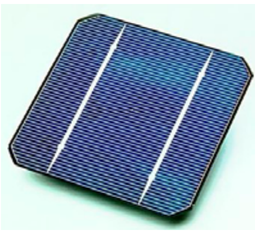
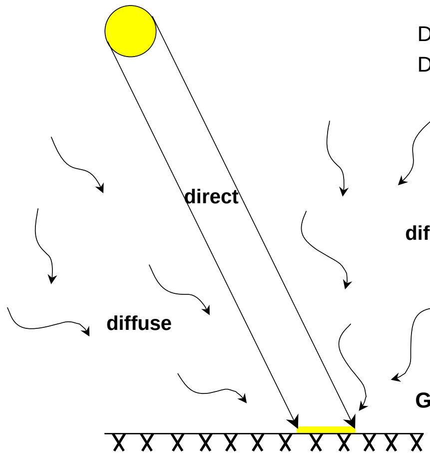
Introduction to Resource Assessments

Carsten Hoyer-Klick

Solar Resource Assessment



Global Horizontal Irradiation (GHI)



Direct Horizontal Irradiation (DHI)
Diffuse Irradiation (DIF)

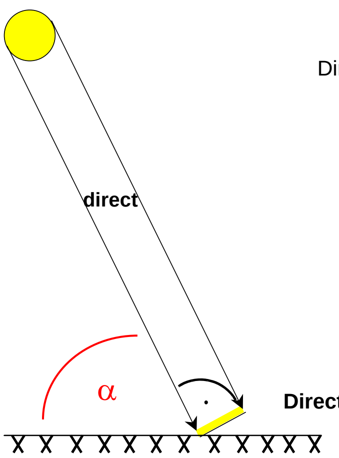
GHI = DHI + DIF

Example:

DHI = 600W/m²
DIF = 150W/m²
→ **GHI** = 750W/m²

Global Horizontal Irradiation (GHI)

Direct Normal Irradiation (DNI)



Direct Horizontal Irradiation (DHI)

DNI = DHI / sin α

Example:

DHI = 600W/m²
α = 50°
→ **DNI** = 848W/m²
DNI > DHI

Direct Normal Irradiation (DNI)

Solar Energy Resources

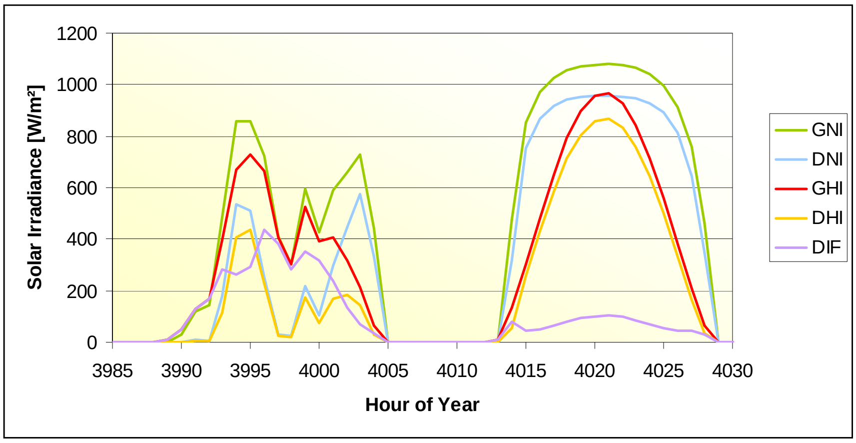
Fixed Non-Concentrating PV
➔ Global (Direct+Diffuse) Irradiation on a Surface tilted towards Equator (GTI)

Sun-Tracking Non-Concentrating PV
➔ Global Normal (Perpenticular) Irradiation on a Surface Tracking the Sun (GNI)

Sun-Tracking Concentrating PV and CSP
➔ Direct Normal Irradiation on a Surface Tracking the Sun (DNI)

Fixed Horizontal Array and Solar Updraft
➔ Global Horizontal Irradiance (GHI)

Solar Energy Resources Time Series



site: Munich, data: meteonorm

Ground Measurements

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Solar radiation instruments

global irradiance

- pyranometer: uncertainty: 2%* – 5%
- reference cells: uncertainty: 5% – 10%

*target accuracy of Baseline Surface Radiation Network (BSRN)

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Eppley, Kipp und Zonen

Solar radiation instruments

diffuse irradiance

- shaded pyranometers
  - pyranometer with shading ring
  - pyranometer with shading disc and sun tracking device
- uncertainty: 4%*- 8%

*target accuracy of Baseline Surface Radiation Network (BSRN)

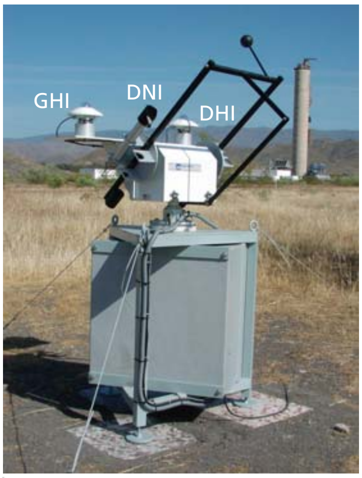
Solar radiation instruments

direct irradiance

- field pyrheliometer
- absolute cavity radiometer (current world reference of calibration)
- combined measurements uncertainty: 1%*
- rotating shadowband pyranometer uncertainty: 2%

*target accuracy of Baseline Surface Radiation Network (BSRN)

Precise sensors *(also for calibration of RSP)***:**



Thermal sensors:
pyranometer and pyrheliometer, precise 2-axis tracking

Advantage:

+ high accuracy
+ separate GHI, DNI and DHI sensors
  (cross-check through redundant measurements)

Disadvantages:

- high acquisition and O&M costs
- high susceptibility for soiling
- high power supply

Instrumentation for unattended abroad sites:

Rotating Shadowband Pyranometer (RSP)

Sensor: Si photodiode

Advantages:

+ fairly acquisition costs
+ small maintenance costs
+ low susceptibility for soiling
+ low power supply

Disadvantage:

- special correction for good accuracy necessary *(established by DLR)*

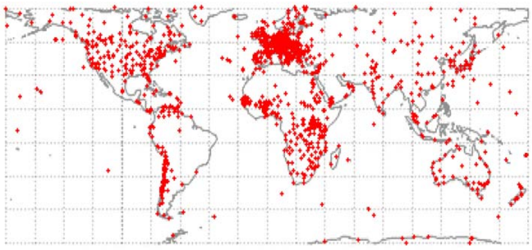
Availability of ground measured data

long term measurements at meteorological stations

- National Meteorological offices
- World radiometric Network (by World Meteorological Organisation)
- Baseline Surface Radiation Network

