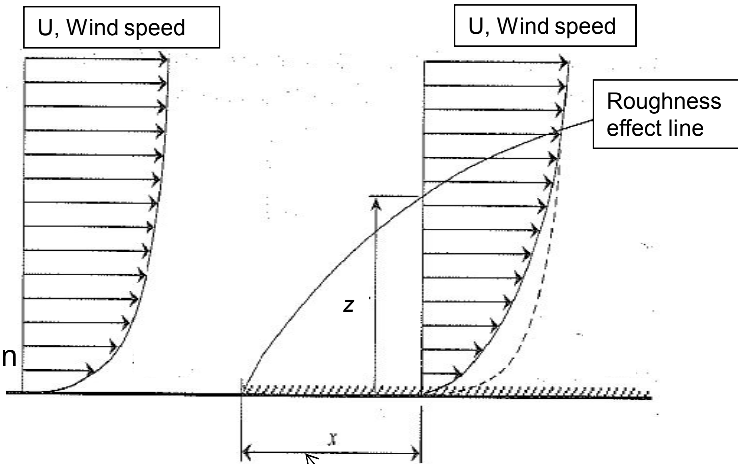


Ref. : Systèmes énergétiques.

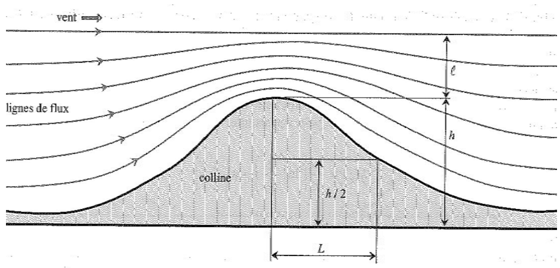
S: Area through which the wind is passing
- Size of the rotor : "Area swept by the rotor"

2.b. Wind speed

u : wind speed (t, z, x)
- time (t)
- Altitude (vertical profile) (z)
- Roughness (*x*)
- Effects orographic (mountain, crest)
- Local thermal effects (sea wind, mountain valley)



Roughness effects



Topography effects

Source : Systèmes énergétiques.

Wind speed altitude profile follows the law

$$u/u_r = (z/z_r)^\alpha$$

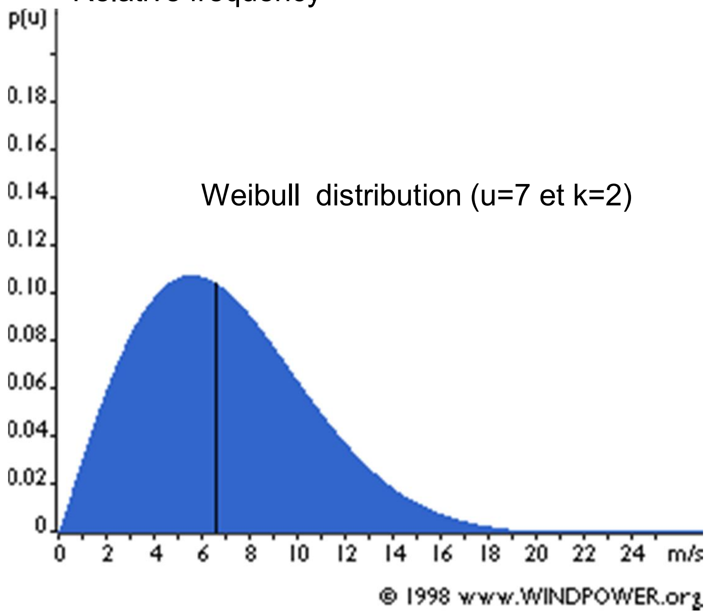
Where α depends on roughness and atmospheric stability

From one point (u_r, z_r), surrounding wind speeds can be modelled taking into account : elevation (z), topography and ground surface cover (roughness).

2.b. Wind speed distribution (year)

Energy potential of a site is evaluated starting from a series of wind speed measurements with regular intervals of 10 minutes over long periods (> 1 year). -> Statistical analysis

Relative frequency



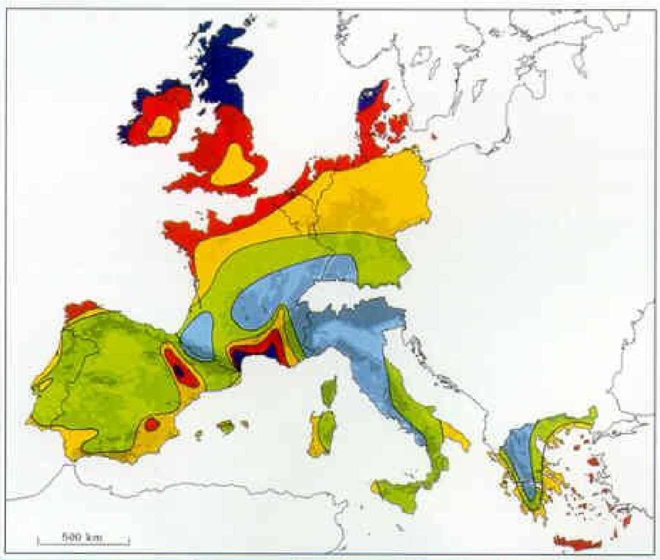
Weibull distribution (u=7 et k=2)

u = average speed

Form coefficient (k : 1-3)

Application :
Knowing the average speed and the roughness parameter, the distribution of speed may be calculated.

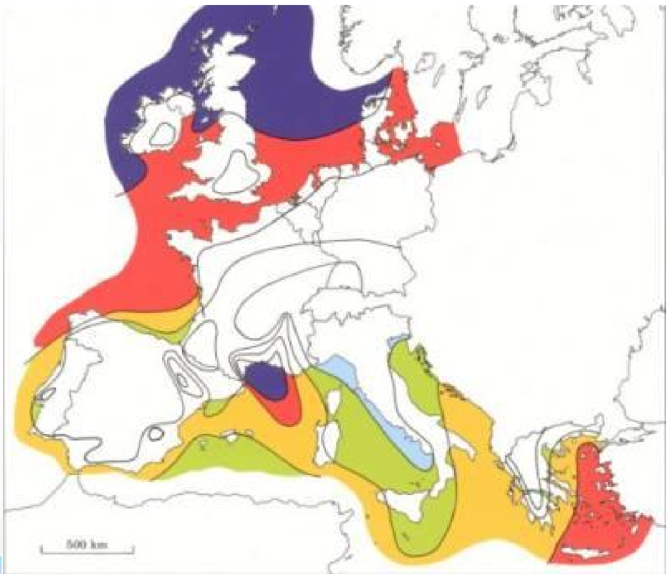
2.b. European wind Atlas (Onshore – Offshore)



Wind speed at 50 metres above ground level for four different topographical conditions (metres per second)

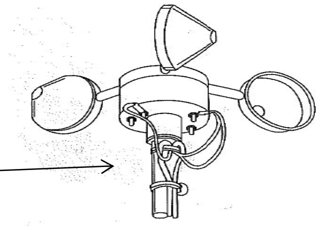
Colour on map	Open plain	At sea coasts	Open sea	Hills and ridges
(dark blue)	> 7.5	>8.5	> 9.0	> 11.5
(red)	6.5 - 7.5	7.0 - 8.5	8.0 - 9.0	10.0 - 11.5
(yellow)	5.5 - 6.5	6.0 - 7.0	7.0 - 8.0	8.5 - 10.0
(green)	4.5 - 5.5	5.0 - 6.0	5.5 - 7.0	7.0 - 8.5
(light blue)	< 4.5	< 5.0	<5.5	<7.0

Fig. 2 Wind map of Europe (Source: European Wind Atlas [Troen and Petersen, 1989])



Wind Energy – The facts : www.ewea.org

2.c. Wind measurements



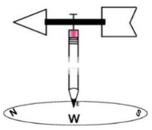
Wind speed (always referred to altitude : m above ground level)

-> Anemometer

- Mechanical
- Lidar (light detection and ranging – Doppler)

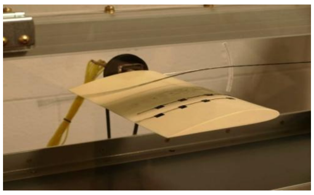
Wind direction

-> Tail vane



Flow quality (laminar)

-> Yarn, flag, smoke tracer



Remarks : Only laminar flow is useful in aerodynamic technologies.
Turbulences also induce mechanical effort in the rotor and the structure

2.c. Site measurements

Energie 2030 Agence

2.d. Belgian wind annual energy

Annual energy production = Rated power x FLH

Installation density

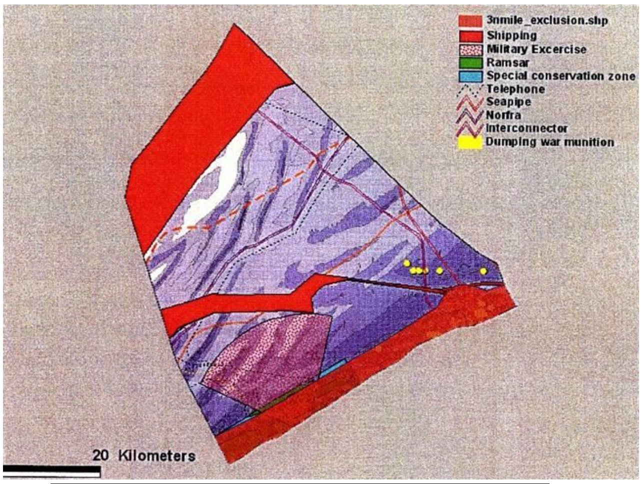
- 6 à 10 MW/km² (with 2 MW wind turbine)
- 10 à 15 MW/km² (with 3 MW wind turbine)

FLH (Full load hours)

Onshore FLH = 1.500 - 2.500 h Offshore FLH = 2.800 - 3.800 h

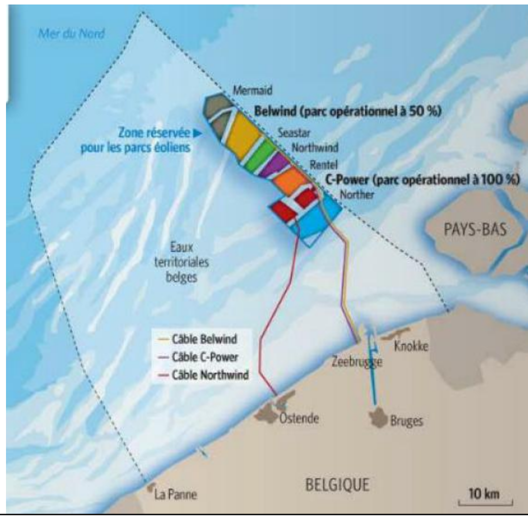
		≈ Annual average power
→ **Onshore** wind farm (2 MW wind turbines) =	**9 - 25 GWh$_e$/ km²**	**≈ 1 – 3 W/m²**
→ (3 MW wind turbines) =	**15 - 38 GWh$_e$/ km²**	**≈ 2 – 4 W/m²**
→ **Offshore** wind farm (2 MW wind turbines) =	**17 - 38 GWh$_e$/ km²**	**≈ 2 – 4 W/m²**
→ (3 MW wind turbines) =	**28 - 57 GWh$_e$/ km²**	**≈ 3 – 6 W/m²**

2.d. Offshore (Belgium) - Wind



Belgian sea area : 3 600 km²
Unusable area : 1 500 km²
Density : 10 MW/km²
Installed Power : 21 000 MW
FLH : 2 800 - 3 800 h
Prod. : 65 à 79 TWh/y

Ref : « Optimal offshore wind development » spsd II, May 2004



Situation in 2013

C-Power : 54 windturbines - 18 km² : 295-325 MW – 100% achoeved

BELWIND : 110 windturbines - 35,4 km² : 330 MW – 50% achieved

Ref : Le Soir 3 July 2013

2.e. Wind speed variability

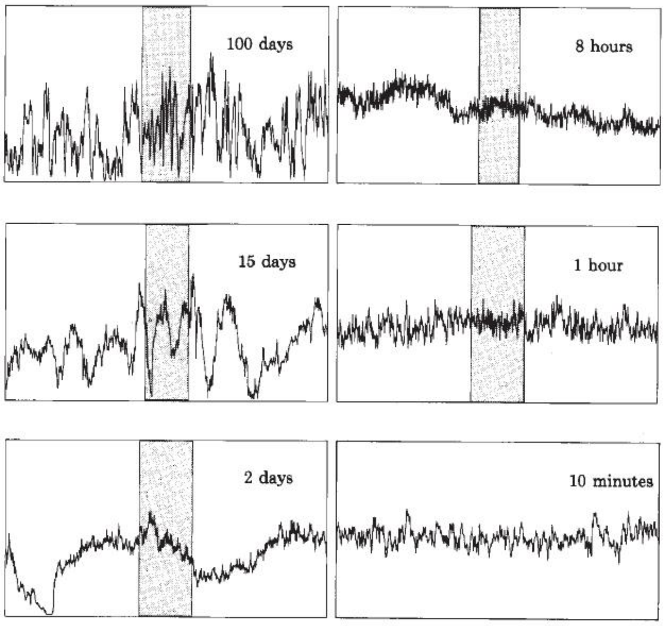


Figure 2.3 Wind speed measured 30 m above flat terrain: vertical axis is wind speed, 0–20 m/s. (Reproduced with permission of Risø National Laboratory for Sustainable Energy)

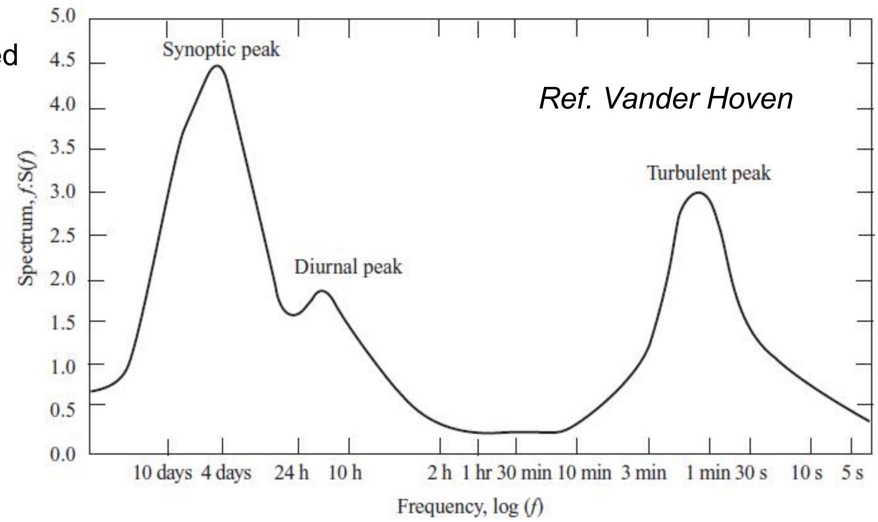
The wind speed at a given location is continuously varying.
There are changes in the annual mean wind speed from year to year (***annual***) changes with season (***seasonal***), with passing weather systems (***synoptic***), on a daily basis (***diurnal***) and from second to second (***turbulence***).

The much larger relative variability in the longer time series (synoptic) as compared with the time series covering hours or less (diurnal, turbulence).

