Part 3: Renewable Energy Resources

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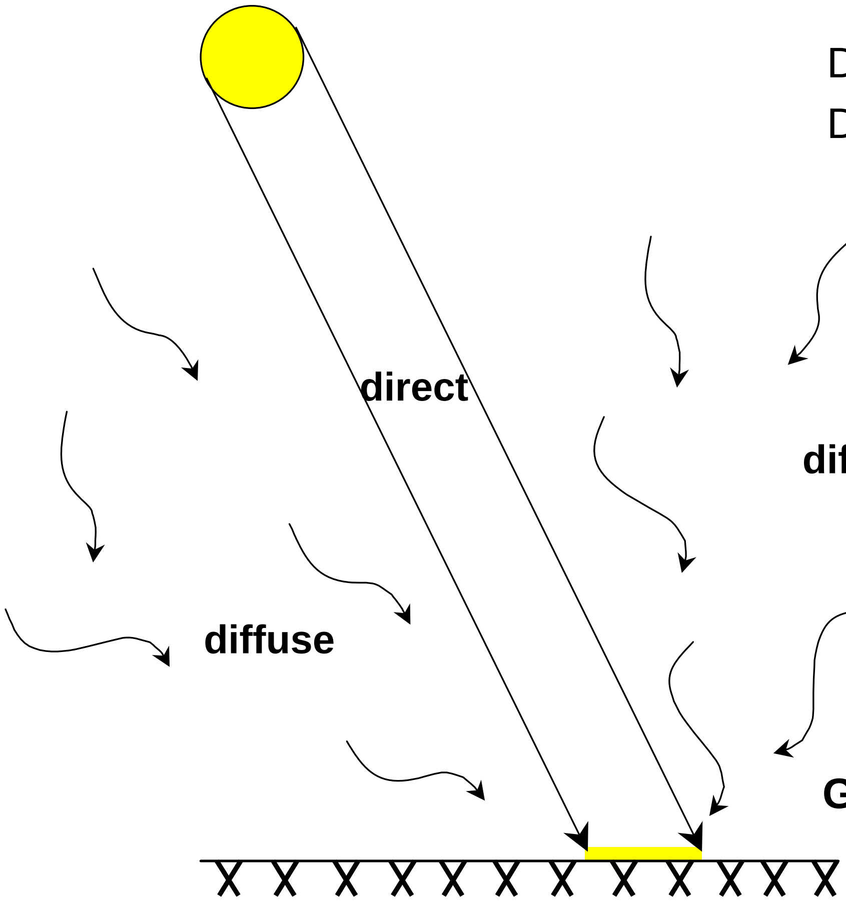
in der Helmholtz-Gemeinschaft

Solar Resource Assessment

Global Horizontal Irradiation (GHI)



Direct Horizontal Irradiation (DHI)

Diffuse Irradiation (DIF)

GHI = DHI + DIF

Example:

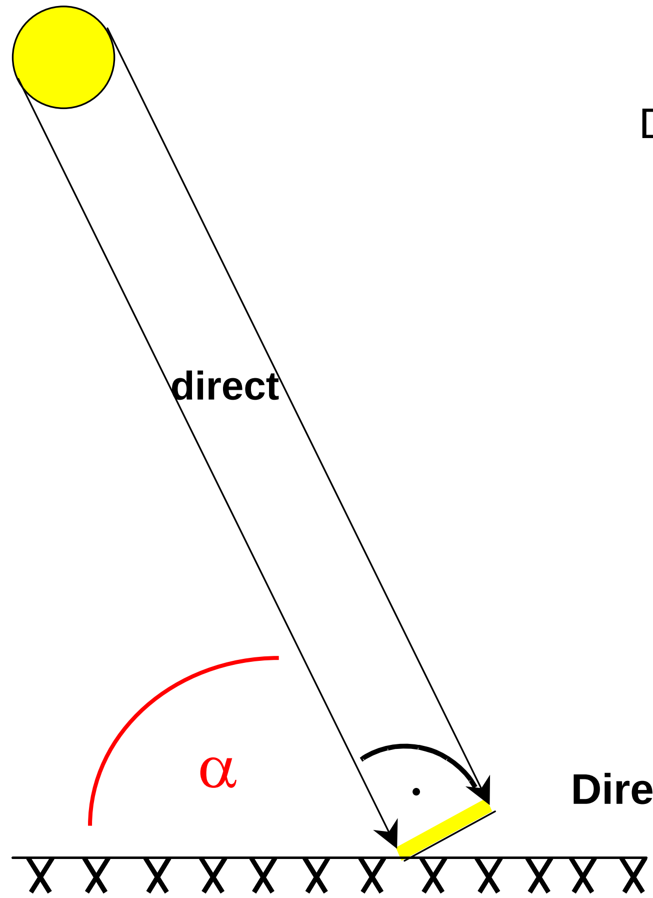
DHI = 600W/m²

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)