World radiometric network (WRDC)

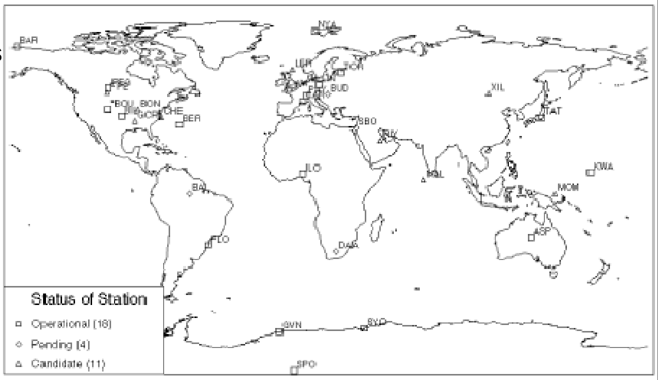
- global irradiance & sunshine duration
- ca. 1200 stations
- monthly or daily values



World Radiometric network 1966- 1993
(source: WRDC/WMO, Cros et al. , 2004)

Baseline surface radiation network BSRN)

- high quality measurements
- global, direct, diffuse
- minute values

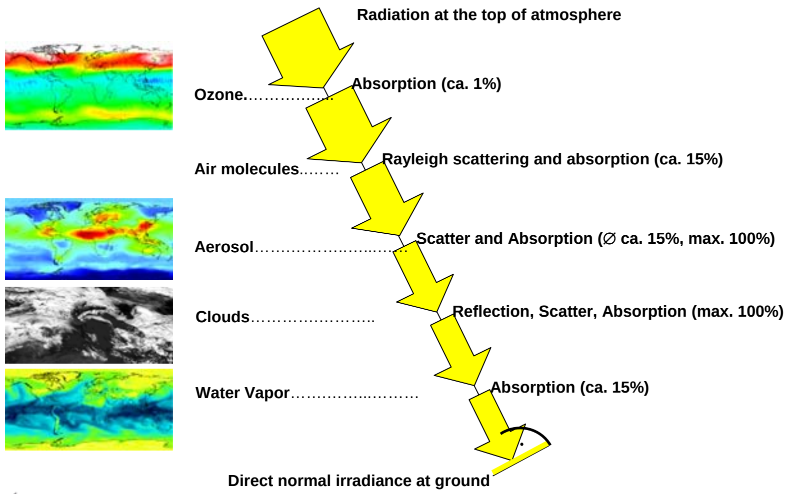


Resource products based on ground measured data

- **spatial interpolation techniques** to derive maps and site specific data
- **stochastic models or average daily profiles**
  to derive values with high temporal resolution
  (daily,hourly or minute values)
- **statistical global to beam models** to derive DNI

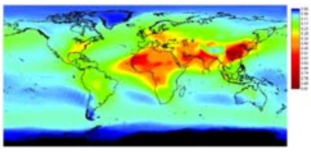
Satellite based assessments

Properties of Solar Radiation

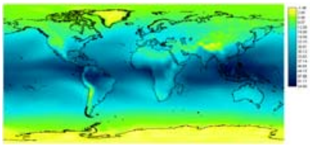


Clear sky Model input data

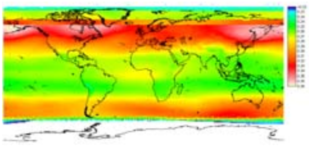
- Aerosol optical thickness
  GACP Resolution 4°x5°, monthly climatology
  MATCH Resolution 1.9°x1.9°, daily climatology



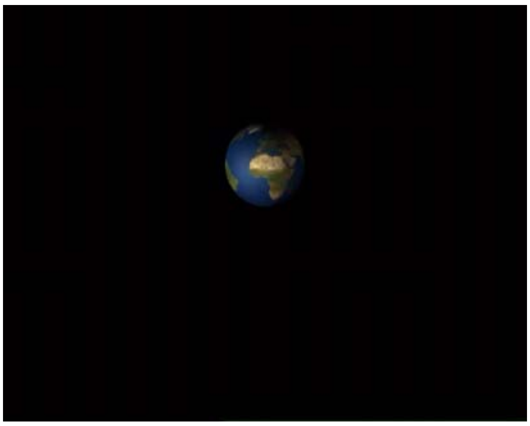
- Water Vapor: NCAR/NCEP Reanalysis
  Resolution 1.125°x1.125°, daily values



- Ozone: TOMS sensor
  Resolution 1.25°x1.25°, monthly values

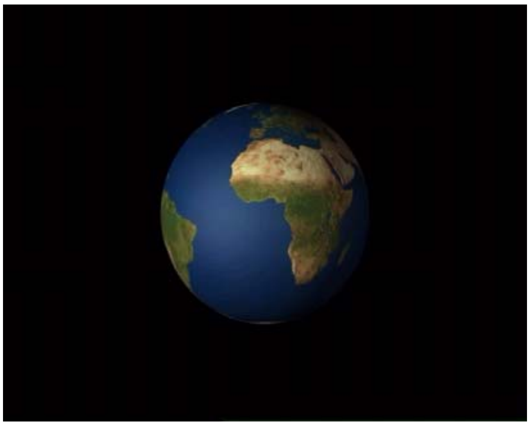


How two derive cload data from satellites



- The Meteosat satellite is located in a geostationary orbit
- The satellite scans the earth line by line every half hour

How two derive cloud data from satellites

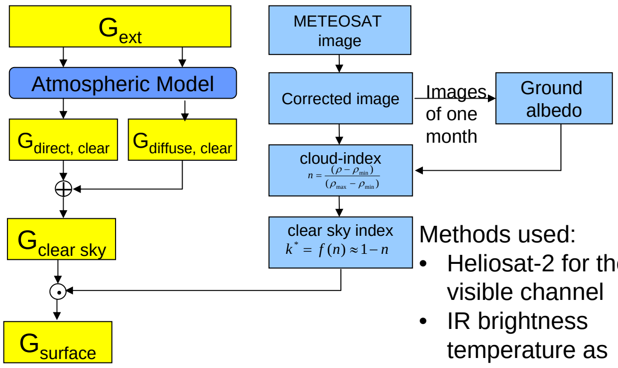


- The Meteosat satellite is located in a geostationary orbit
- The satellite scans the earth line by line every half hour
- The earth is scanned in the visible …