Ref : Renewable Energy in Power Systems - Leon Freris - David Infield

2.e. Wind speed variability

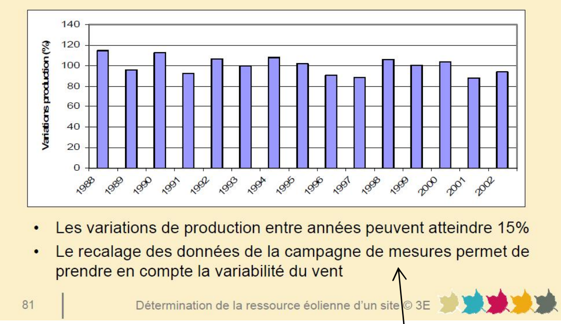
Normalised variance

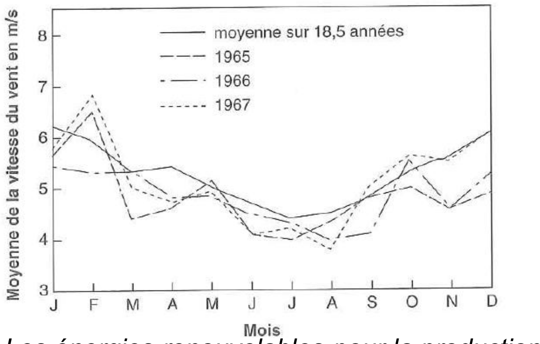


Spectral density presentation
In a spectral density function the height indicates the contribution to variation (strictly the variance) for the frequency indicated. A logarithmic scale as used here is the norm, and allows a very wide range of frequencies/timescales to be represented easily. The *y* axis is scaled by *n* to preserve the connection between areas under any part of the curve and the variance. The area under the entire curve is the total variance.
-> The largest contribution to variation is the synoptic variation.

Ref : Renewable Energy in Power Systems - Leon Freris - David Infield

2.e Wind variability synthesis



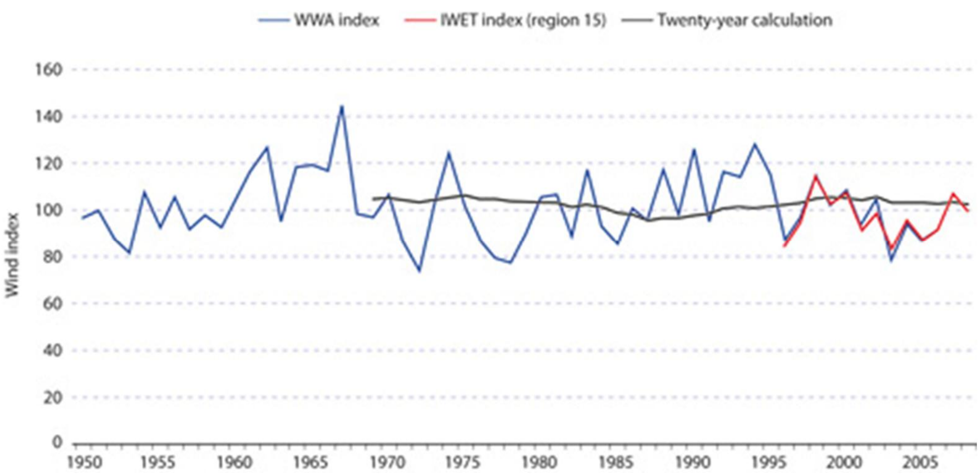


Ref : Les énergies renouvelables pour la production d'électricité - Leon Freris - David Infield

Variability

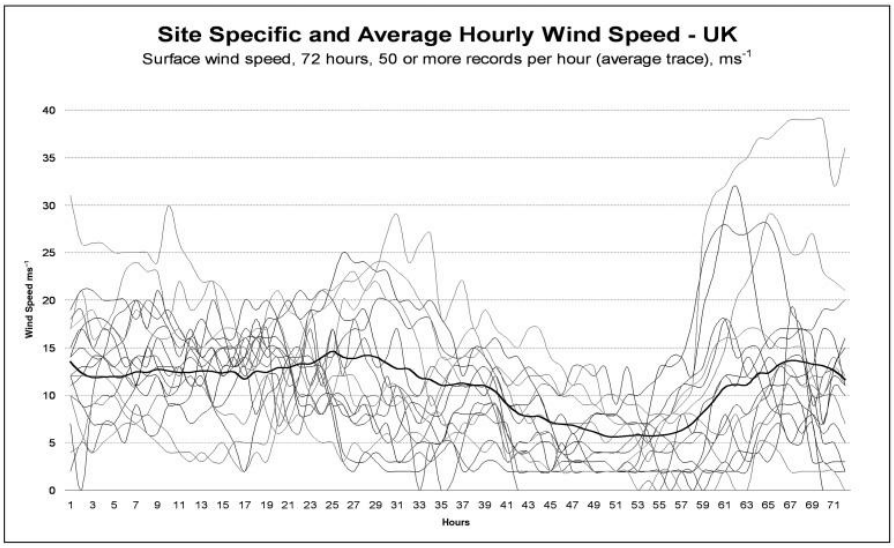
Annually : Low (15%)
Seasonally : High, more wind in winter than in summer
Monthly: Low
Weekly : Very high (meteorological cycle)
Dayly : High
Hourly : Low
Minute : Low (out of boundary layer)
Very high (inside boundary layer)
Second : Low (out of boundary layer)
Very high (inside boundary layer

2.e Multi annual wind variability



he IWET *wind index* is a production index. It characterises the production of wind turbines for 25 different regions in Germany. The wind index is specified as a percentage and applies for one region and one month or one year respectively. It is a statistical average which specifies how much the monthly or annual yield of wind turbines in a specific region deviates from the long-term average of all reporting wind turbines. Since the beginning of 2004, the long-term average has been formed from the years from 1989 to 2002. The process includes a correction using regression straight lines to increase forecast certainty.
http://www.windwaerts.de

2.e. Aggregation and geographical dispersion



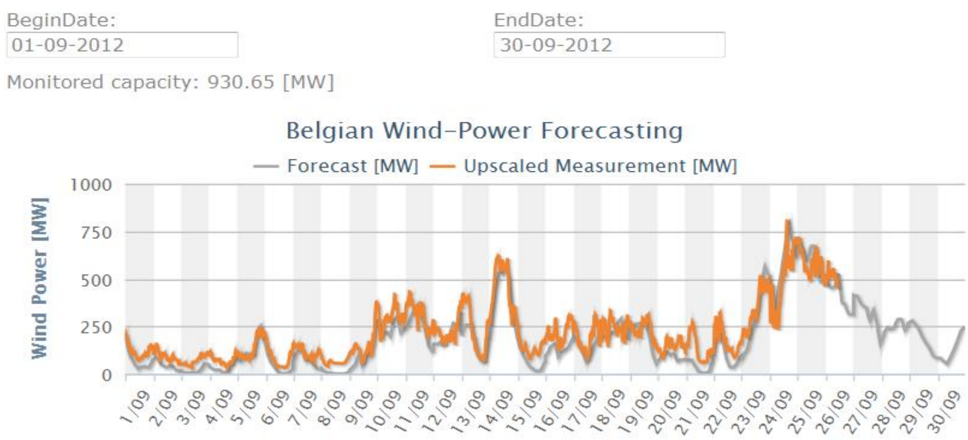
A wind farm has less short term variability than a single wind turbine due to their dispersion across the site, so the aggregate output from several geographically dispersed wind farms has less short term variability than the output from a single wind farm.

-> The benefit on <u>short term variability</u> (hour) of geographical dispersion

Ref : Renewable Energy in Power Systems - Leon Freris - David Infield

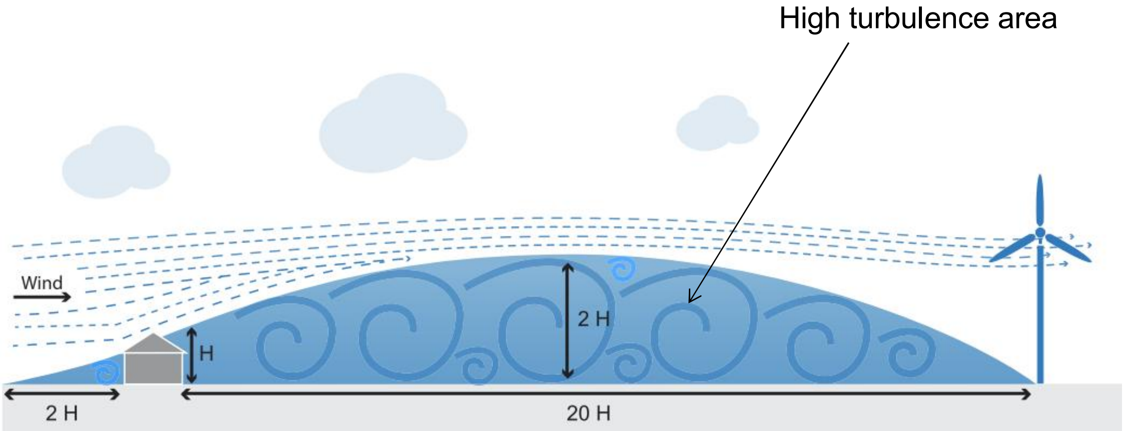
2.e. Wind power into the grid

Measurements and forecasting

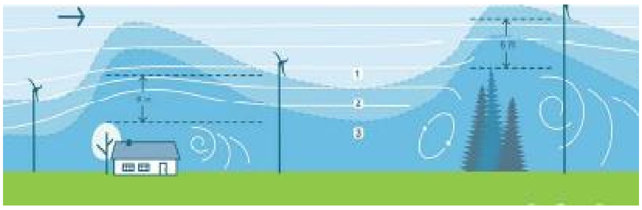


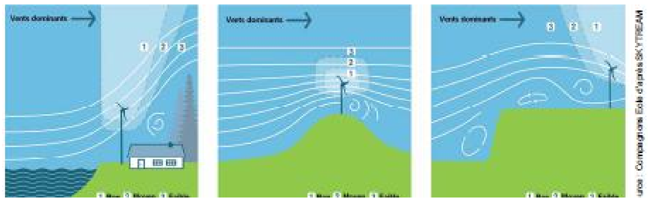
Belgium
http://www.elia.be/en/grid-data/power-generation/wind-power
Portugal
http://www.centrodeinformacao.ren.pt/EN/InformacaoExploracao/Pages/EstatisticaDiariaDiagrama.aspx
Spain
https://demanda.ree.es/generacion_acumulada.html

2.f. Wind turbine place precautions – Avoid turbulence area



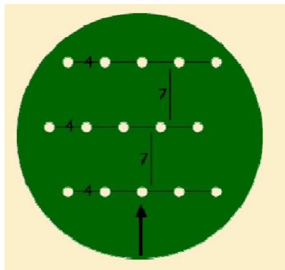
Ref Wind Power, GIPPE Paul





2.f. Wind park precautions – Distance between turbines

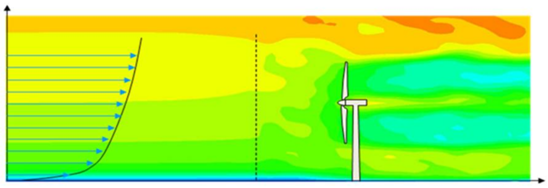
Maintain a sufficient distance between the wind turbines to reduce the **wake effect**. Take into account the prevailing direction of the wind.

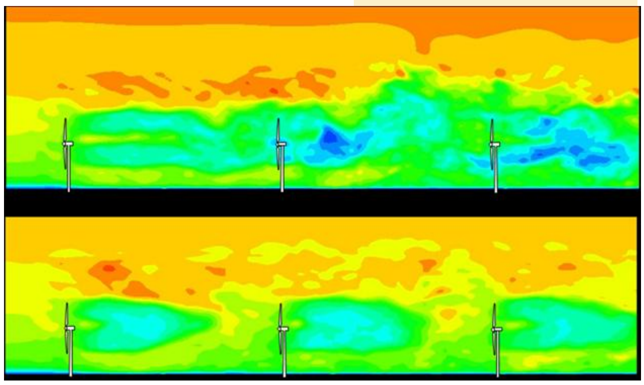


Rule of thumb :

4 x the rotor diameter perpendicular to the prevailing wind direction

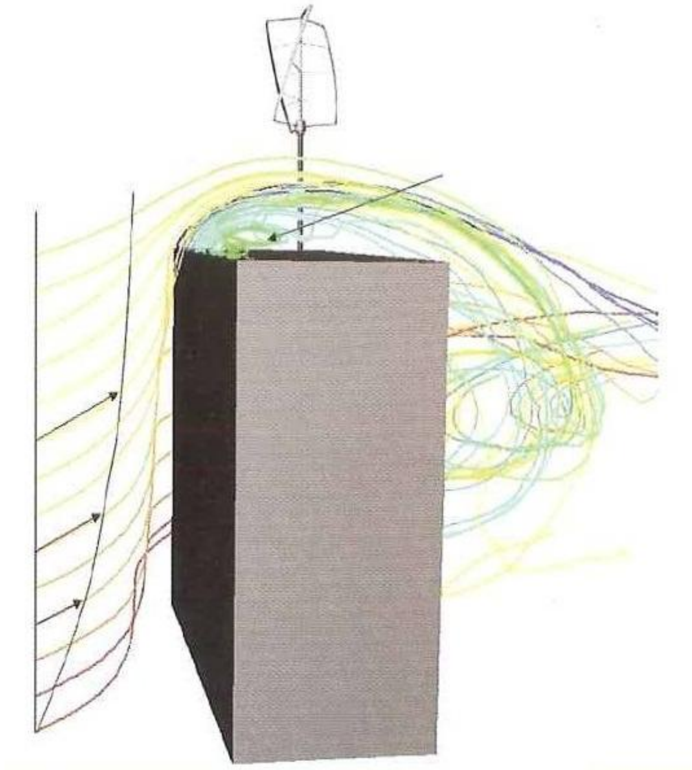
7 x the rotor diameter in the prevailing wind direction





http://space.hgo.se/ivanell/?q=node/6

2.f. Wind and buildings –European study WINEUR

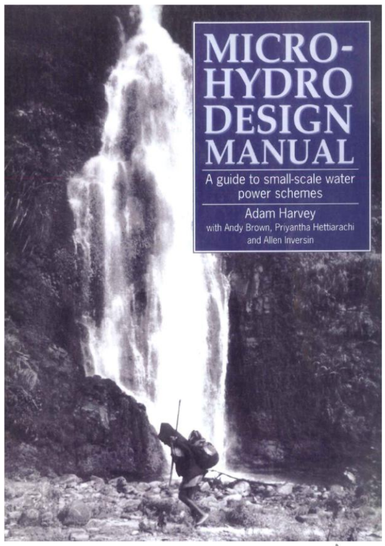


Recommendations for wind established on buildings :
- The roof of building should be approximately 50% higher than the surrounding building/obstacles
- The lowest position of the rotor has to be above the roof by at least 30% of the building height (see picture)
- Take into account : safety, vibration, shadow.

http://www.urbanwind.net

3. RIVER

a. Form and origin
b. Power
c. Measurements (flows, head)
d. Annual energy
e. Variability (short term, daily, seasonal)
f. Energetic conversion precautions



Reference : “Micro-hydro design manual - A guide to small-scale water power schemes”; Adam HARVEY. ITDG publishing. 1993 – ISBN 1 85339 103 4

3.a. Form and origin – Energy of river

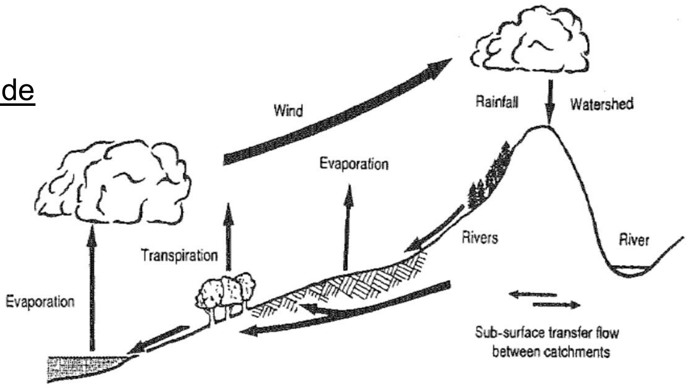
Form = Gravitational and kinetic energy

Hydropower origin is the sun -> Water cycle

To make hydroelectric power you need altitude and water flow.