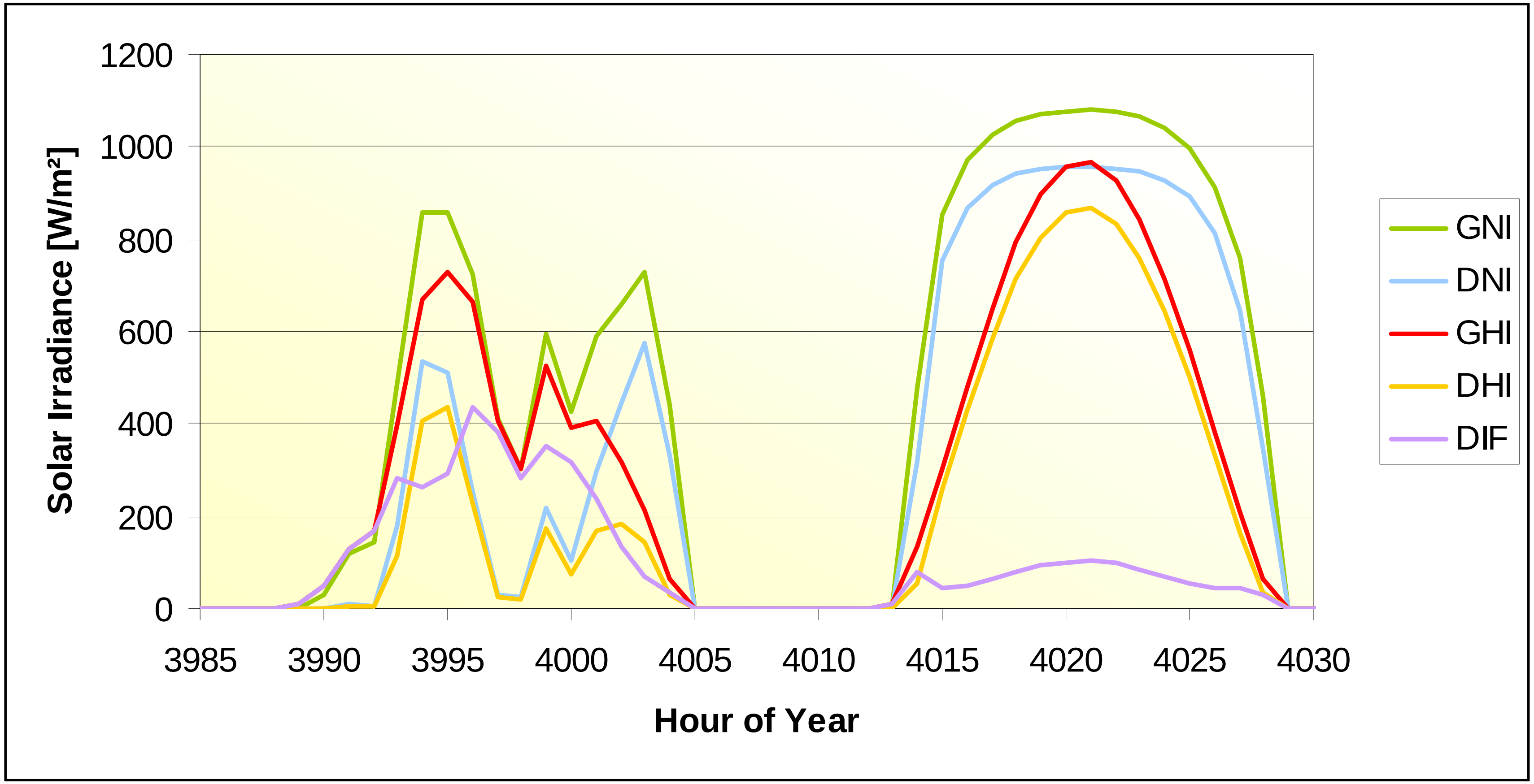
Sun-Tracking Concentrating PV and CSP

➔ Direct Normal Irradiation on a Surface Tracking the Sun (DNI)

Fixed Horizontal Array and Solar Updraft

➔ Global Horizontal Irradiance (GHI)