How two derive cloud data from satellites

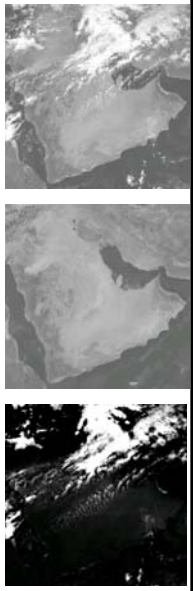
- The Meteosat satellite is located in a geostationary orbit
- The satellite scans the earth line by line every half hour
- The earth is scanned in the visible and infra red spectrum

Calculation of solar radiation from remote sensing

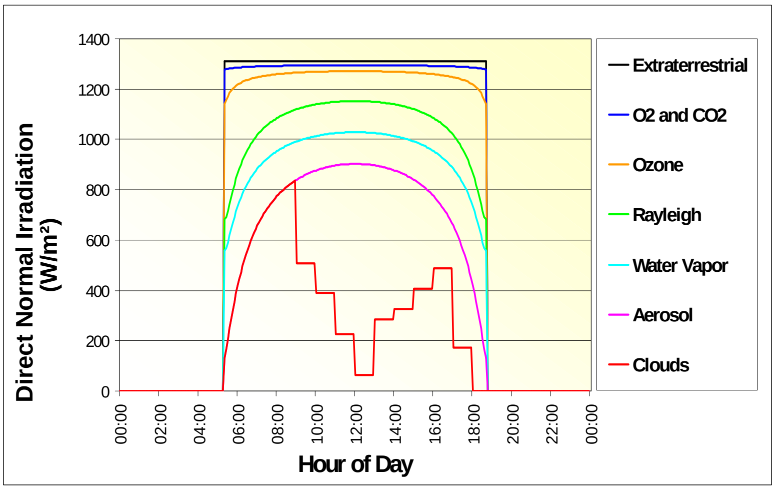


Methods used:

- Heliosat-2 for the visible channel
- IR brightness temperature as indicator for high cirrus clouds (T < -30°C, DNI = 0)

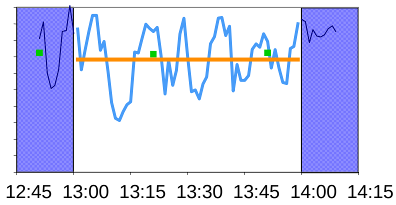


Radiative Transfer in the Atmosphere



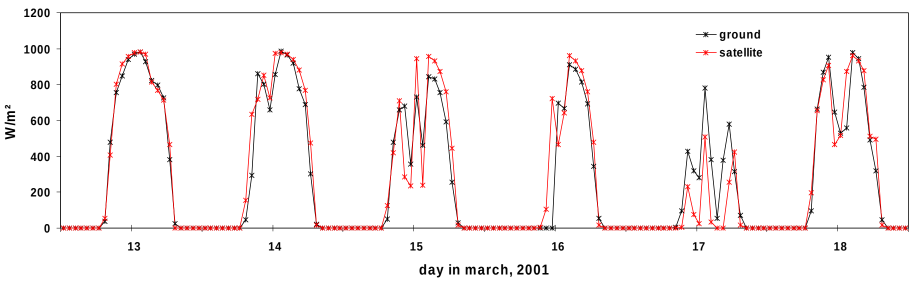
Comparing ground and satellite data: time scales

Hi-res satellite pixel in Europe



- Ground measurements are typically pin point measurements which are temporally integrated
- Satellite measurements are instantaneous spatial averages
- Hourly values are calculated from temporal and spatial averaging (cloud movement)

Example for hourly time series for Plataforma Solar de Almería (Spain)



Ground measurements vs. satellite derived data

Ground measurements

Advantages

+ high accuracy *(depending on sensors)*
+ high time resolution

Disadvantages

- high costs for installation and O&M
- soiling of the sensors
- sometimes sensor failure
- no possibility to gain data of the past

Satellite data

Advantages

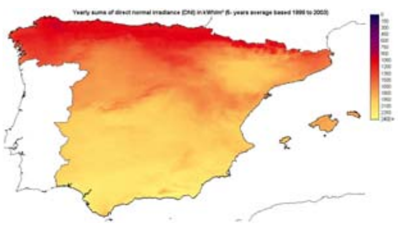
+ spatial coverage
+ long-term data *(more than 20 years)*
+ effectively no failures
+ no soiling
+ no ground site necessary
+ low costs

Disadvantages

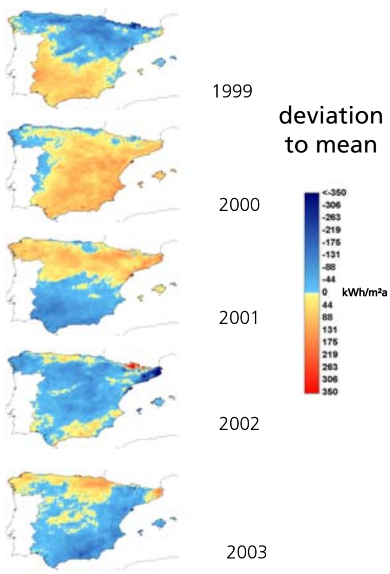
- lower time resolution
- low accuracy at high time resolution

Inter annual variability

- Strong inter annual and regional variations

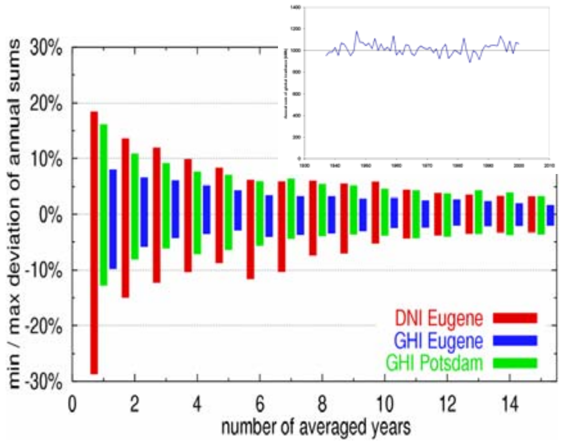


Average of the direct normal irradiance from 1999-2003



Long-term variability of solar irradiance

- over 10 years of measurement to get long-term mean within ±5%

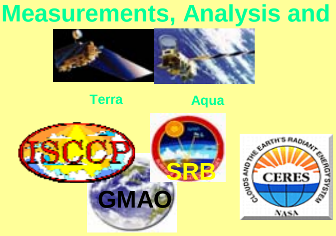


Data Sources

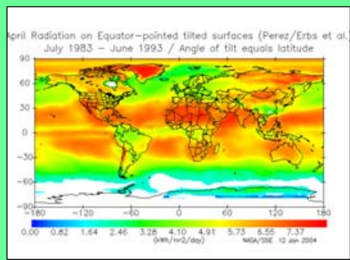
NASA-SSE

Earth System Science → **Applied Science Outcome**

NASA Satellite Measurements, Analysis and



Surface Meteorology and Solar Energy (SSE) Datasets And Web interface



Growing over the last 7 years to nearly 14,000 users, nearly 6.4 million hits and 1.25 million data downloads