River water flow depends on :
• Rainfall regime
• Melting cycle (ice, snow)
• Water retention of soil (i.e. moor has a retention capacity) or artificial dam
• Subsurface flows
• Evapotranspiration intensity
• Water abstraction (irrigation, industrial uses)

Seasonal fluctuations

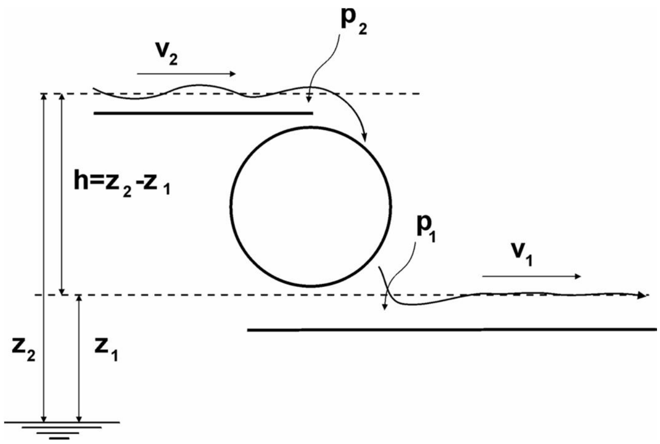


3.b. Hydropower

The power of a dynamic fluid is given by **Bernouilli's equation**
(m = flow mass/time)

$$P = m\left(\frac{1}{\rho}(p_2 - p_1) + g(z_2 - z_1) + \frac{1}{2}(v_2^2 - v_1^2) + w_{1,2}\right)$$

Pressure Gravitational Kinetic Mechanical



Hydro power

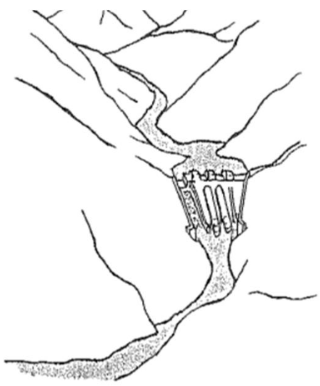
P (W) = 9,81 x Q (l/s) x H (m)

Q : Flow rate
H : Effective head

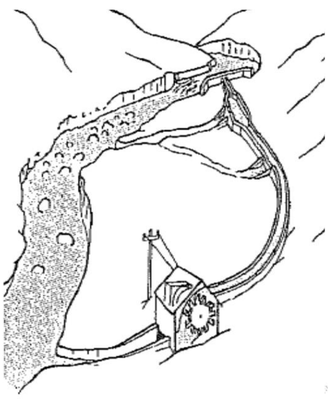
3.b. River hydropower

Various possibilities of hydro scheme

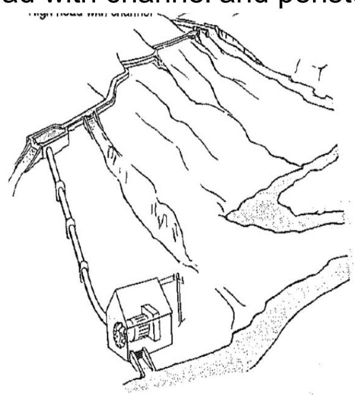
Head with barrage



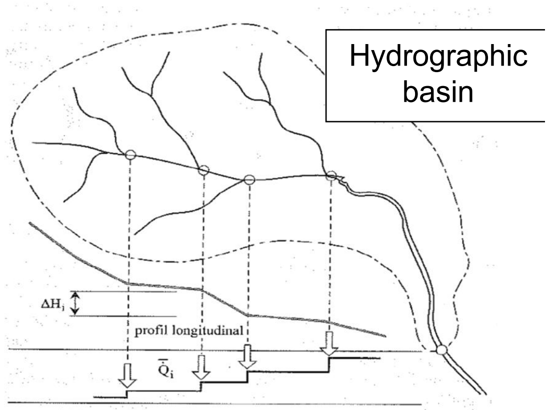
Head with channel



Head with channel and penstock



Ref : Micro-hydro design manual ; Adam HARVEY



Basin power = +/- 10 Σ Qi * Hi

Ref : Systèmes énergétiques.

3.c. Measurements

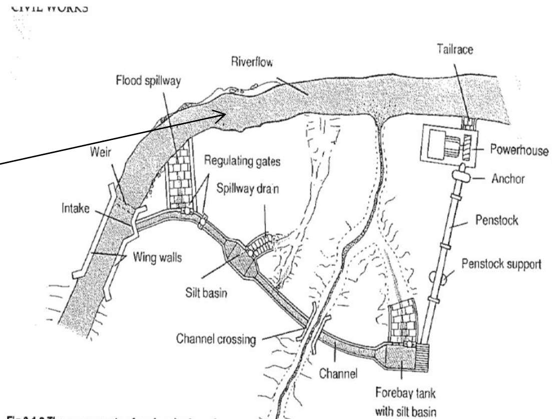


Fig 3.1.2 The components of a micro-hydro scheme

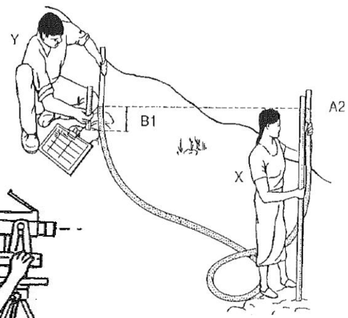
<u>H, Q and their variation define the turbine choice</u>

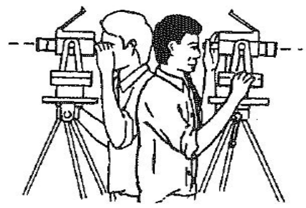
Rem. You can not use all the river flow. A minimum flow must be maintained in the short circuit part of the river.

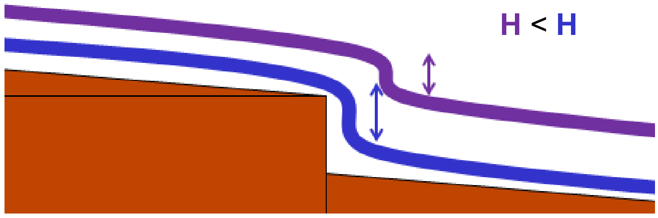
<u>Height (H) measurement</u>

Measurement equipment : topographical map, altimeter, GPS, water-filled tube, surveyor's rod)

H variability : During flood, H can be reduced (overall for low head site







Ref : Micro-hydro design manual ; Adam HARVEY

3.c. Flow (Q) measurements

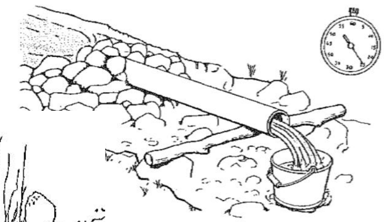
On site measure :

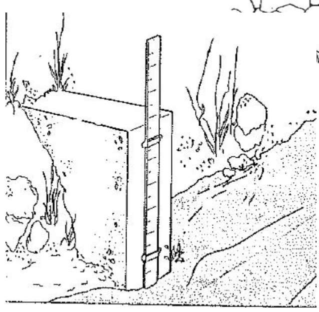
- Bucket method
- Stage control (measured depth of water) on natural section or on common sharp-crested weirs
- Measure of water profile on a calibrated sharp-crested weirs
- Velocity area method : Q = waterspeed x canal area. Measure waterspeed (calibrated propeller)
- Salt dilution method :Measure of electrical conductibility after salt dilution

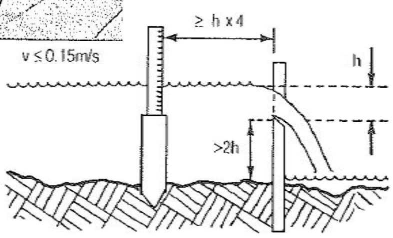
- Extrapolation with existing sites measurements

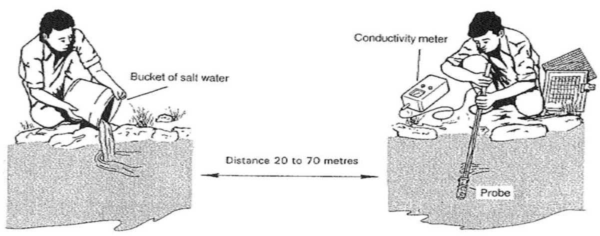
Wallonia : CENN
http://aqualim.environnement.wallonie.be

Wallonia : Waterway: http://voies-hydrauliques.wallonie.be



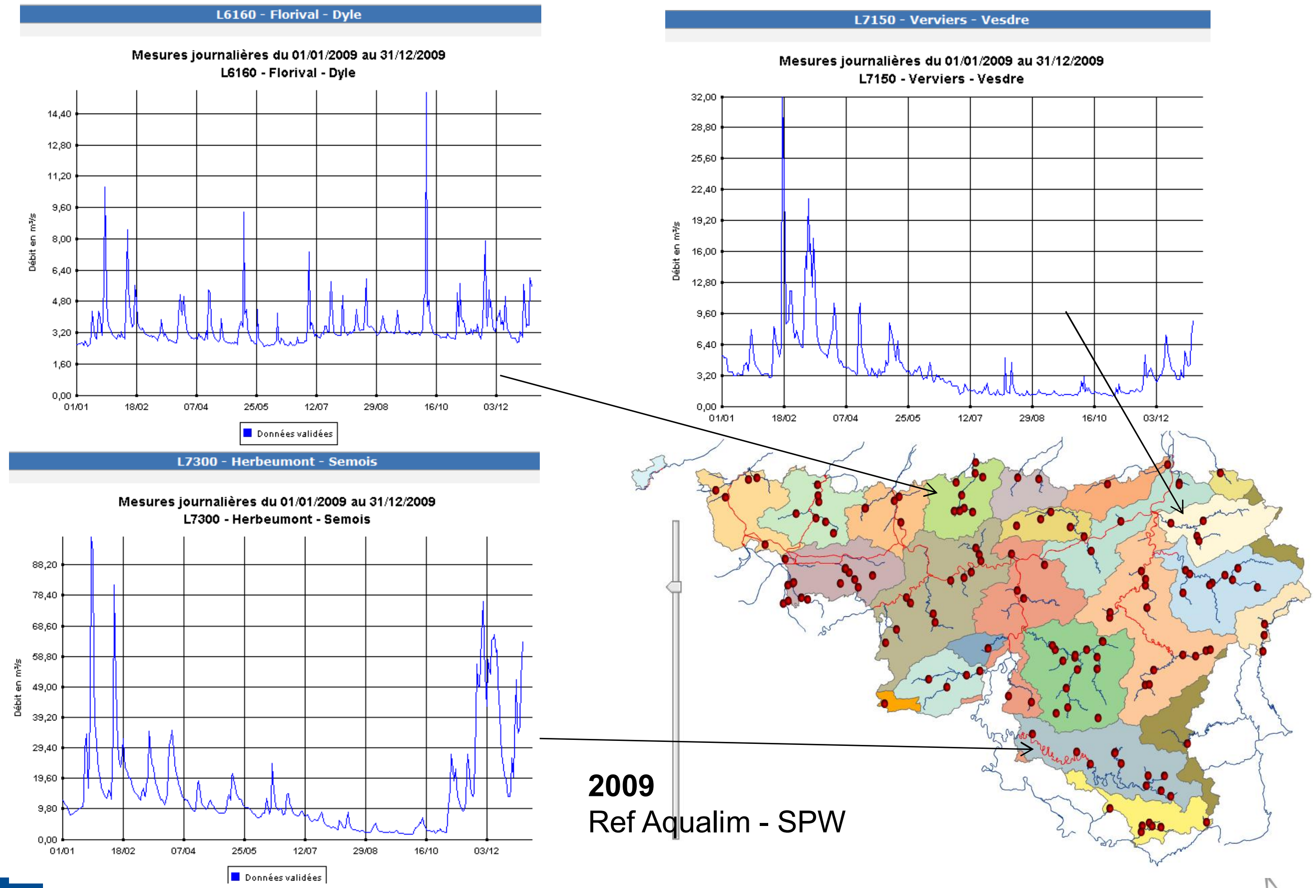






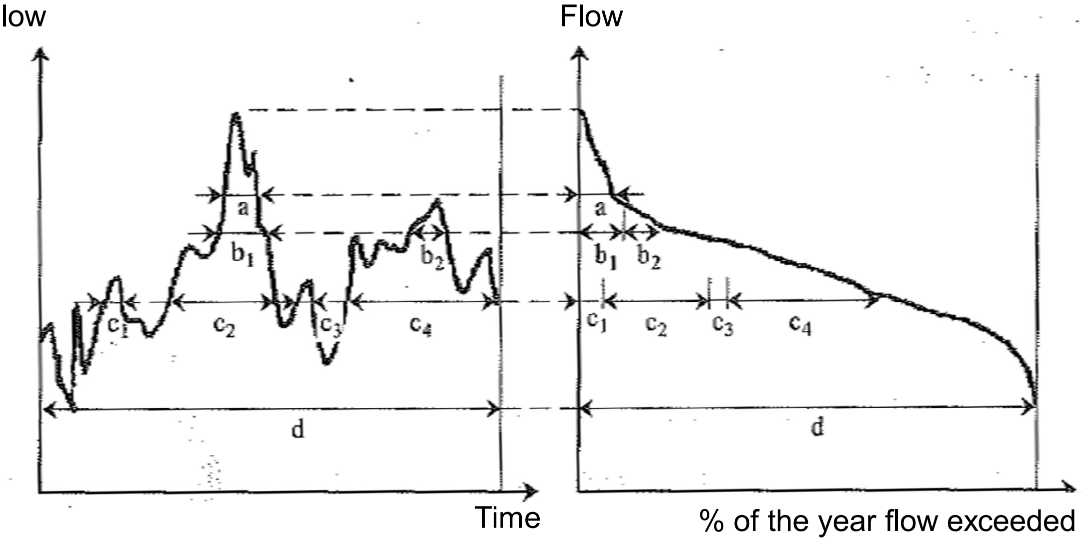
Ref : Micro-hydro design manual ; Adam HARVEY

3.c. Examples of 3 Belgian rivers



3.d. Flow duration curve (FDC)

The day by day flow is converted in flow duration curve (FDC) by placing them with highest figures on the lower figures placed progressively over to the right.