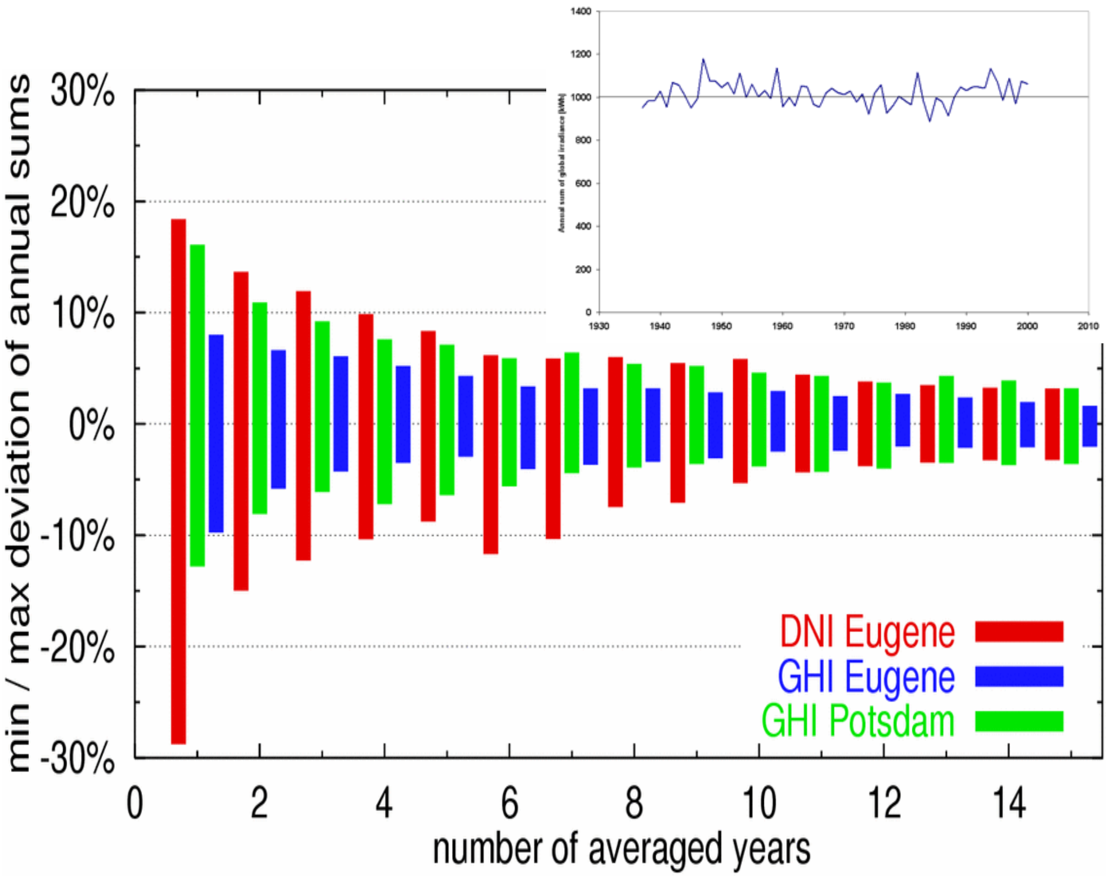
Solar Energy Resources Time Series



site: Munich, data: meteonorm

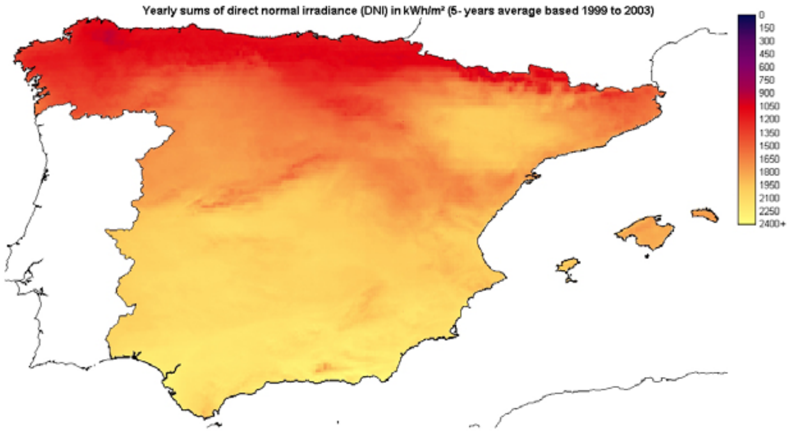
Long-term Variability of Solar Irradiance