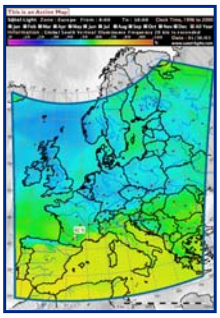
SSE Web Site

Over 200 solar energy and meteorology parameters averaged from 10 years of data

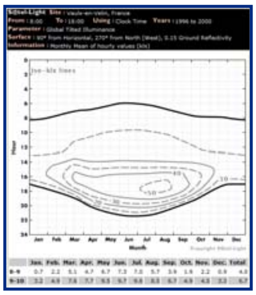
Satel-light

- 5 years of half hour data from 1996 to 2000
- Coverage: Europe

Maps



Diagrams



Data files

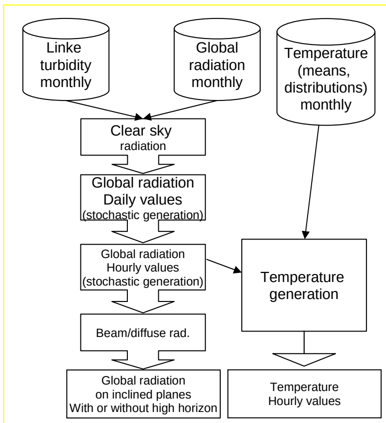
Meteonorm

- Based on ground data
- Satellite assisted interpolation between stations
- stochastic models to derive higher resolution data
- global to tilted models

Meteonorm

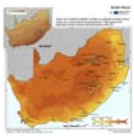
Climate data
Chain of Algorithms

- 8050 stations
- 8 parameters:
  - Global radiation (horizontal, inclined)
  - Air temperature
  - Dewpoint temperature
  - Wind speed and direction
  - Sunshine duration
  - Precipitation
  - Days with precipitation



PVGIS

- **DATA**
  - *solar radiation (Europe, Africa & SW Asia)*
  - *ambient temperature (Europe)*
  - *+ terrain, land cover…*
- **ASSESSMENT TOOLS**
  - *solar radiation for fixed and sun-tracking surfaces*
  - *output from grid-connected PV*
  - *performance of standalone PV (only Africa)*
- **MAPS**
  - *interactive*
  - *static*



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

PVGIS

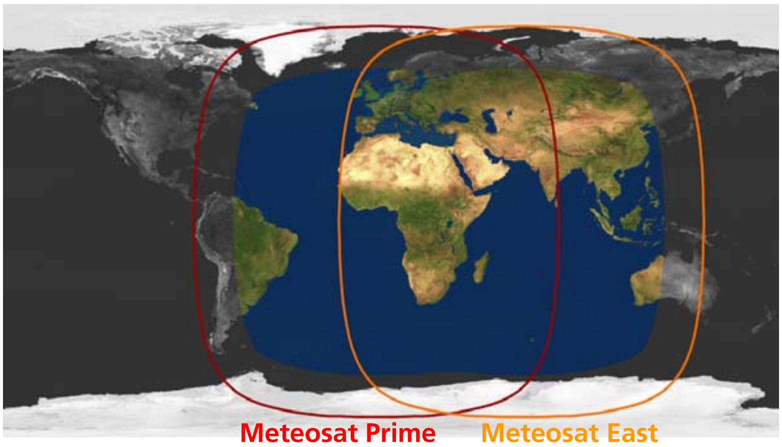
Calculation of grid-connected PV performance

- Calculation takes into account angle-of-incidence effects
- For crystalline silicon and CIS/CIGS, the effects of temperature and irradiance on the conversion efficiency are modelled.
- Generic (user-selected) value for BOS losses.
- Calculates output for:
  - Specified inclination and orientation
  - Optimum inclination for given orientation
  - Optimum inclination and orientation
  - 1- and 2-axis flat-plate tracking

Helioclim

- same area for H1, H2, H3
- uncertainties of irradiance values assessed and provided
- dissemination through the SoDa Service
- access to data in one click
- access on-pay, except 1985-1989 (daily) and 2005
- coupled to other services, e.g. irradiance on inclined surface

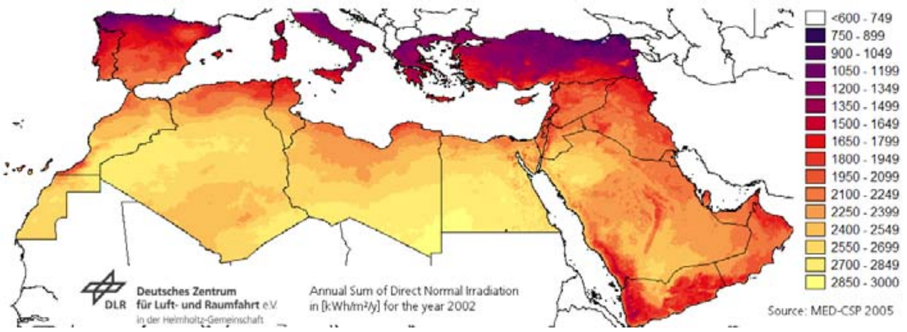
Satellite data: SOLEMI – Solar Energy Mining



- SOLEMI is a service for high resolution and high quality data
- Coverage: Meteosat Prime up to 22 years, Meteosat East 10 years (in 2008)

Results of the satellite-based solar assessment

Digital maps: e.g. annual sum of direct normal irradiation



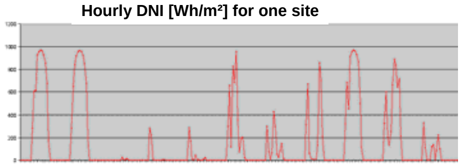
The original digital maps can be navigated and zoomed with Geographical Informations Systems like ArcView or Idrisi.