Flow day by day

Flow duration curve

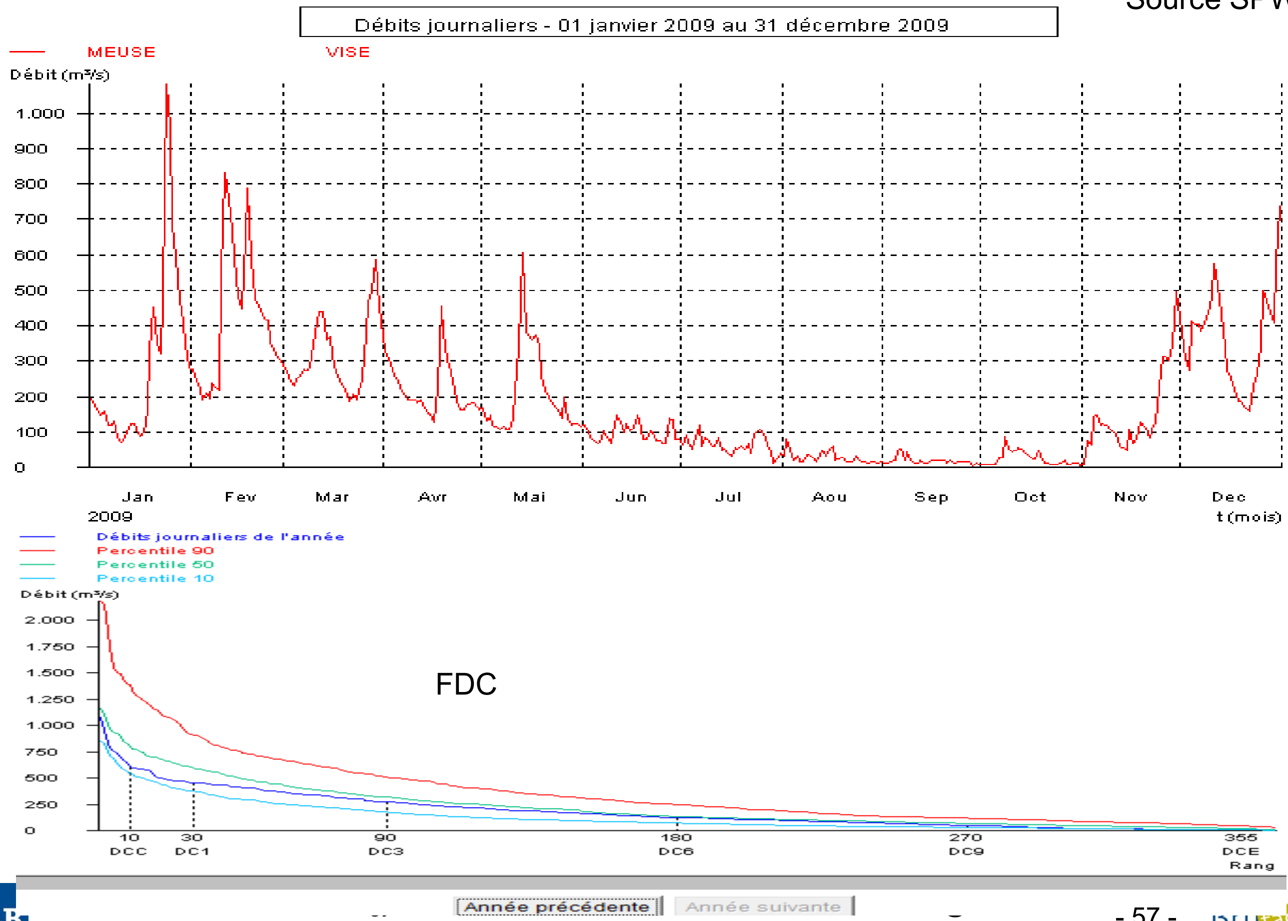
The annual hydroenergy can be calculated = ∫ P dt (P = 9,81 x Q x h)

The annual energy output will depend on the convertor effiency

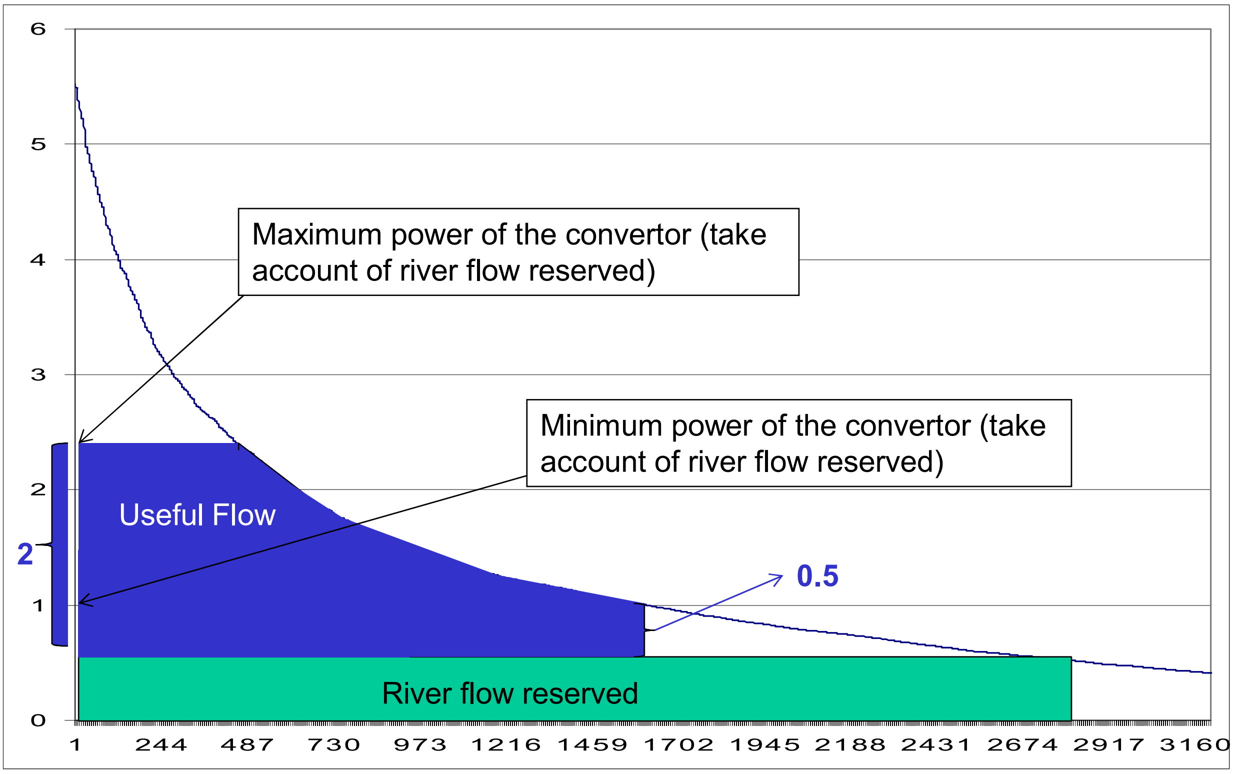
Ref : Systèmes énergétiques.

3.d. River flow Meuse - Visé

Year 2009
Source SPW



3.d. Usefull water flow– (m³/s)



Ref : Facilitateur hydroénergie - Wallonia

3.d. Annual energy

Depending of priorities, the FLH (Full load hours) of a site can be different.

- Maximize electric supply all over the year (grid off system)
- Maximize annual electric production (grid connected system)
- Optimize financial return

The actual average FLH of Belgian hydroelectric park is 2,500 - 4,500 h
Some hydroelectric plants have FLH up to 7,000 h

3.e. Variability

River water flow depends on :

• Rainfall regime
• Melting cycle (ice, snow)
• Water retention of soil (i.e. moor has a retention capacity) or artificial dam
• Subsurface flows
• Evapotranspiration intensity
• Water abstraction (irrigation, industrial uses)

3.f. Energetic conversion precautions

River flow reserved

Impact on fishes (fish ladder)

4. OCEAN

a. Tides
b. Water currents
c. Waves
d. Salinity gradient

References :

- Renewable energy – G. Boyle – Chapter 6 – p 196-205 Chapter 8 p.303-312

4.a. Tides

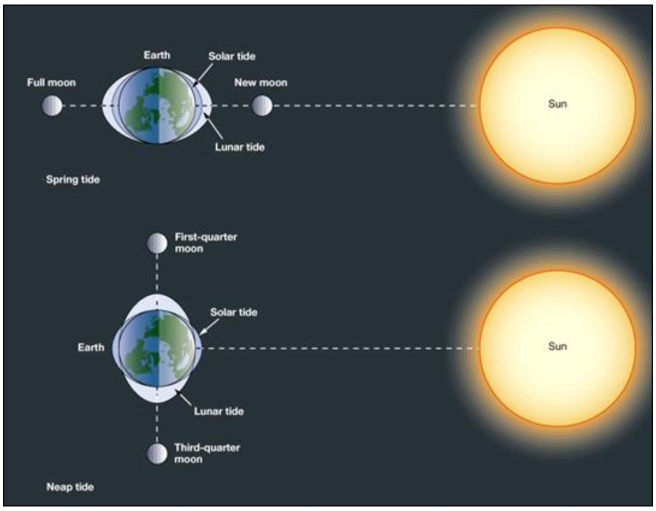
Tide

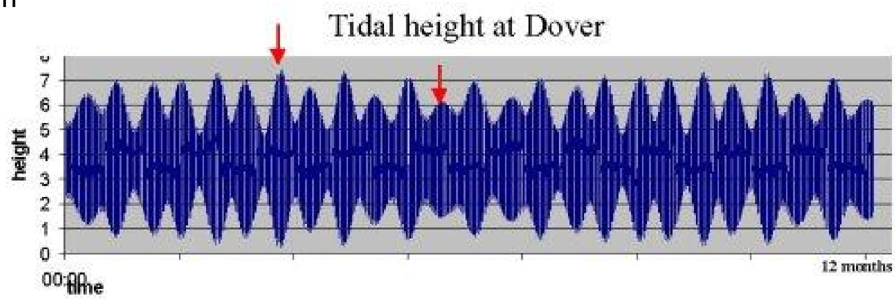
The potential energy created by the difference in water levels can be used.

E (J) = ½ g ρ A H² ρ = 1 025 kg/m^3
A = basin area(m²) H = (m)

Pm (W) = 0,225 A H² because 2 tides every 24 hours 48,8 minutes

i.e. Rance basin (France)
A = 22 km² - H = 11,4 m



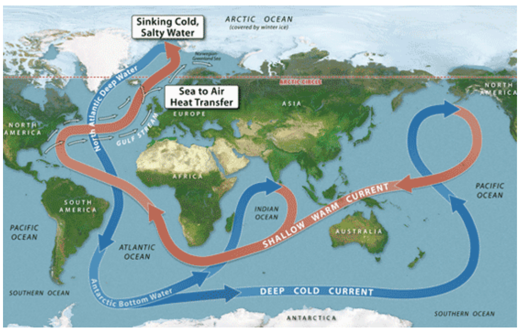


4.a. Tidal potential world

4.b. Water currents

Origin and form

- Origins: (1) Thermal earth balance; (2) Tides; (3) Rivers
- **(1) Marine currents** (**oceanic streams** move slower than winds - several km/day – 0,05 m/s)



- **(2) Marine current (tides) :** can reach interesting water speed if favourable costal characteristics
- (3) **Rapids** in river due to downslope

Form = Kinetic energy

Power : $P = ½ \rho S v^3$

Water density: ρ = 1000 - 1025 kg/m³

Waterspeed : v (m/s)

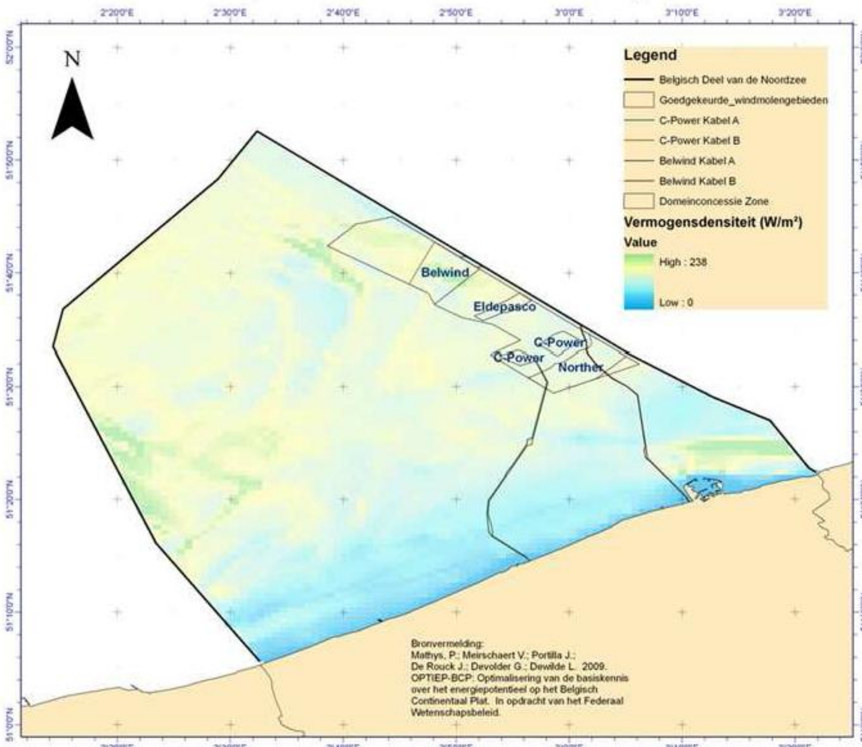
Crossed area: S (m²)

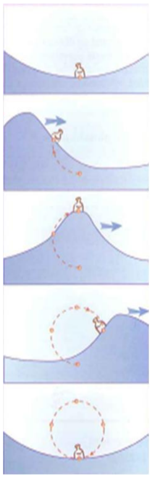
V (m/s)	P (kW/m²)
1	0.5
2	4.0
3	13.5
4	32.0
5	62.5
6	108.0
7	343.0
8	512.0

4.b. Belgian annual ressource

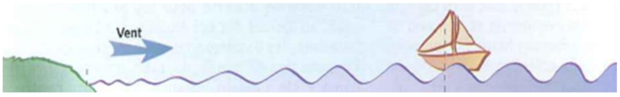
The principal origin of **water current in Belgian sea is tidal effect.**

BOREAS, Mathys *et al.* 2011
(funded by BELSPO), *In Press*





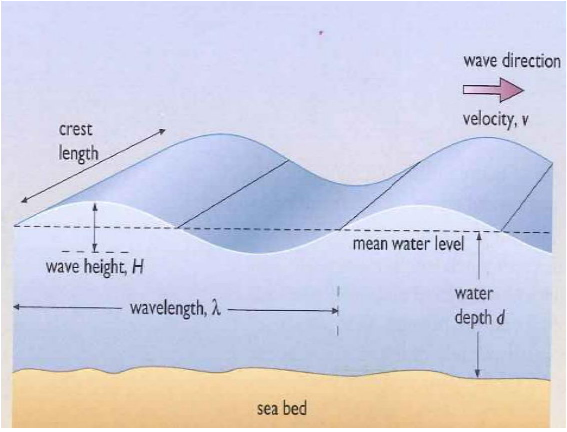
4.c. Waves



Waves are created by winds.
The waves are a transfer of potential energy at the surface of water.
The waves are not a displacement of water. They are simply a distortion of the surface of the water.
Only the waves that break (for example on a beach) temporarily move water.