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

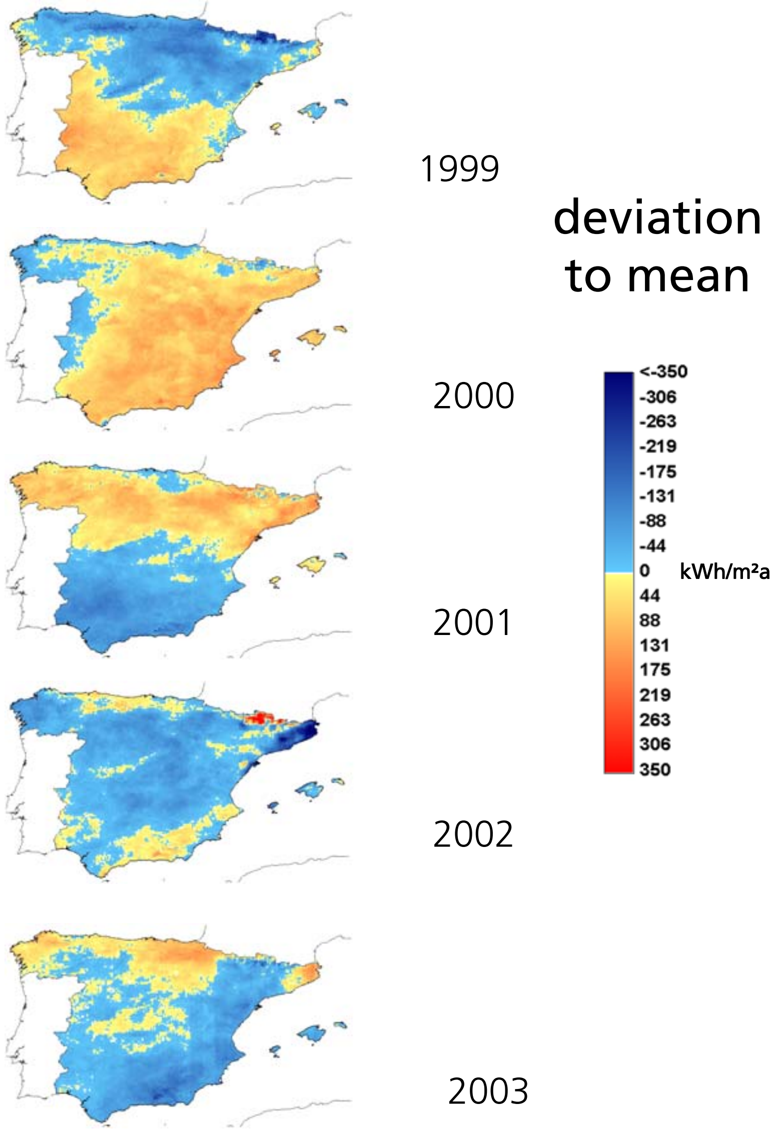


Inter Annual Variability

- Strong inter annual and regional variations



Average of the direct normal irradiance from 1999-2003



DNI Ground Measurements

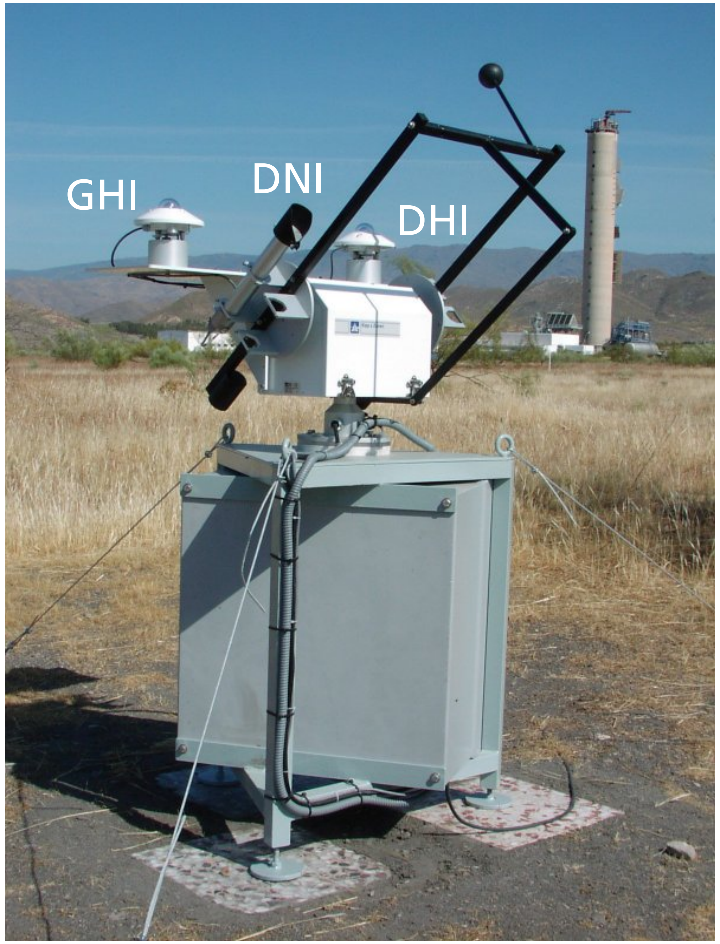
Solar Radiation Instruments

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:

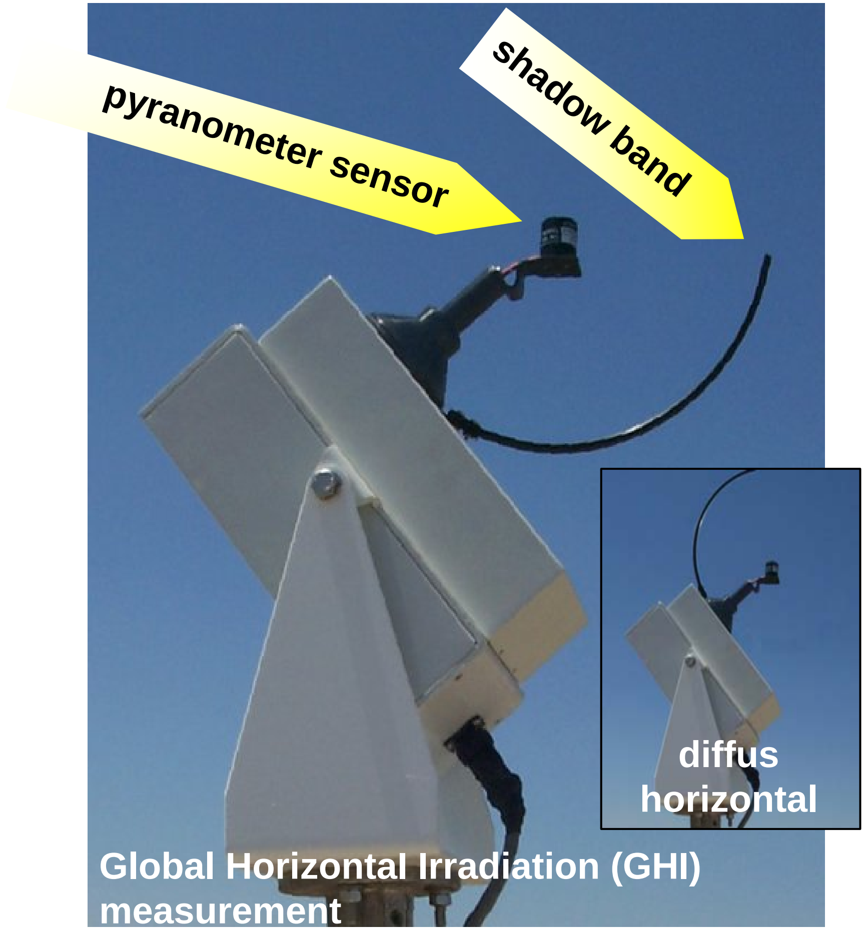
+ high accuracy
+ separate GHI, DNI and DHI sensors
  (cross-check through redundant measurements)

Disadvantages:

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

Instrumentation for Unattended Sites:

Rotating Shadowband Pyranometer (RSP)



Sensor: Si photodiode

Advantages:

+ low acquisition cost
+ low maintenance cost
+ low susceptibility for soiling
+ low power supply

Disadvantage:

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

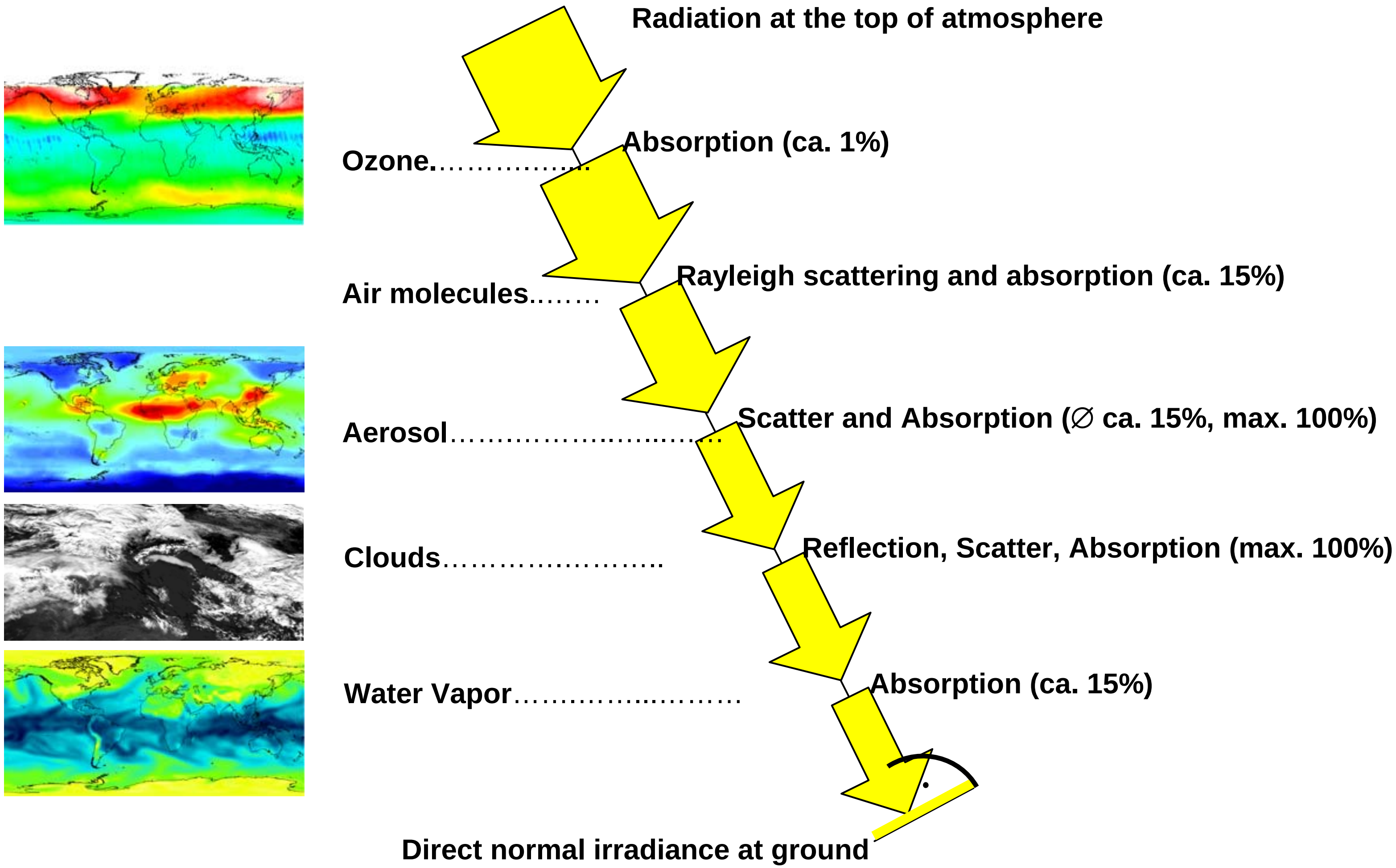
Availability of Ground Measured Data

long term measurements at meteorological stations

- National Meteorological offices
- World Radiometric Network (WRDC)
- Baseline Surface Radiation Network (BSRN)
- Own measurements

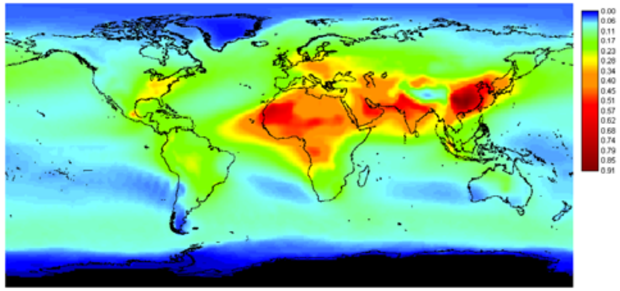
DNI from Satellite Data

Properties of Solar Radiation

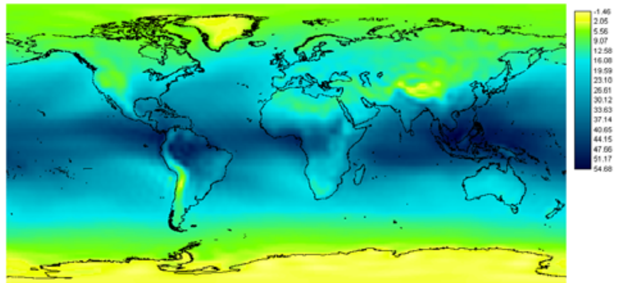


Clear Sky Model Input Data

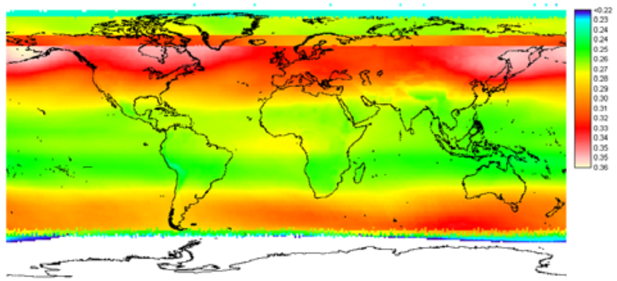
- Aerosol optical thickness
  GACP Resolution 4°x5°, monthly climatology
  MATCH Resolution 1.9°x1.9°, daily climatology



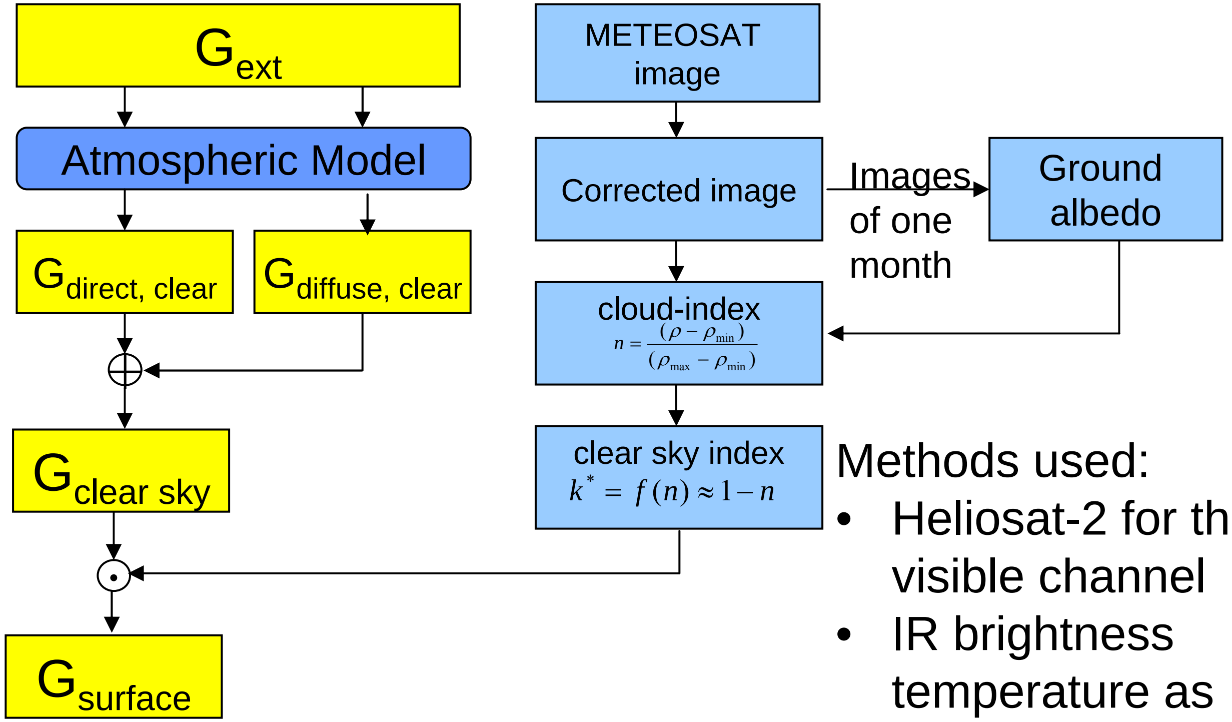
- Water Vapor: NCAR/NCEP Reanalysis
  Resolution 1.125°x1.125°, daily values