Temporal resolution of input data: 1 hour
Spatial resolution of digital map: 1 km x 1 km per Pixel
Long term analysis: up to 20 years of data

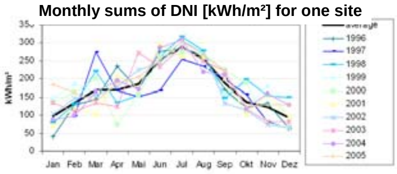
Results of the satellite-based solar assessment

Time series: for single sites, e.g. hourly, monthly or annual

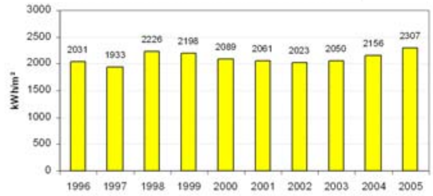
Hourly DNI [Wh/m²] for one site



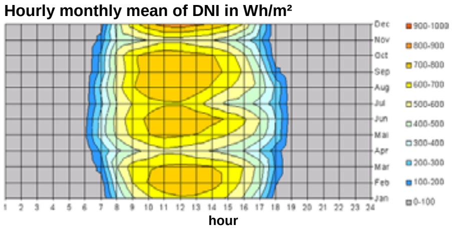
Monthly sums of DNI [kWh/m²] for one site



Annual sums of DNI [kWh/m²] for one site

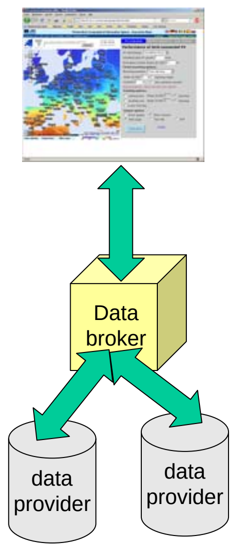


Hourly monthly mean of DNI in Wh/m²

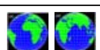
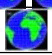
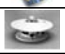
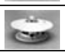


Unifying Access

- Lessons learned from SoDa:
  - General portal is beneficial for solar energy users
  - SoDa used proprietary software and communication standards
  - High maintenance efforts in operating the portal
- New approach in MESoR:
  - Open source software portal with large development community Internet standard communication protocols
  - Google Maps API for ease of use
  - The portal is a broker for data bases located elsewhere, it does not store and offer data itself
  - Connexion with larger intiative (GEO/GEOSS - IEA-Task36 SHC)



Resource products: input and extension

product	input	area	period	provider
NASA SSE		World	1983-2005	NASA
Meteonorm		World	1981-2000	Meteotest
Solemi			1991->	DLR
Helioclim			1985->	Ecole de Mines
EnMetSol			1995->	Univ. of Oldenburg
Satel-light		Europe	1996-2001	ENTPE
PVGIS Europe		Europe	1981-1990	JRC
ESRA		Europe	1981-1990	Ecole de Mines

<10 years   10-20years   >20 years

Resource products: Resolution

product	input	temp resolution	spatial resolution
NASA SSE	ISCCP	averag. daily profile	100 km
Meteonorm		synthetic hourly/min	1 km (+SRTM)
Solemi		1h	1 km
Helioclim		15min/30min	30 km // 3-7 km
EnMetSol		15min/1h	3-7 km // 1-3 km
Satel-light		30min	5-7 km
PVGIS Europe		averag. daily profile	1 km (+ SRTM)
ESRA		averag. daily profile	10 km

□ synthetic high resolution values □ measured high resolution values

Resource products: parameters

product	parameters
NASA SSE	GHI, DNI, DHI, clouds
Meteonorm	GHI,DNI,DHI, shadowing, illuminance
Solemi	GHI, DNI
Helioclim	GHI, DNI
EnMetSol	GHI, DNI,DHI, spectra
Satel-light	GHI,DNI, DHI, illuminance
PVGIS Europe	GHI,DHI, shadowing
ESRA	GHI, DNI, DHI

Combining Ground and Satellite Assessments

- Satellite data
  - Long term average
  - Year to year variability
  - Regional assessment
- Ground data
  - Site specific
  - High temporal resolution possible (up to 1 min to model transient effects)
  - Good distribution function

Good Solar Resource Assessments

- Based on long term data
- Site specific, high spatial resolution
- Sufficient temporal resolution for the application
- Modeled data set has been benchmarked, information on quality is available
- For large projects: Based on combined sources (e.g. Satellite and ground data).

Wind Resource Assessment

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Outline

- Logarithmic wind profile
- WAsP based Resource Assessments
- Numerical Wind Atlases
- Offshore wind estimations

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Logarithmic wind profile

- Wind speed increases with height above ground
- Profile depends on surface properties (roughness length)
- Resource assessments therefore need exact characterizations of the surroundings of the measurement and wind turbine site

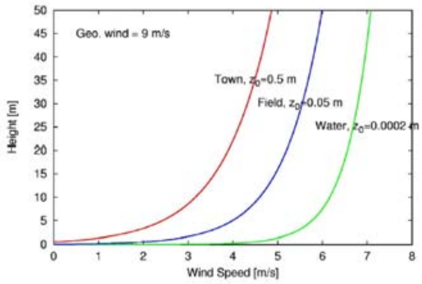
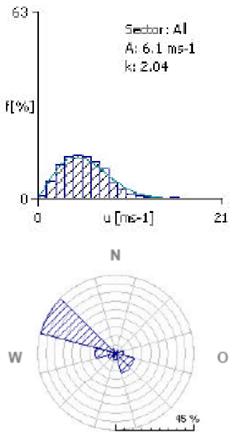


Image source: RISØ/DTU

Site specific wind resource assessment

Important information is:

- **Distribution of wind speeds** (can be approximated by a Weibull distribution with parameters A and K)
- **Distribution of wind directions** Wind rose shows probability of a wind from a certain sector (This needs to be set in relation with the local roughness in this sector)



How do I estimate the resource at a site?

- Local measurement
  - High effort, needs time
- Estimation from a more distant measurement
  - The WAsP Method
- Wind Atlases
  - Based on measurements
  - Numerical wind atlas

Measurements

- Measurements of meteorological stations at 10m above ground are often of limited accuracy and use for wind energy applications
- Dedicated 50m masts with at least 3 sensors at different heights are much more expensive but much better suited to derive data for wind energy.
- Most such measurements are operated privately and the data is not accessible.

The WAsP Method

WAsP: Wind Atlas Analysis Application Program

- How to apply measurements from one location to new locations ?
  - Step 1: Create a generalized wind climate by removing local effects at measurement site
  - Step 2: Create a new local wind climate by adding local effects at the wind turbine site.

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What are local effects?

- Nearby obstacls: Houses, close trees, etc.
- Changes in roughness: From fields to wood, to settlements, ...
- Changes in orography: Hills, valleys

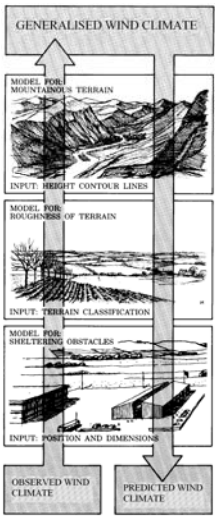

Image source: RISØ/DTU

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The WAsP Approach

- Local effects are removed from wind measurements to derive a generalized wind climate (for a uniform surface)
- The generalized wind climate is adapted to proposed sites.
- Input
  - A suitable number of measurements
  - A Meso-Scale numerical weather model.