$$P = \frac{\rho g^2 H^2 T}{32\pi}$$

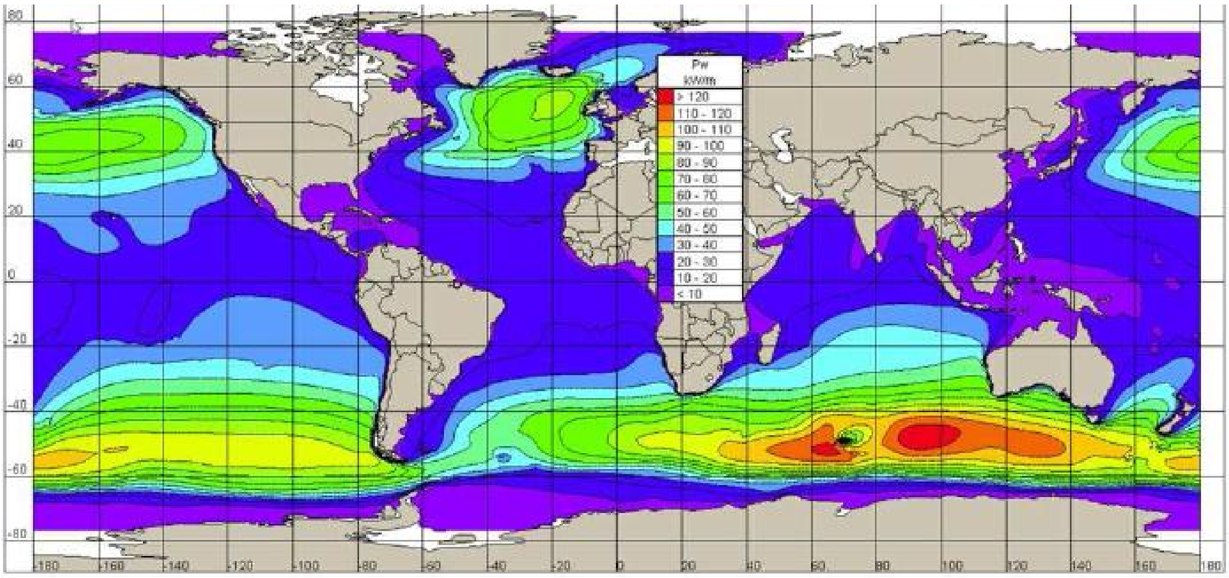
(In an idealized ocean wave)



Deep water (d> ½ λ)
V = gT/2π ≈ 1.5 T
Long waves travel faster than shorter waves

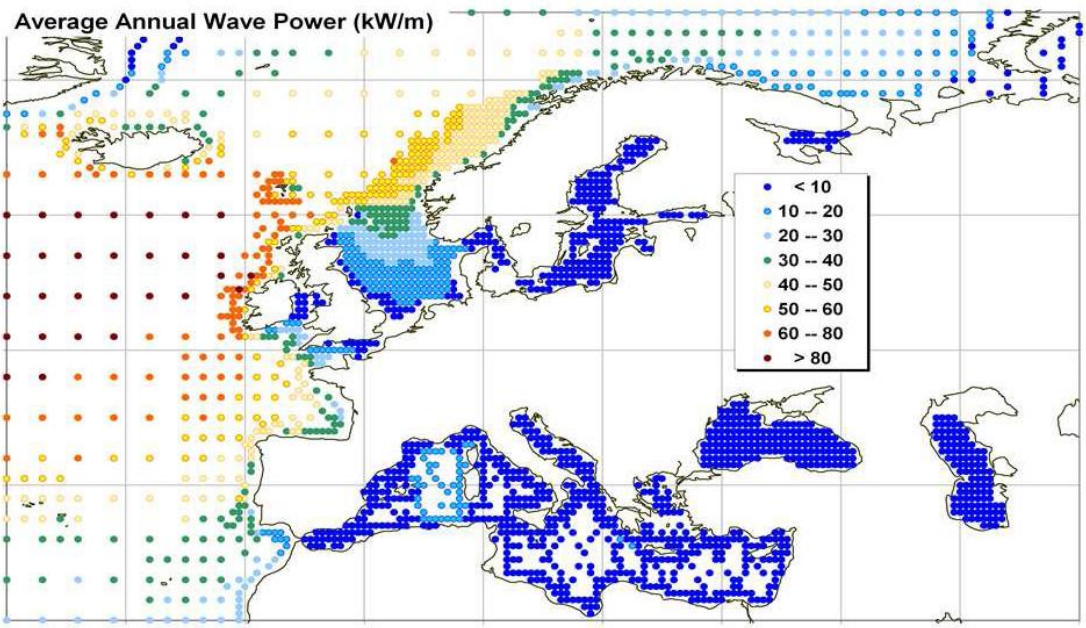
Shallow water
V = √ gd ≈ 3 √d

4.c. World average annual wave power



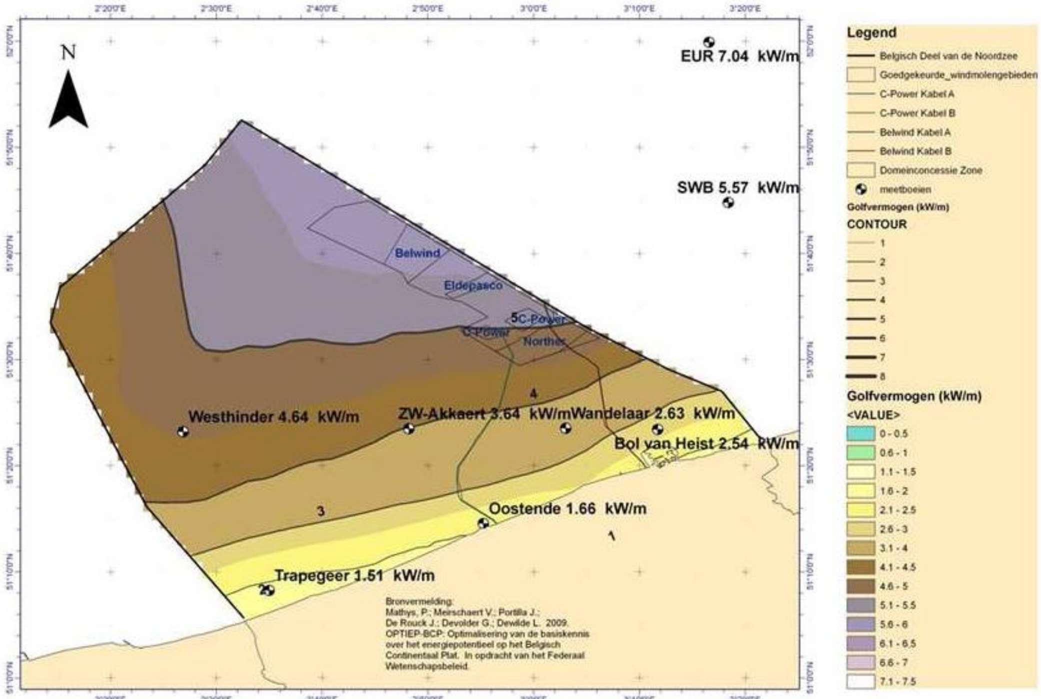
Cornett 2008

4.c. European average annual wave power



Available wave power, expressed in kW/m wavecrest. Source: WorldWaves data/OCEANOR/ECMWF.

4.c. Belgian average annual wave power



Wave energy in kW/m

BOREAS, Mathys *et al.* 2011 (funded by BELSPO), *In Press*

4.d. Salinity gradient

Energy can be gained by mixing of two streams with different salt concentrations (e.g. sea water and river water).

Salinity Gradient Power (SGP) are still at the embryonic stage.

Indeed, near coastal areas where freshwater flows into the sea, energy can be produced from the salinity gradient between fresh runoff and saline reservoirs. The salt brine rejected by industrial activity can also be considered as a possible source with rivers flowing nearby

To convert SGP into electricity, two main techniques exist:

Pressure-Retarded Osmosis (PRO) and Reverse ElectroDialysis (RED)

Ref: Jo Hermans, Energy survival guide p.134

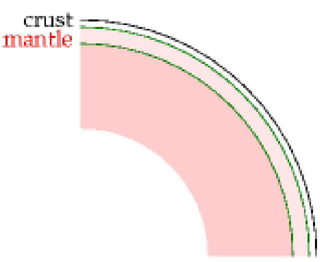
5. NATURAL HEAT FLOWS and RESERVOIRS

a. Form and origin
b. Soil heat reservoir
c. Water heat reservoir
d. Air heat reservoir
e. Heating degree-days
f. Renewable geothermal precautions

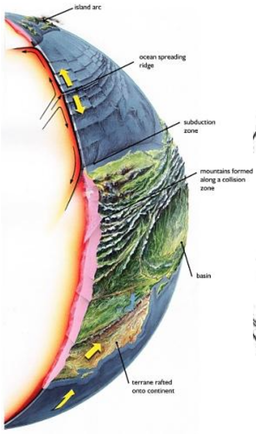
References :
- Renewable energy – G. Boyle – RE Boyle : Chapter 9 (p 342-358)
- Sustainable energy – D. MacKay : Chapter I16

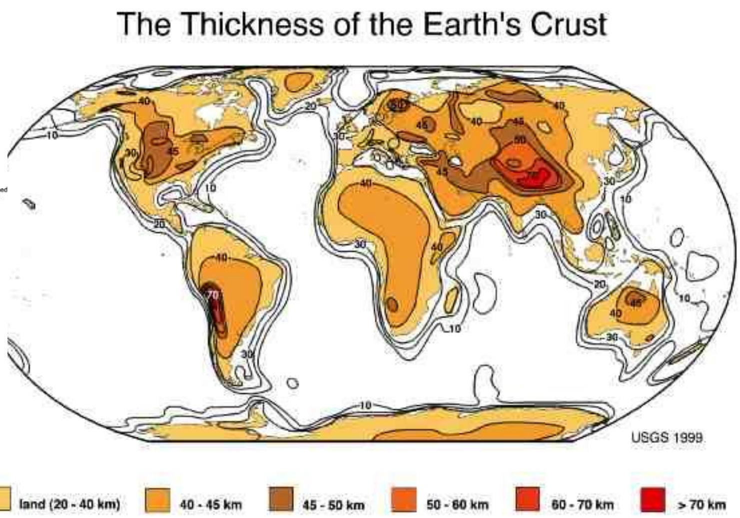
5.a. Geothermal energy origin

Geothermal energy in the crust comes from two mechanisms: from radioactive decay in the crust of the earth, and from heat trickling through the mantle from the earth's core.



Ref. D. MacKay





Earth crust thickness is not uniform :
20-70 km in continental region
5-10 km in oceanic region
Under Earth crust, temperature is about 500 -1,000 °C
Earth core is about 5,000 °C

5.a. Natural heat flows and reservoirs - Origin

In Belgium, sun is the main origin of natural heat of the ground surface.
(Like all region without geothermic or volcanic activities).

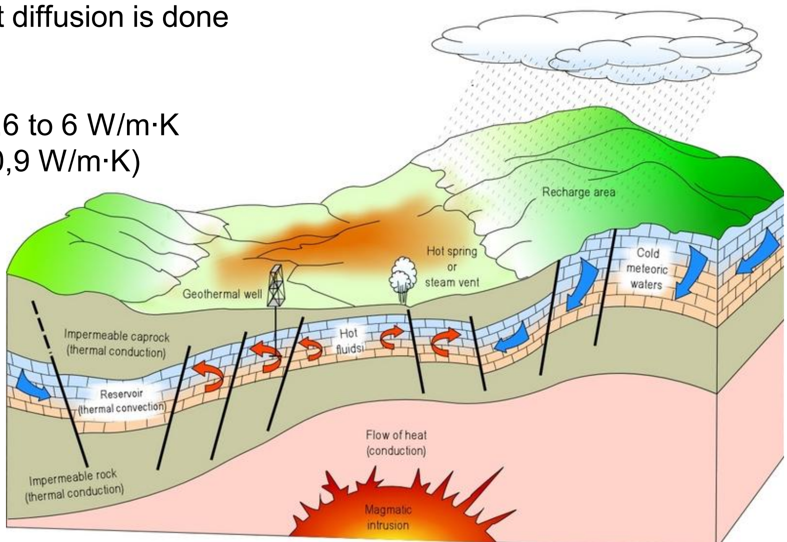
Solar origin (Heat flow from sun)
The ground and ocean surface are heated by the solar radiation.
The ground exchange heat with the surrounding atmosphere.

Geothermal origin (Heat from earth core)
From two mechanisms Geothermal heat diffusion is done

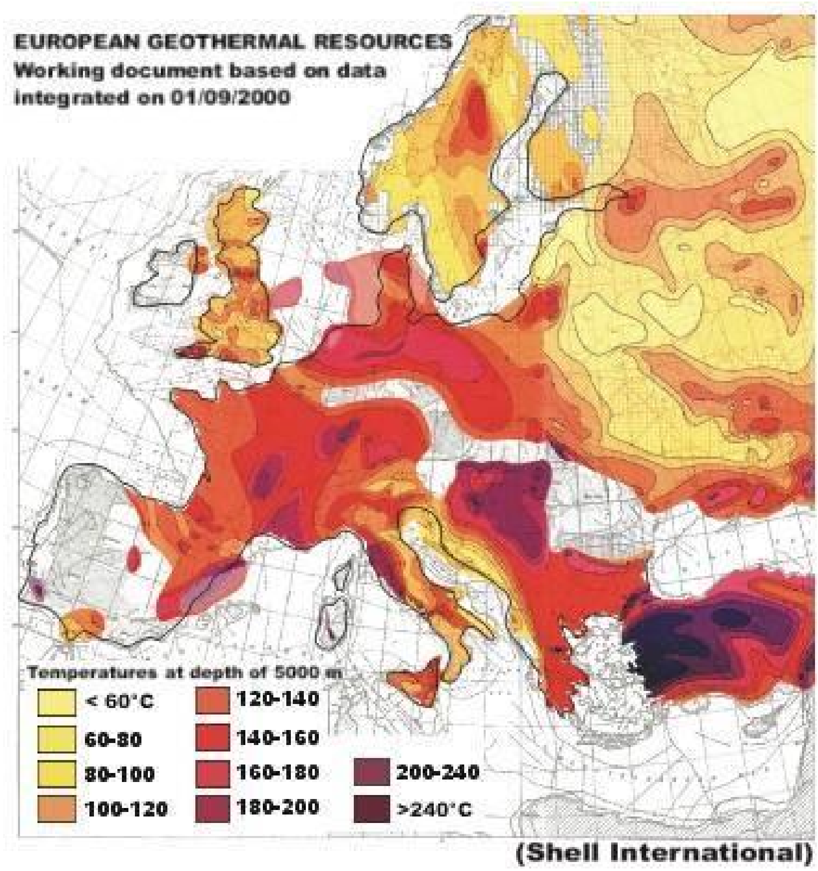
- by conduction
  Rocks thermal conductibility : from 0,6 to 6 W/m·K
  (Comparison: Cu = 390; Concrete = 0,9 W/m·K)

- by convection (warm water, vapors or lava in volcanic sites)

Subjacent geothermic activities
Increase geothermal energy potential



5.b. European subsoil temperatures



Ref :

"Rock temperatures at 5 km depth (Courtesy of EEIG "Heat Mining", European Hot Dry Rock Project)"

5.b. Soil temperatures

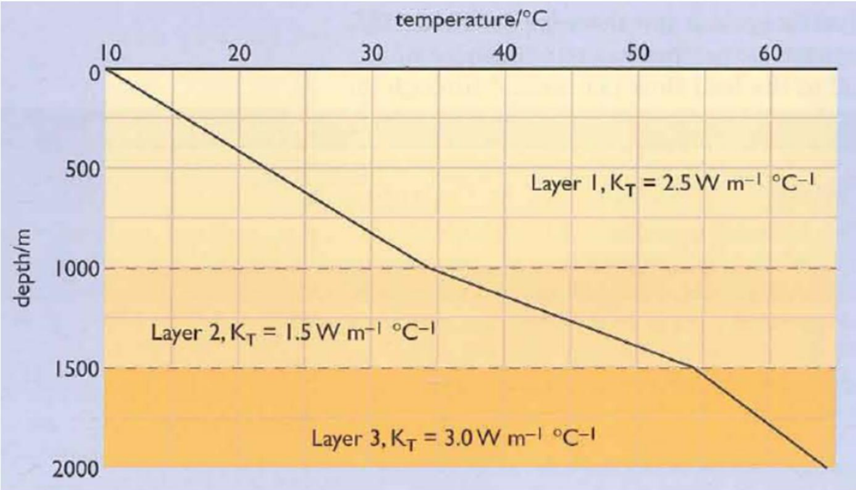
In Belgium the soil at a depth of 5 m has an average temperature of ≈10 °C.
Going more in depth, the temperature increases following a gradient.
In sedimentary basins, the gradient depends on thermal conductivity (K_T) of the ground.