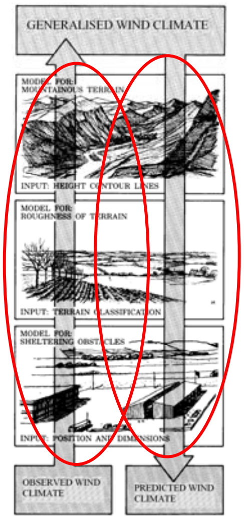


Image source: RISØ/DTU

Wind Atlas based on measurements

- A suitable number of high quality measurements is characterized for its local effects
- A generalized wind climate is produced for each measurement (roughness 0.03m, 50 m height)
- The measurements are combined into an atlas
- Sample: European Wind Atlas by Troen and Petersen, 1989 based on 220 stations
- Limitations for complex terrain and costal zones

Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
(dark blue)	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
(red)	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
(orange)	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
(green)	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
(light blue)	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Image source: RISØ/DTU

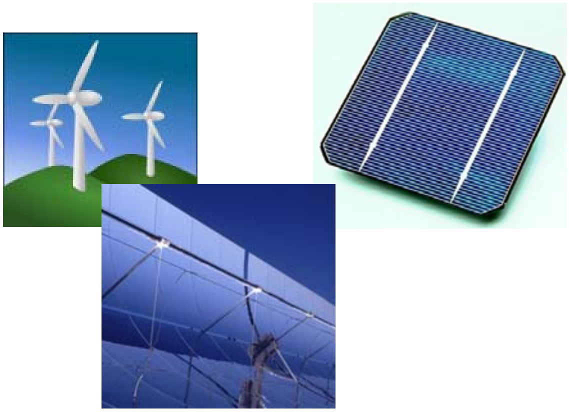
Offshore

- The wind profile is more complex due to
  - larger thermal inertia of the water
  - wind and wave interactions
  - time lag of wave development
- Nearly no measurements, very few platforms e.g. in front of the Danish or German coast
- But: Wind speed can be assessed by measuring the wave height with radar satellites. Limitations exist close to the coast.

Data sources

- Wind Atlases of RISØ/DTU: www.windatlas.dk
- SWERA: http://swera.unep.net
- Wind resource assessment is a commercial business
- Some companies/institutions are:
  - AWS Truewind
  - 3tier
  - Garrad Hassan
  - Cener
  - NREL
  - National Met Offices

Sample Applications



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Example: Global Wind Atlas

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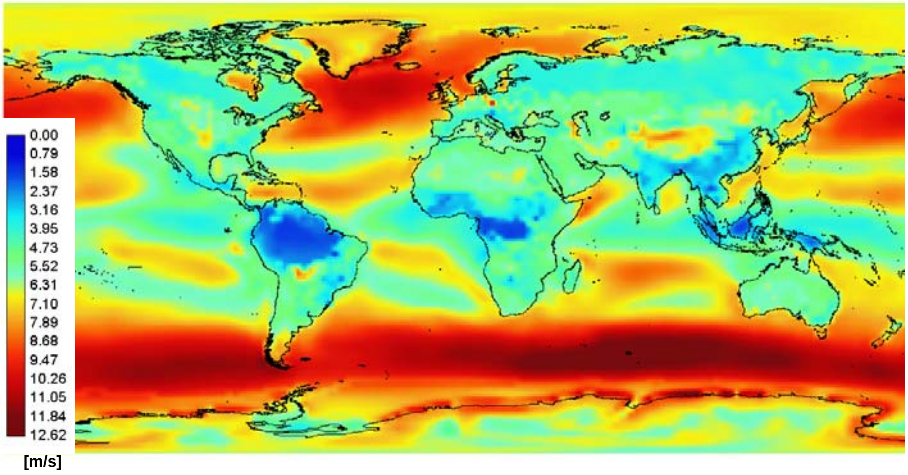
Annual Average Wind Speed at 50 m Height