In Belgian subsoil

- Thermal gradient is **≈ 30°C/km**
- Geothermic flow is **0,025 to 0,150 W/m²**

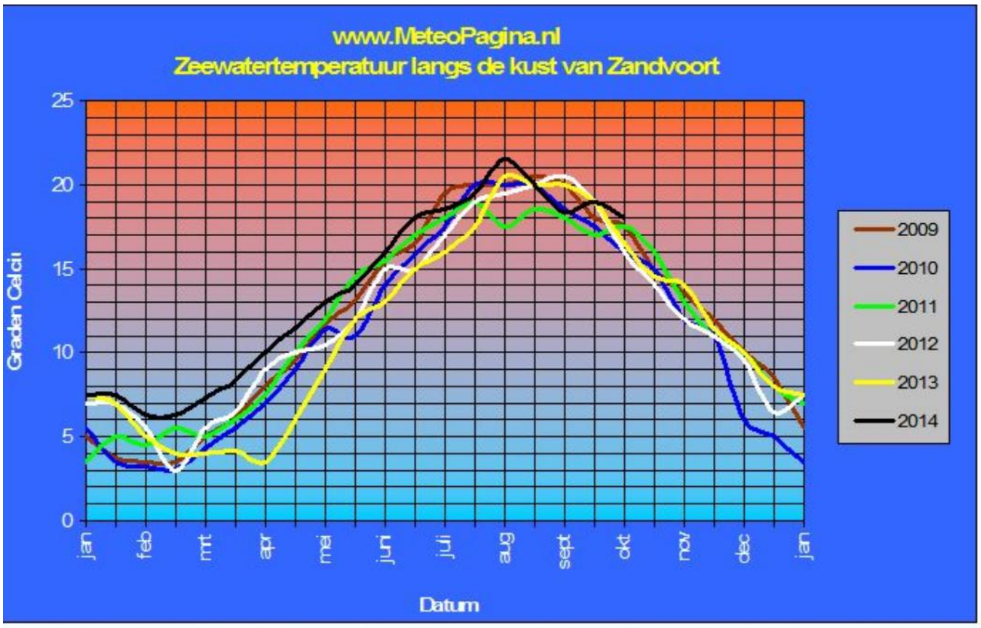
Geothermic flow = Conductivity x gradient

(Comparison: Average **solar flow in Belgium = hundred W/m²**)



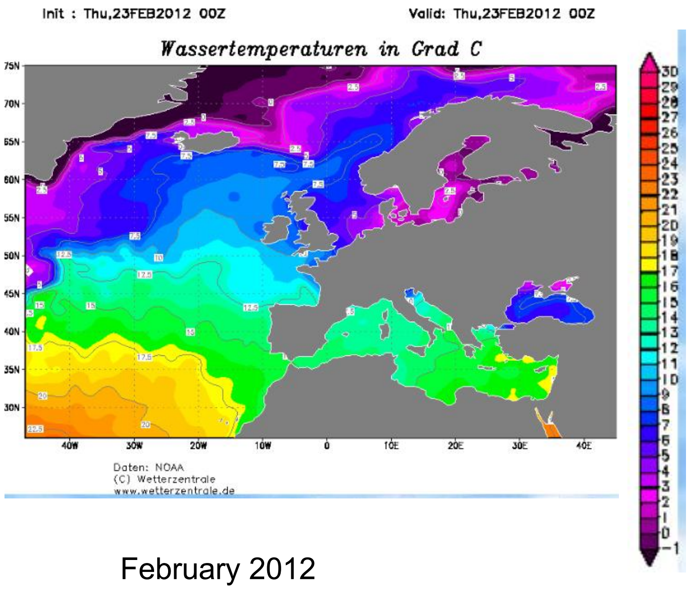
5.c. Sea water heat reservoir – Seasonal variation of surface temperature in Belgium

North sea surface temperature - Annual evolution
(Zandvoort is closed to Amsterdam – Nl)

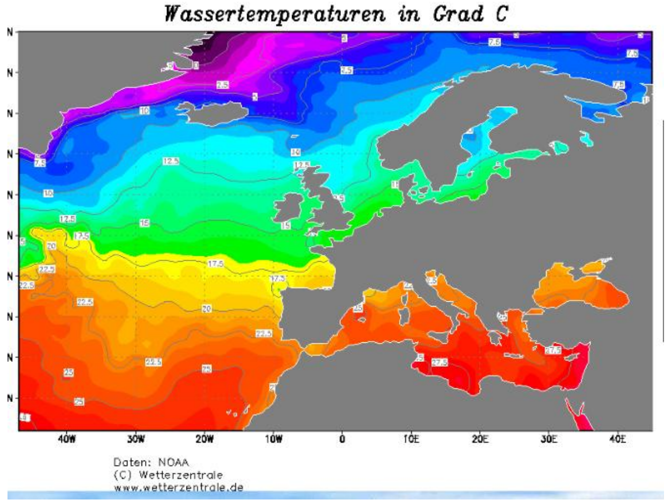


Het verloop van de zeewatertemperatuur *(zwemwater / surfwater-temperatuur)*
langs de kust van Noordwijk / Zandvoort / IJmuiden / Wijk aan zee
en het temperatuurverloop in voorgaande jaren.

5.c. Sea water heat reservoir – Seasonal variation of surface temperature in Europe



February 2012



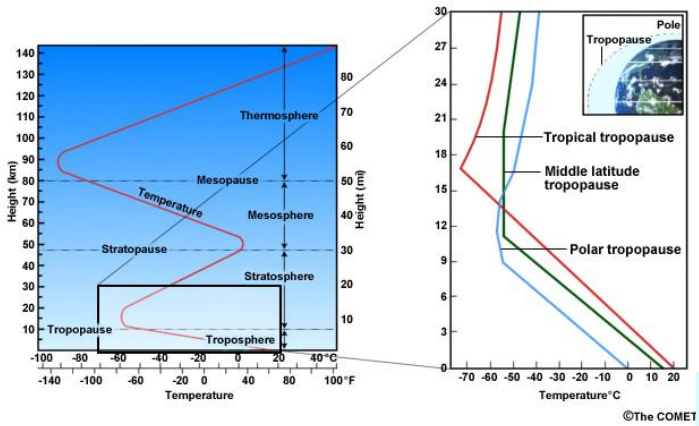
September 2012

http://home.hccnet.nl/v.d.horn/meteopagina/zeewatertemperatuur.htm

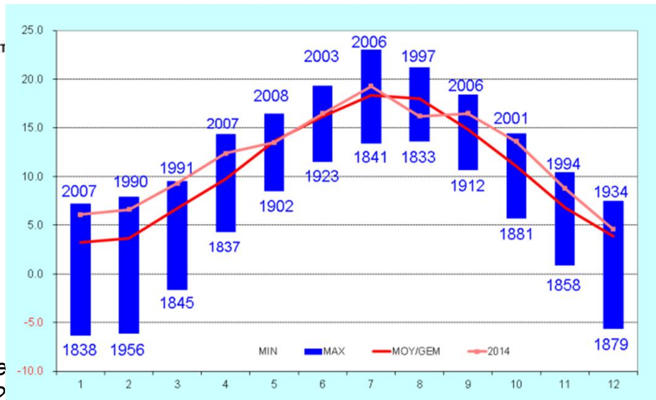
5.d. Atmosphere heat reservoir

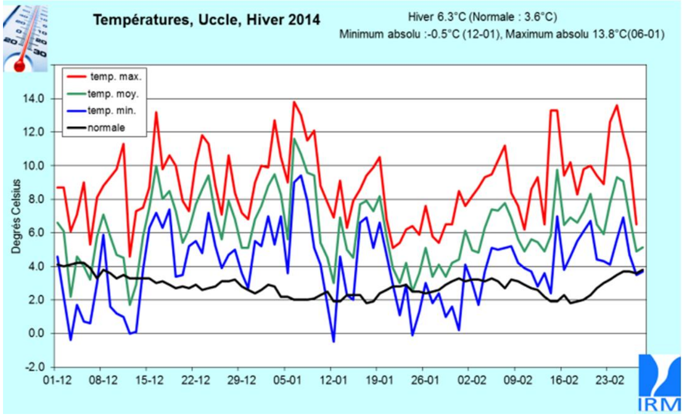
Atmosphere is heated by the ground and the oceans surface by IR radiation and convection. (Sun radiation heats mainly earth surface than atmosphere).

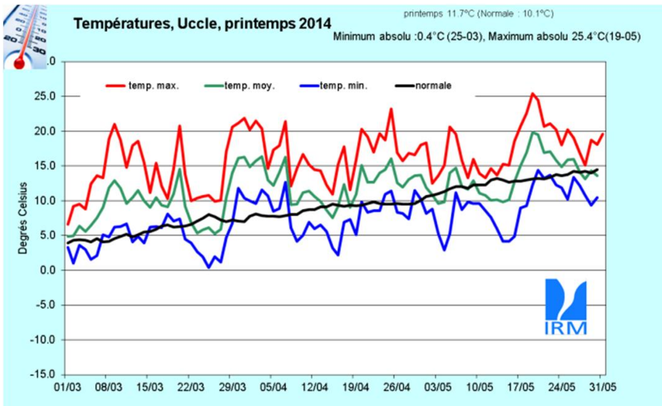
Air temperature in the atmosphere decreases with altitude because of air pressure decrease with altitude- standard vertical gradient: 0,65°C/100m.

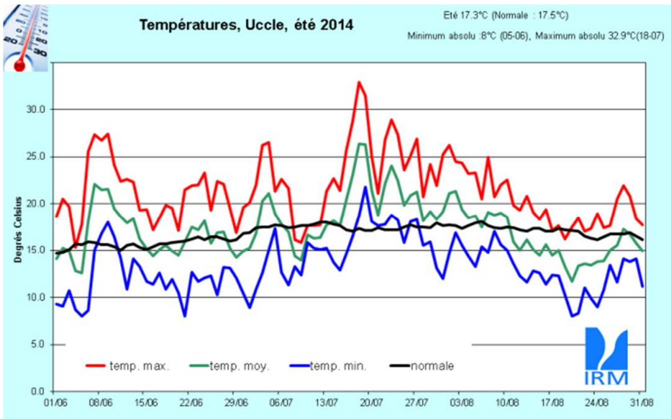


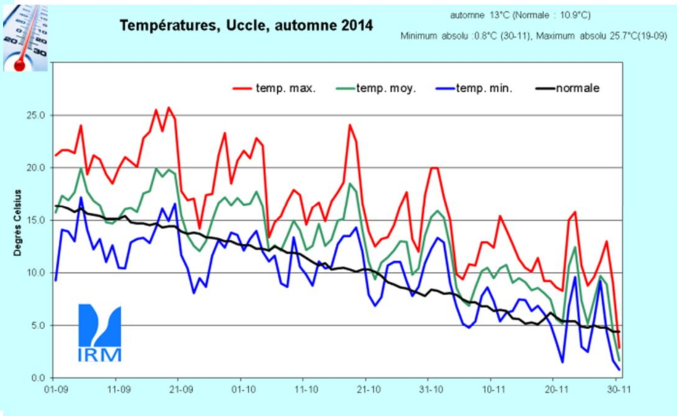
Actually, at ground level, air temperature depends on meteorological situation.











5.d. Air temperature drive heating heat

Heat flow is created by temperature difference **Φ = k ΔT**

When temperature goes under 15°C for a long period, building could need to be warmed up with heating systems. Overall if building hasn't good thermal insulation.

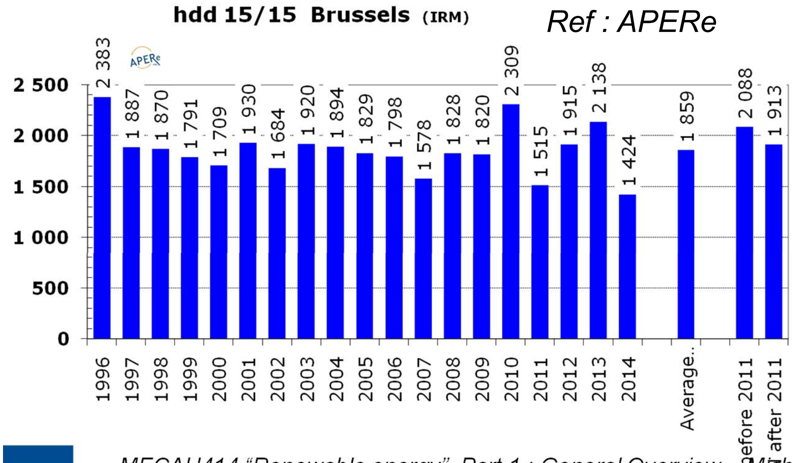
Thermal losses through a surface is calculated by
Φ = U·S·ΔT
[U = U value; S = Area ; ΔT = difference of temperature between inside and outside)]

A simple method to assess the thermal losses uses **heating degree-days (HDD)**

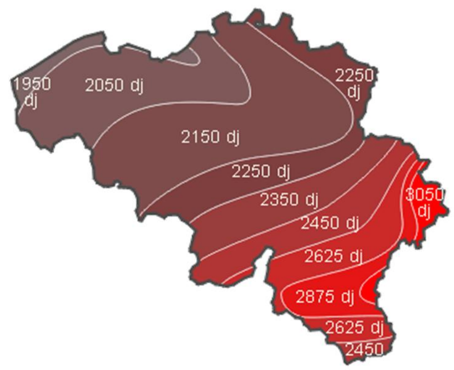
5.e. Heating degree-days (hdd)

HDD 15/15 : In buildings, energy consumption tends to depend on the outside air temperature. The colder the outside air temperature, the more energy it takes to heat a building to a comfortable temperature.
Heating degree-days express the severity of the cold in a specific time period taking into account **outdoor temperature** and **room temperature.** There are several methods of calculation hdd. For example: hdd 15/15 = $\sum_i$ hdd_i

hdd_i = (**15 °C** - Tm) if Tm is lower than or equal to 15 °C (heating threshold)
Or 0 if Tm is greater than **15 °C**
Tm is the mean outdoor temperature over a period of one or several days: $(T_{min} + T_{max}) / 2$
Calculations are to be executed on a daily basis, added up to a calendar month -and subsequently to a year.