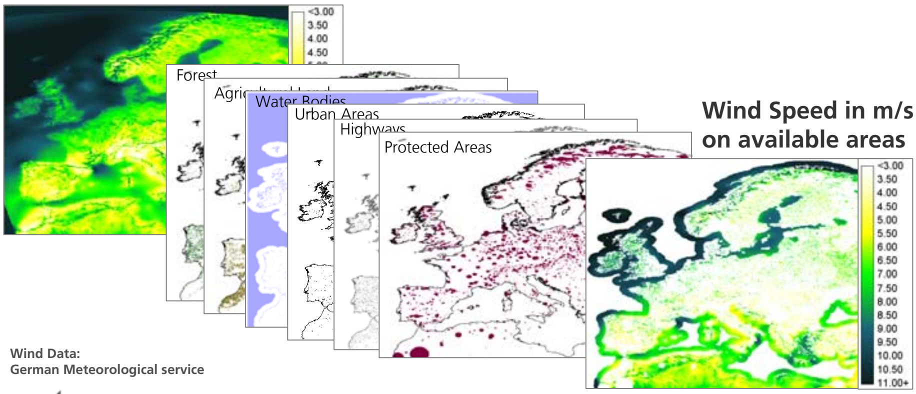
http://eosweb.larc.nasa.gov/sse/

Example: Wind Cost Potential Functions

Wind Power Potentials in Europe

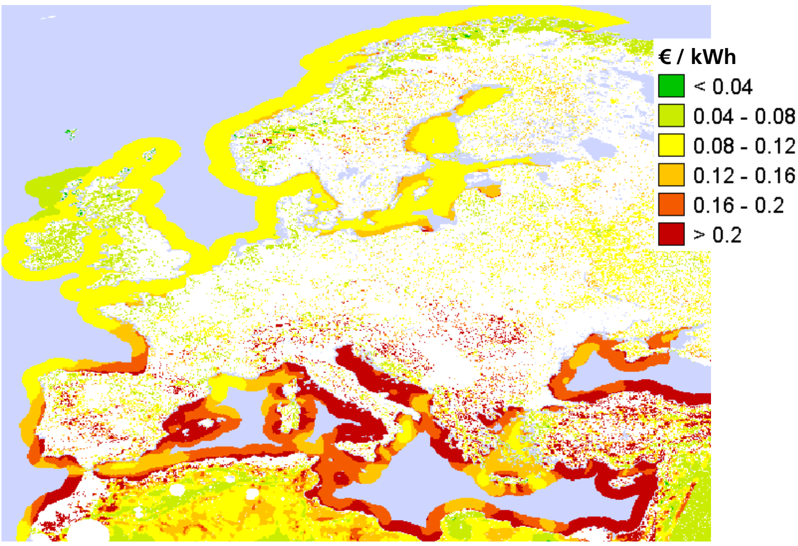
Resource and Land Availability

Wind Speed in m/s

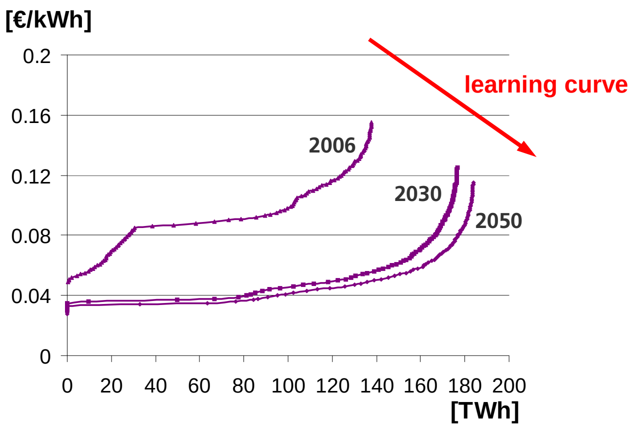


Wind Data:
German Meteorological service

Wind Electricity Cost: Technology and Cost Status 2006



Cost Potential Functions for Wind Power in Germany



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Scholz 2009

Example: Offshore Wind Potentials

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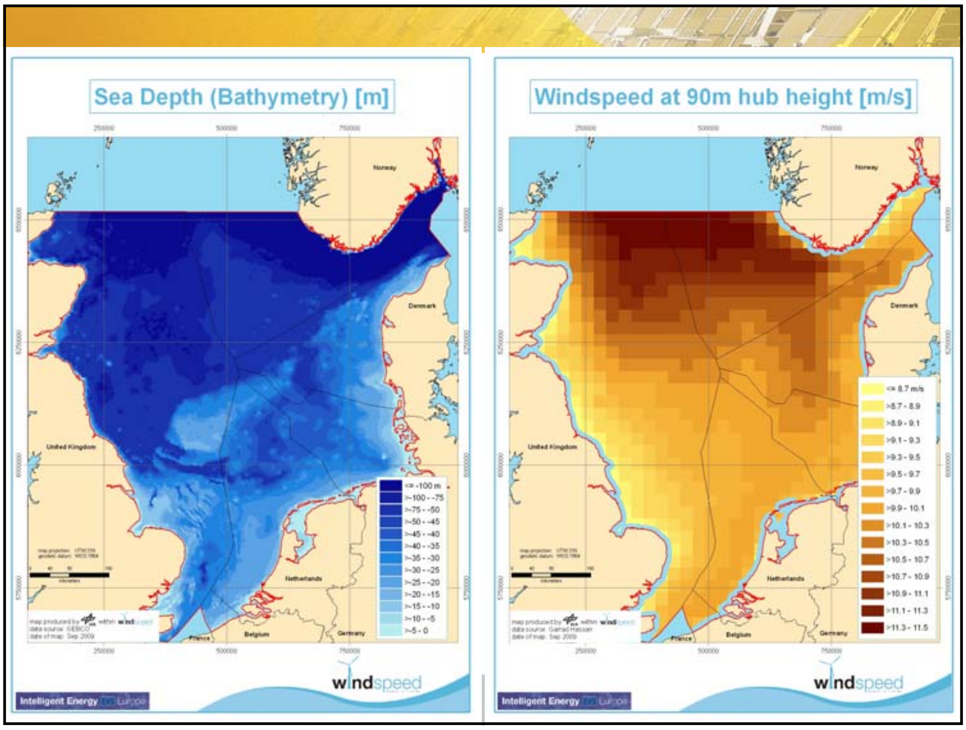
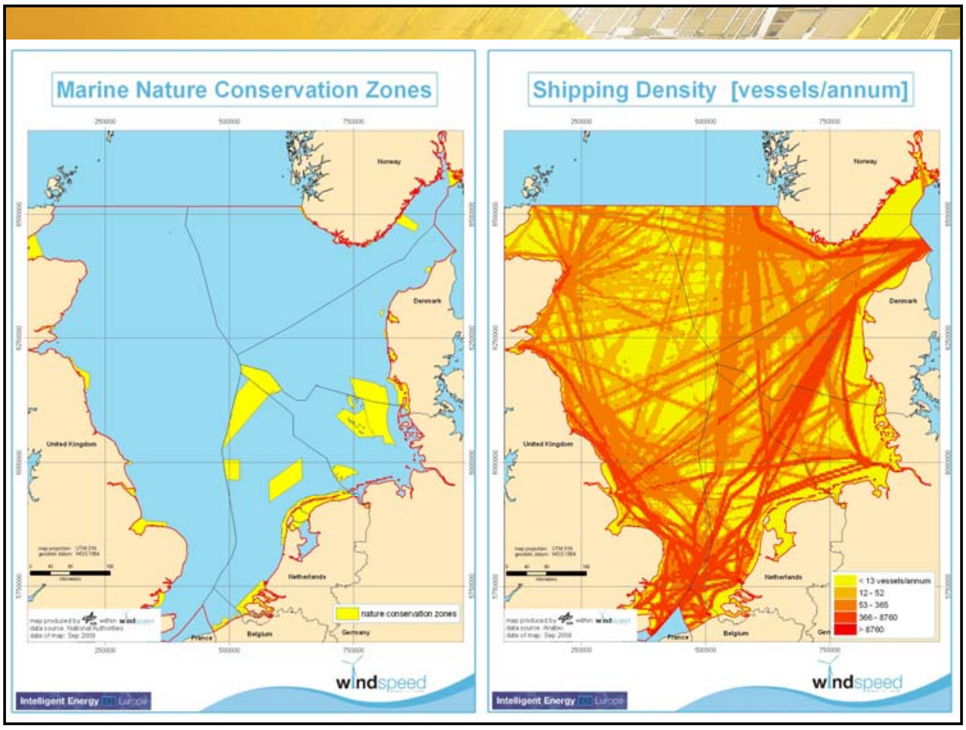
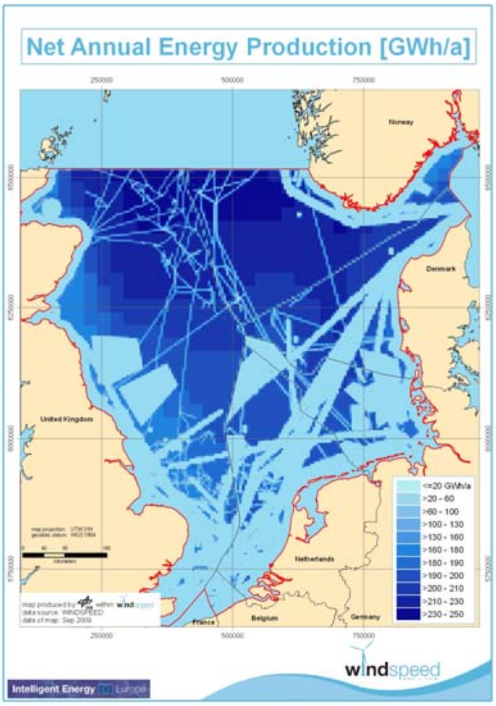

Sea Depth (Bathymetry) [m]
Norway
Denmark
United Kingdom
Netherlands
Belgium
France
Germany
<= -100 m
>-100 - -75
>-75 - -50
>-50 - -45
>-45 - -40
>-40 - -35
>-35 - -30
>-30 - -25
>-25 - -20
>-20 - -15
>-15 - -10
>-10 - -5
>-5 - 0
windspeed
Intelligent Energy Europe
Windspeed at 90m hub height [m/s]
Norway
Denmark
United Kingdom
Netherlands
Belgium
France
Germany
<= 8.7 m/s
>8.7 - 8.9
>8.9 - 9.1
>9.1 - 9.3
>9.3 - 9.5
>9.5 - 9.7
>9.7 - 9.9
>9.9 - 10.1
>10.1 - 10.3
>10.3 - 10.5
>10.5 - 10.7
>10.7 - 10.9
>10.9 - 11.1
>11.1 - 11.3
>11.3 - 11.5
windspeed
Intelligent Energy Europe


Marine Nature Conservation Zones
Norway
Denmark
United Kingdom
Netherlands
Belgium
France
Germany
nature conservation zones
windspeed
Intelligent Energy Europe
Shipping Density [vessels/annum]
Norway
Denmark
United Kingdom
Netherlands
Belgium
France
< 13 vessels/annum
12 - 52
53 - 365
366 - 8760
> 8760
windspeed
Intelligent Energy Europe



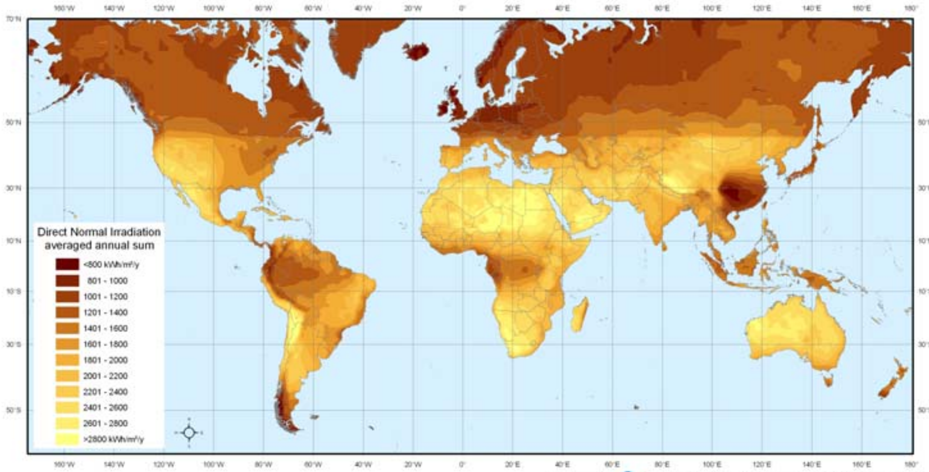
Progressive Model DRAFT!

Country	AEP [TWh/a]
BE	1.6
DE	80.4
DK	261.3
NL	15.2
NO	597.8
UK	1050.4

www.windspeed.eu

Example: CSP Export Potentials

Solar Energy Resource Assessment



Data based on NASA SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(http://eosweb.larc.nasa.gov/sse/)

Map created and map layout by DLR 2008
(http://www.dlr.de)

Land Area Resource Assessment

Exclusion of:
slope,

land use,

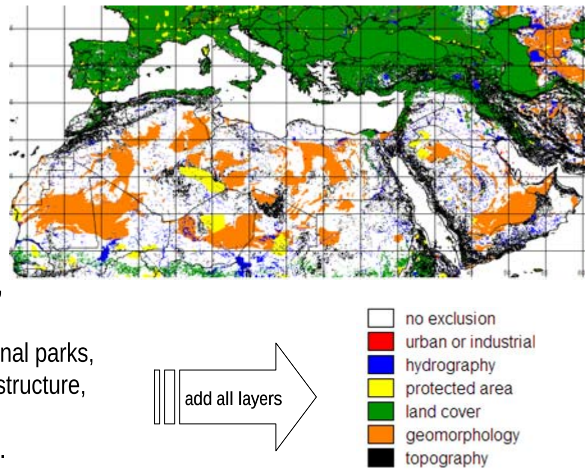
water,

dunes,

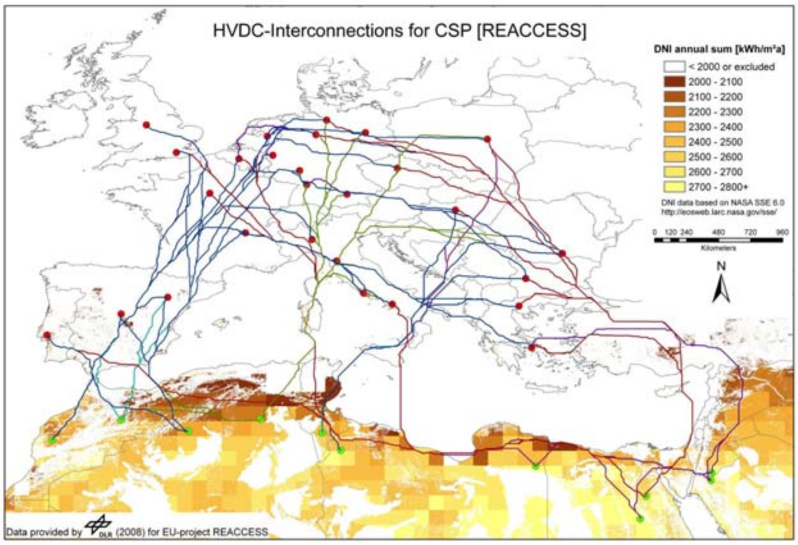
national parks,
infrastructure,

etc....

add all layers



Solar Electricity Corridors to Europe: REACCESS *



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www.dlr.de/tt/csp-resources