Ref : APERe



Ref : UCL – Climat 2000

Weather normalisation

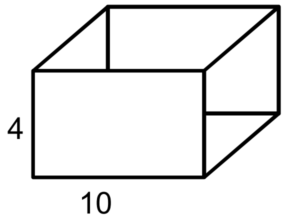
"Weather normalization", or "weather correction", allows you to *adjust* your energy-consumption figures to factor out the variations in outside air temperature.
In theory, you can then compare the normalized figures fairly.

Weather normalization of energy consumption use hdd applying a rule of three.

	Cons. (kWh)	hdd	Cons. Norm (kWh)
Normal		1,913	
2013	175,400	2,138	
2014	168,200	1,424	

5. Exercice

1.a Considering a HDD = 2,000 Kd, calculate the annual heat loss of the classroom if the walls were in contact with outside, annual thermal comfort and a heat transfer coefficient U = 2W/m²K



$\Phi = U\ S\ \Delta T$ [U = U value; S = Area]
Heat loss = $Q = \Phi\ t$
-> $\mathbf{Q = U\ S\ \Delta T\ t = U\ S\ HDD}$
HDD = 2,000 Kd
S = 10m x 4m x 4 + 10m x 10m = 260 m²

Q = 2 x 260 x 2000 (W/m²K x m² x Kd) = 1,040,000 Wd = 24,960,000 Wh ≈ 25 MWh

b. Considering a natural gas boiler with an efficiency of 75%, how much gas will be burned?

$E = Q/\eta$ = 25 MWh/0.75 = 33.3 MWh ≈ 3.300 m³ natural gas

c. CO_2 emission?
0.251 kg CO2/kWh (N1 + N2)

Emission ≈ 8.4 tCO_2

5.f. Renewable geothermal precautions

Geothermal is an attractive renewable because it is "always on," independent of the weather; if we make geothermal power stations, we can switch them on and off so as to follow demand.

But how much geothermal power is available?
We could estimate geothermal power of two types:
- the power available at an ordinary location on the earth's crust
- the power available in special hot spots (volcanic places like Iceland)

Ordinary locations are so much more numerous in Europe.
There are no hot spots in Belgium

Sustainable geothermal power is limited by the heat regeneration of the geothermal reservoir. The speed at which heat travels through solid rock limits the rate at which heat can be sustainably sucked out of the red-hot interior of the earth without reducing the temperature.

In Belgian subsoil geothermic flow is **0.025 to 0.150 W/m²**

Ref. D. MacKay

6. BIOMASS

a. Form and origin
b. Energy (Wood, Biogas, Biofuels)
c. Energetic conversion precautions

References :

- Renewable energy – G. Boyle – RE Boyle : Chapter 4 (p 106-123)
- Sustainable energy – D. MacKay : Chapter I6

6.a. Biomass

Definition : Biomass is the general term for energy derived from living material that is produced by biological process. (not included fossils fuels and their by-products).

Energy form : Chemical – carbohydrate

Origin : Photosynthesis is the mechanism in which plant take carbone dioxide and water from their surroundings and use energy from sunlight to convert these into **carbohydrate** which make up vegetable matter.

$6\ CO_2 + 6\ H_2O$ + sun light -> $C_6H_{12}O_6 + 6\ O_2$ (ΔG = 2.868 kJ/mole)

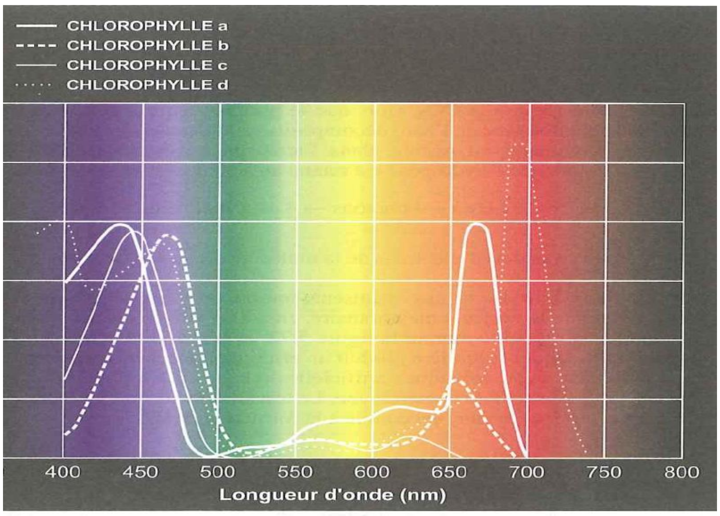
Main carbohydrates
- Monosaccharide $[CH_2O]_n$ (glucose, fructose)
- Disaccharides (lactose)
- Polysaccharides (starches, hemicelluloses, cellulose, lignin).

6.a. Photosynthesis efficiency

Annual energy efficiency, Sun -> biomass : **0,6%**

RE p 113

For C4 plants (miscanthus, sugar cane, maize, ...) growing in tropical regions, can give 1-2 %
Algae can give more



;.71 Spectres d'absorption des différents types de chlorophylle. (Source: [5.40].)
Used with permission from BSCS Green version.

6.a. Biomass origin

Wood
Forestry
Wood industry residues

Residues and wastes
From agriculture: crop residues, manure, food wastes
From domestic : urban wastes, demolition wastes
From industry: wastewater sludge , industrial organic wastes

Energy crops
Sugar plants
Vegetable oil
Wood crops (Short rotation coppice)
Algae

Fig. Récolte de TtCR

6.a. Biomass conversion

Solid fuels
- Drying wood (<100°C) -> Dry wood
- Roasting (< 300°C) -> Dry fuel and hydrophobic
- Pyrolysis (< 800°C) -> Charcoal
- Conditioning (logs, chips, pellets))
- Storage
- Transport

Wood and charcoal (bakala) - RDCongo

Gas fuels
- Biomethanisation -> $CH_4 + CO_2$
- Gasification -> Syngas ($CO_2 + CO + H_2$)
- Storage
- Transport

Liquid fuels
- Pyrolysis -> tars
- Fermentation and extraction -> bioethanol
- Extraction -> Vegetable oil
- Chemical or thermochemical transformation
- Syngas conversion into methanol
- Storage
- Transport

Pellets delivery by blowing truck

6.a. Biomass solid fuels

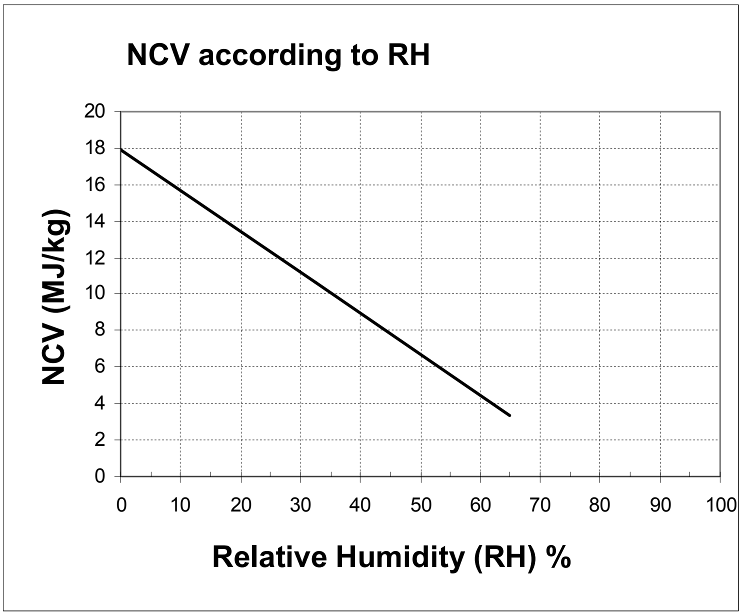
- Logs
- Wood coal
- Wood chips
- Pellets
- Grain and straw

Mass density depend on wood essence, stack and humidity

6.b. Wood NCV

Biomass is chemical energy.
Origin : Links C-C and C-H.

Humidity reduces dramatically NCV.
Because, heat is partly used for heating water and overall to evaporate it.



1 MJ = 1/3.6 kWh (0.278)

6b. Solid biomass - NCV, ashes and resource

NCV (1 kg)

- Dry wood (0% RH) = 18 MJ = 5 kWh_{heat}
- Natural dry wood (20% RH) = 12,6 MJ = 3,5 kWh_{heat}
- Green wood (50% RH) = 6,8 MJ = 1,9 kWh_{heat}

RH = Relative humidity
DM = Dry matter

- Dry grain (0% RH) = 18 MJ = 5 $kWh_{chaleur}$
- Dry grain (15% RH) = 4,2 kWh_{heat}

- Dry straw (0% RH) = 4,7 kWh_{heat}
- Dry straw (15% RH) = 4,0 kWh_{heat}

(Cereals grains : Wheat, oats, triticale, barley, maize/corn.)

Ashes

Wood : 0,5 - 1% Grains : 1,5 - 2,8 % Straw : 7 - 8 %

Resource annual - Belgium

(photosynthesis 0,6% -> 12 t/ha)
Wood (DM) : 6.8 - 12 t/ha (Short rotation coppice)
Wood (DM) : 2 - 4 t/ha (Forest management) (50% matter - 50% heating)
Grain (DM) : 5 - 9 t/ha Straw (DM) : 3 - 5 t/ha

Ref : ValBiom

6.b. NCV of biomass gasification

Gasification of biomass is a thermochemical process.
High temperature and anaerobic conditions, the wood turns into a gas mixture :
$CO_2 + C \rightarrow 2\,CO$
$H_2O + C \rightarrow CO + H_2$

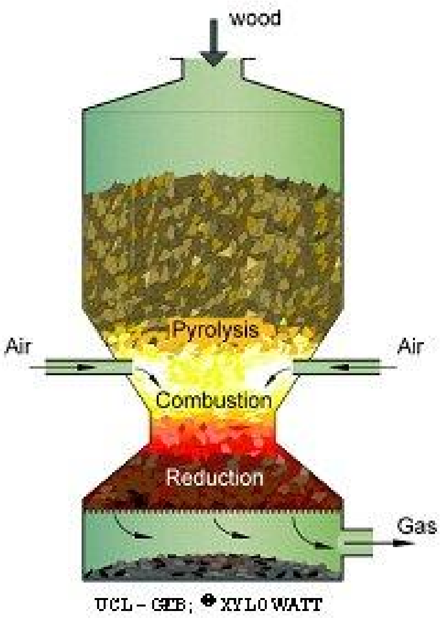
$CO + H_2$ (Syngas is the given name)

Gas mixture produced by gasification :

25% CO
14% H_2
2% CH_4
10% CO_2
49% N_2

NCV H_2 = 3 kWh/Nm³ NCV CO = 3,5 kWh/Nm³

NCV gas mixture= 5,5 MJ/m³ = 1,5 kWh/Nm³



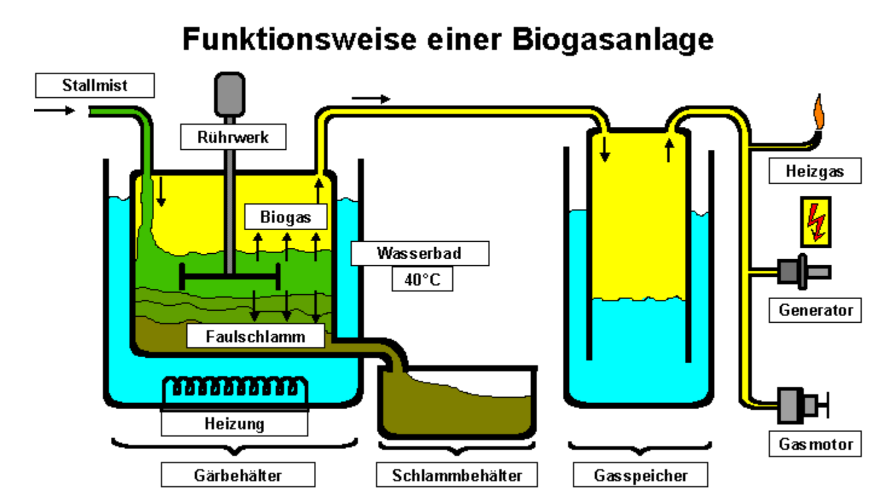
6.b. NCV of biogas

Biogas production
Biogas production is a biological process.
The anaerobic digestion of organic material is a biological process operated by specific bacteria.
It produces mixture gas CH_4-CO_2. The energetic interest is afford by methane (CH_4).

NCV is proportional with methane content.

% CH_4	NVC kWh/Nm^3
50	4,3
60	5,1
70	6,0

T : 15°C - p atm



Example of biogas production scheme

6.b. NCV of biofuels

First generation
- Ethanol and ETBE (*Ethyl Tertio Buthyl Ether*) – from fermentable matter such sugar
- Vegetable oil– from oil seed
- Biodiesel –Trans esterified vegetable oil

Second generation
From wood (Wood crops and waste) -> Methanol
From algae (Higher productivity)

NCV
Ethanol = 5,9 kWh/l
ETBE = 7,5 kWh/l
Methanol = 4,4 kWh/l (15,9 MJ/l)
Rapeseed oil= 9,5 kWh/l
Biodiesel = 9,2 kWh/l

Comparison : Diesel = 9,8 kWh/l - Petrol/Gasoline = 8,7 kWh/l

Ref : ValBiom

6.b. Biofuels productivity

Ref : ValBiom

Belgian annual gross productivity
Ethanol   Wheat : 2 500 l/ha;
Maize/Corn : 2 800 l/ha
Beet : 6 000 l/ha
Rapeseed oil : 1500 l/ha
Biodiesel (1500 l +140 kg methanol – 140 kg glycerine) → 1590 l

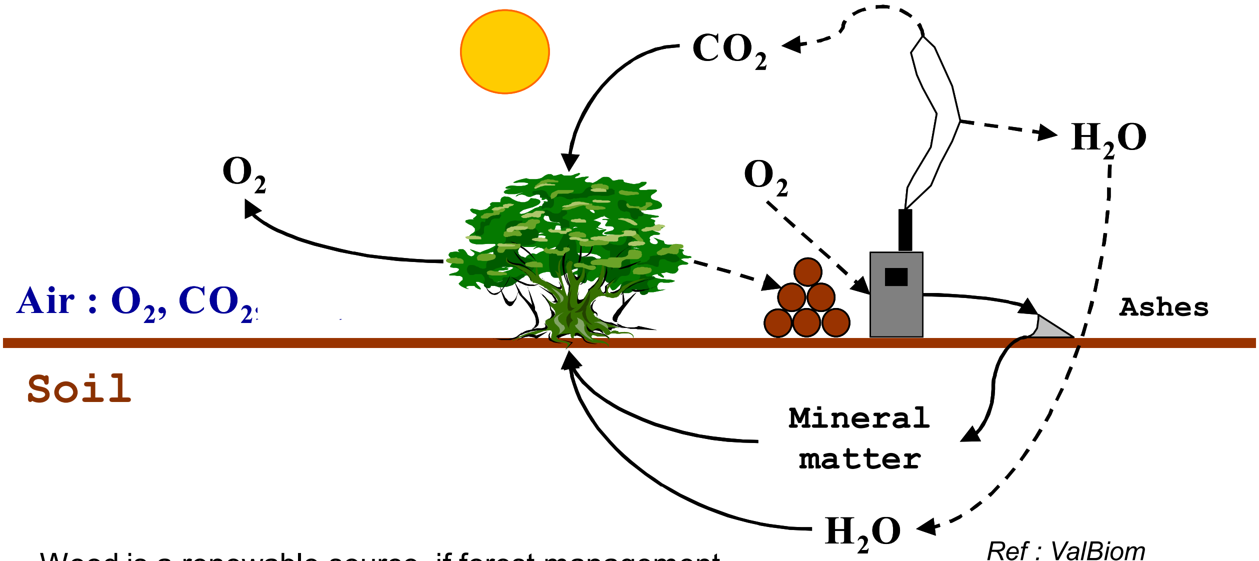
Energetic ratio = Ratio Energy production with Energy consumption by the biofuel production (mechanical, energy contents, agricultural input)
Beet ethanol : 1,4 - 2
Wheat ethanol : 1,8 - 2
Rapeseed Oil: 3 - 4,7
Rapeseed biodiesel : 2 - 3

Net annual productivity

$$Q_{net} = Q_{gross} \frac{(R-1)}{R}$$

Wallonia Usable agriculture area UAA = 7 600 km²

6.c. Biomass – Precautions



Ref : ValBiom

Wood is a renewable source, if forest management.

The combustion of wood does not increase the conc. CO_2 in the air if forest management

Precautions: Wood not contaminated, dry, closed fireplace 800°C and correctly air input (enough and warmed), washing of smoke (ashes)

7. Resource - SYNTHESIS

Available resource = Gross energy (GWh/km²)

Technical potential = Net energy (GWh/km²) and Annual average power (W/m²)

Resource energy potential is a question of
1. land availability,
2. "quality" exposure of energy resource flow,
3. conversion efficiency of renewable energy

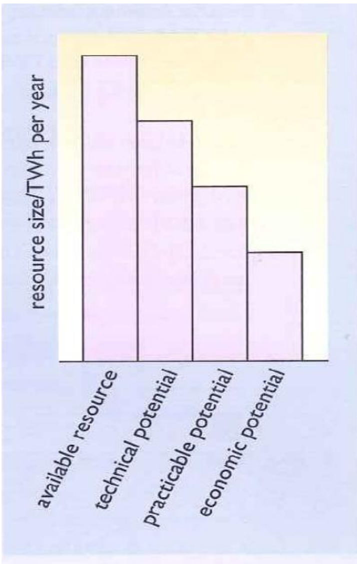


Figure 10.4 A notional ranking of renewable-energy resource sizes – the 'practicable' resource or 'economic' resource may be considerably less than the 'available' resource.

BOYLE

References :
- Renewable energy – G. Boyle – RE Boyle : Chapter 10 (p 388-391)
- Sustainable energy – D. MacKay : Chapter I18, II25

Renewable Energy

Renewable energy sources → **Conversion system** → **Energy end use**

Wind	Wind turbine (windfarm, isolated or urban turbine) Water pumping windmill, sail	**Electricity** **Work**
Watercourse **Tide – Wave – Ocean current** **Salinity gradient**	Water mill, hydropower plant, Tidal/ocean power station Power station	**Work or electricity**
Sun	Solar water heater, solar oven and dryer Photovoltaic system, thermodynamic power plant Solar cooling	**Heat** **Electricity** **Cold**
Biomass	Food — Metabolism Solid fuel, Biogas, Biofuel — { Burning equipment, Engine, Cogeneration	**Work and heat** **Heat** **Work or electricity** **Heat and electricity**
« Natural » Heat **Flow/Reservoir** (geothermal, oceanic or indirect solar heat)	Bioclimatic architecture, natural lighting, natural ventilation, ground-coupled heat exchanger Heat pump Geothermal well	**Heat, light** **Thermal comfort** **Heat** **Heat (electricity)**

Resource potential (GWh/km²)

Energy potential depends on available area for energy harvesting

Gross Energy (GEnergy) = Energy content of the RES
Net Energy (NEnergy) = Final energy after conversion = Average and [range]
NEnergy = GEnergy x Conversion efficiency

1 - Sun

GEnergy = ∫ S x Irradiation dt

Belgium : Annual energy on horizontal area : 1,000 kWh/m² or 1,000 GWh/km²

NEnergy (electricity) = 1,000 x 10% [6-20%] = 100 GWh_e/km² [50-200]

NEnergy (heat LT)* = 1,000 x 40% [30-60%] = 400 GWh/km² [100-500]

* heat LT means Low Temperature (30 - 100°C) – low enthalpy and high entropy

2 - Wind

GEnergy = ∫ P(S,v) dt (P = ½ ρ S v³)

NEnergy (electricity) = Wind installed power x FLH

Belgium FLH = 1,500 – 2,500 h - Offshore FLH = 2,800 – 3,800 h

With 2 MW turbine : 6 - 10 MW/km² → onshore : 15 GWh_e/ km² [9-25]
offshore: 25 GWh_e/ km² [15-40]

With 3 MW turbine : 10 - 15 MW/km² → onshore : 25 GWh_e/ km² [15-40]
offshore: 40 GWh_e/ km² [30-60]

3 - River

GEnergy = ∫ P(Q, h) dt ($P = 9.81\ Q\ h$)

NEnergy (electricity) = Installed hydropower x FLH

FLH = 2,500 – 4,500 h

Technical potential hydropower : 150 MW

] 600 GWh [350-700] For Belgium.

4 - Natural Heat (Air, Water, Ground)

For air, water and upper ground, the resource depends on the size of the exchanger and the required temperature.

GEnergy of Geothermal energy = 0.025 – 0.150 W/m² x 8,760h = 1 GWh/km² [0.22 – 1.3]

NEnergy (electricity) GEnergy x [10-30%] = 0.2 GWh/km² [0.02 – 0.4] (If t° up to 120°C)

NEnergy (heat LT) GEnergy x 90% = 1 GWh/km² [0.2 – 1.2]

5 - Biomass

GEnergy = Photosynthesis

Efficiency 0.6 % → **6 $GWh_{chemical\ energy}$/km²**

NEnergy (electricity) = 6 x [10-30%] = 1 GWh_e /km² [0.6 - 1.8]

NEnergy (heat HT) = 6 x [50-80]% = 4 GWh_e /km² [3.0 - 4.8]

7. Average annual power - Belgium

Power per unit land or water area	
Wind	2 W/m²
Offshore wind	3 W/m²
Tidal pools	3 W/m²
Tidal stream	6 W/m²
Solar PV panels	5–20 W/m²
Plants	0.5 W/m²
Rain-water (highlands)	0.24 W/m²
Hydroelectric facility	11 W/m²
Geothermal	0.017 W/m²

Table 18.10. Renewable facilities have to be country-sized because all renewables are so diffuse.

Synthesis table for Belgium

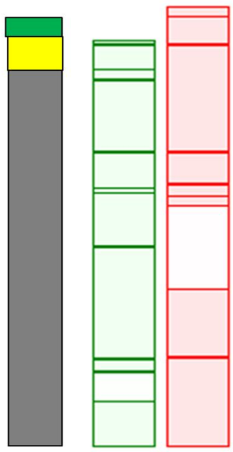
- Annual energy per km² (resource – Electricity – Heat)
- Average annual power (Resource – Electricity – Heat)

Rem. Order of magnitude and theoretical following MacKay Method

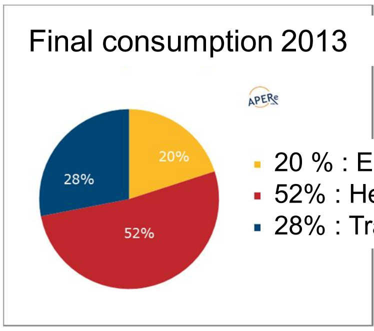
S Belgium (km²)	30 528						
S Belgian sea (km²)	3 462	**Annual energy**			**Average annual power**		
RES	**Technology (Efficiency)**	**Resource** *GWh/km²*	**Electricity** *GWh/km²*	**Heat** *GWh/km²*	**Resource** *W/m²*	**Electricity** *W/m²*	**Heat** *W/m²*
Sun	PV (10%) Solar thermal (40%)	1000	100	400	114	11,4	46
Wind	Wind onshore - 3MW		25	-		2,9	-
Wind	Wind offshore - 3MW		40	-		4,6	-
River	Hydroelectric		0,02	-		0,02	-
Ocean current		80	ND	-	9	0,9	-
Wave		ND	ND	-			-
Natural heat (air, water, upper ground)	Heat exchanger	ND	-	ND		-	
Geothermal (5 km)	Geothermal heat (90%) ORC elec plant (15%)	1	0,2	0,9	0,11	0,017	0,1
Biomass	Boiler (75%) Thermal plant (30%)	6	1,8	4,5	0,68	0,2	0,5

Balance Consumption and RES - belgium

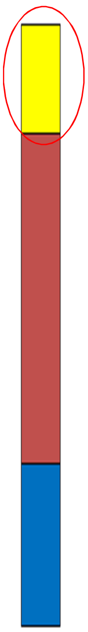
Belgium (km²)
30.500
3.600
Solar
Wind onshore
Wind offshore
Hydroelectric
Geothermal
Biomass



Final consumption : 100 kWh/d·p
Primary supply: 165 kWh/d·p
Total consumption : 230 kWh/d·p

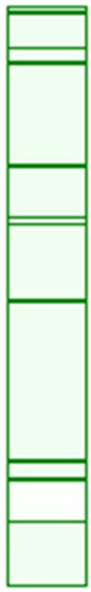


Balance Electricity consumption and RES - Belgium



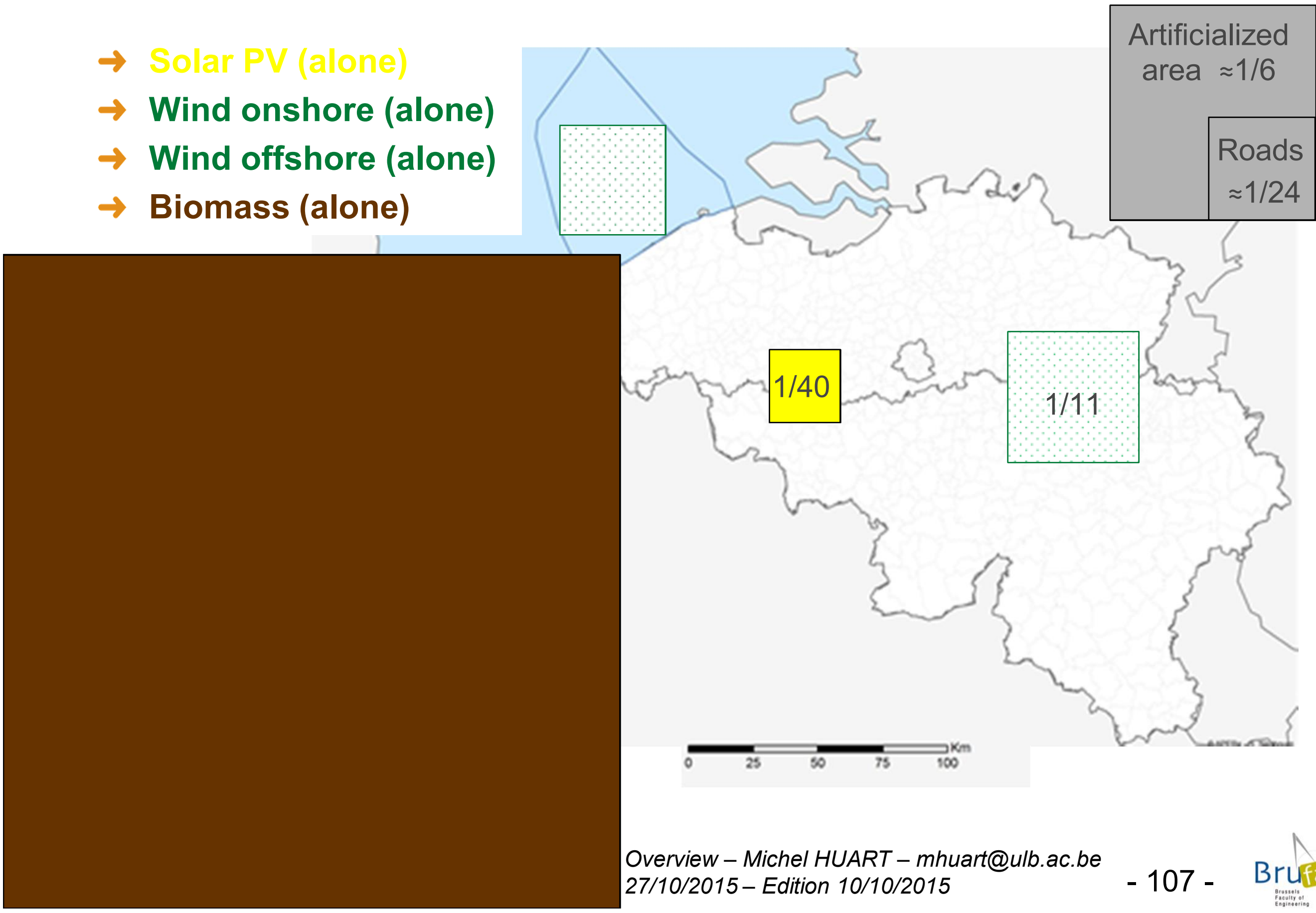
Belgium area land: 30,528 km²; sea 3,454 km²
Wallonia 16,844 km² (15% artificialized: building; within roads 4.4%)

80 TWh electricity/year :
- PV = 800 km² (2.6% du Belgian area)
- Wind onshore = 2,700 km² (9%)
- Wind offshore = 1,800 km² (50%)
- Biomass (domestic)= 50,000 km² (165 %)
- (Hydroelectricity = 0.3 à 0.6 TWh)
- Geothermic = ?
- Biomass import ?
- E-SER import ?



- Efficiency and Behaviour (Reduce the consumption)
- Demand side management (follow the flows)
- Storage short term (daily)
- Storage seasonal

Land requirement for electricity today consumption



02. Learning outcomes

- Enumerate the different RES ?
- Give the main features of each RES : Form, origin, power, measurements, annual energy, variability, energetic conversion precautions, ...
- Make an assessment of the energy potential of an area?
- Resource energy potential parameters?