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

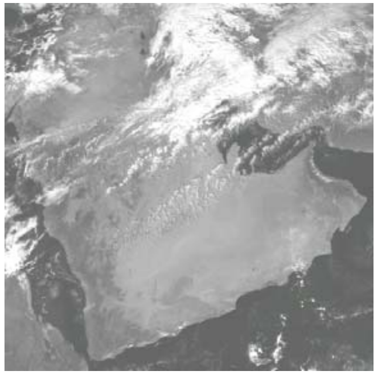


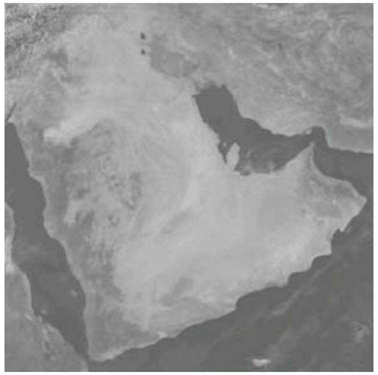
Calculation of Solar Radiation from Remote Sensing

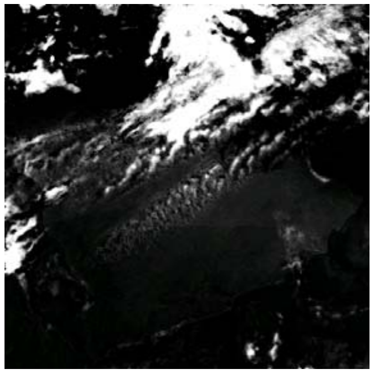


Methods used:

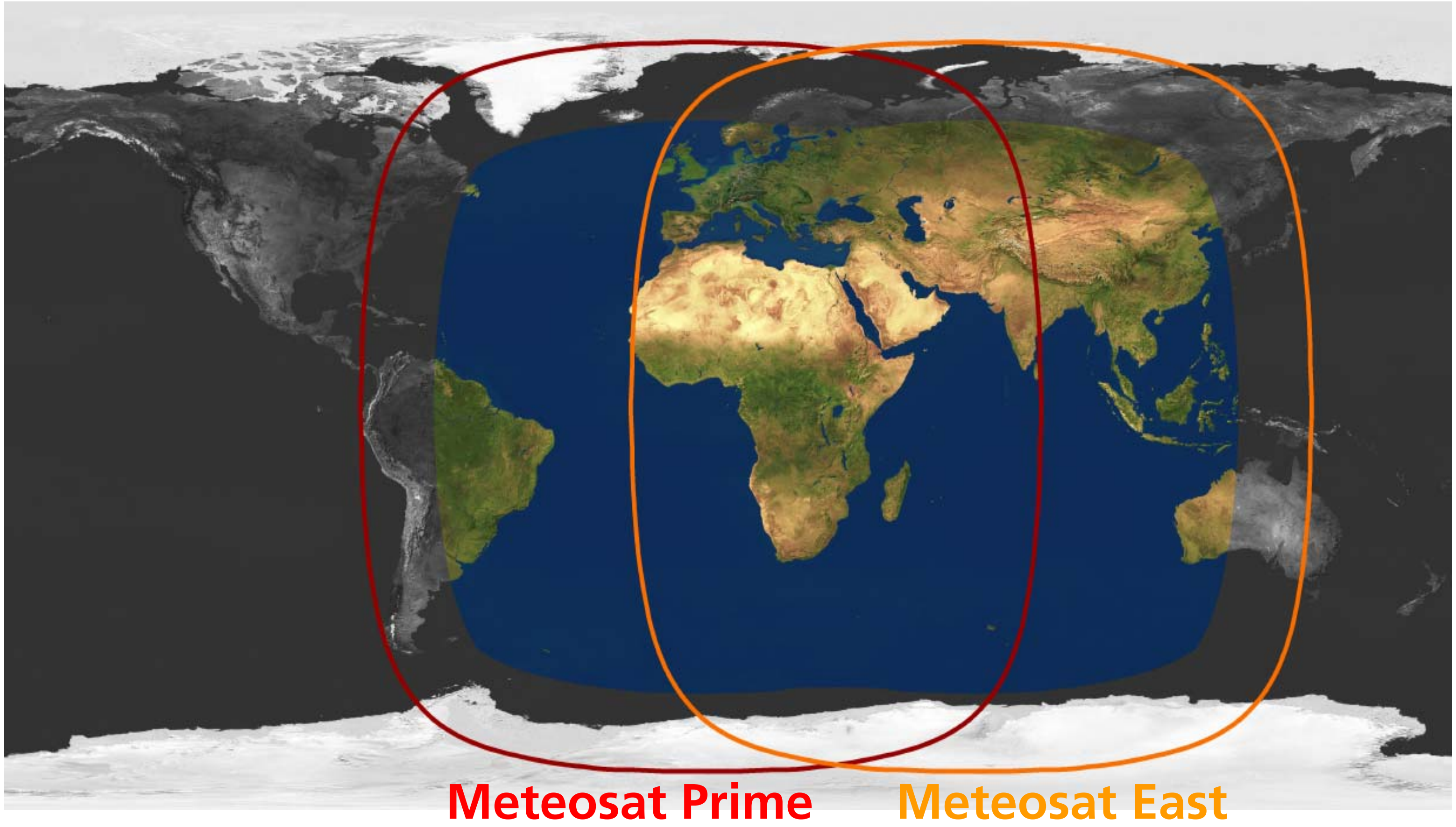
- Heliosat-2 for the visible channel
- IR brightness temperature as indicator for high cirrus clouds (T < -30°C, DNI = 0)





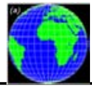


Satellite Data: SOLEMI – Solar Energy Mining



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

Resource Products: Input and Coverage

product	input	area	period	provider
NASA SSE	ISCCP	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

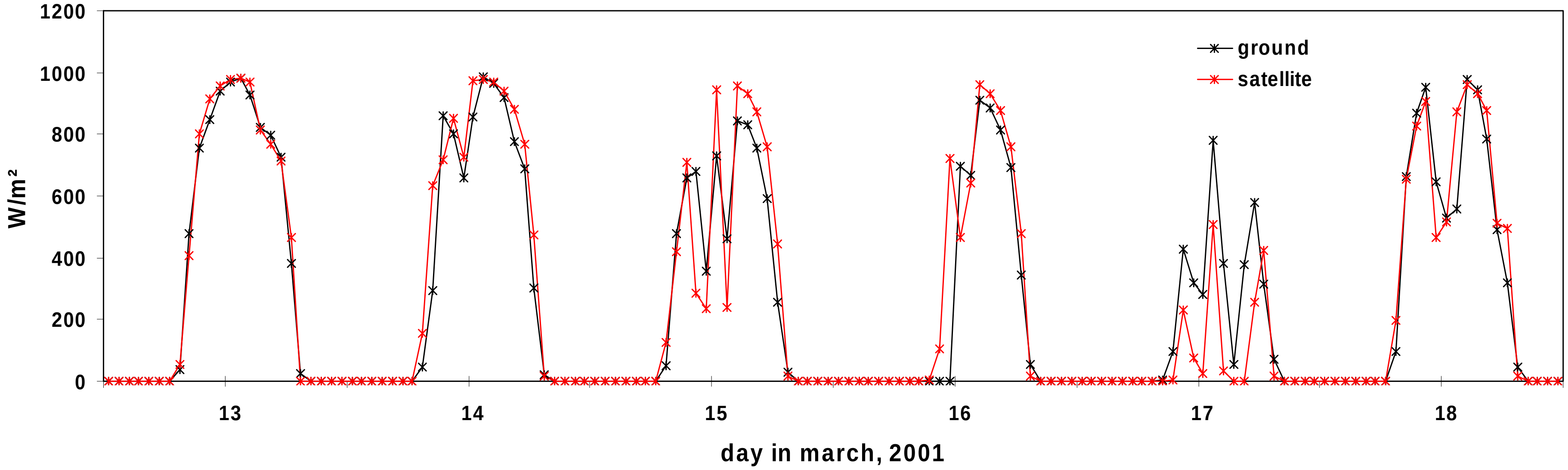
□ synthetic high resolution values □measured high resolution values

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 Satellite and Ground Data

Example of Hourly Time Series for Plataforma Solar de Almería (Spain)



Ground Measurement vs. Satellite Data

Ground Measurement

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

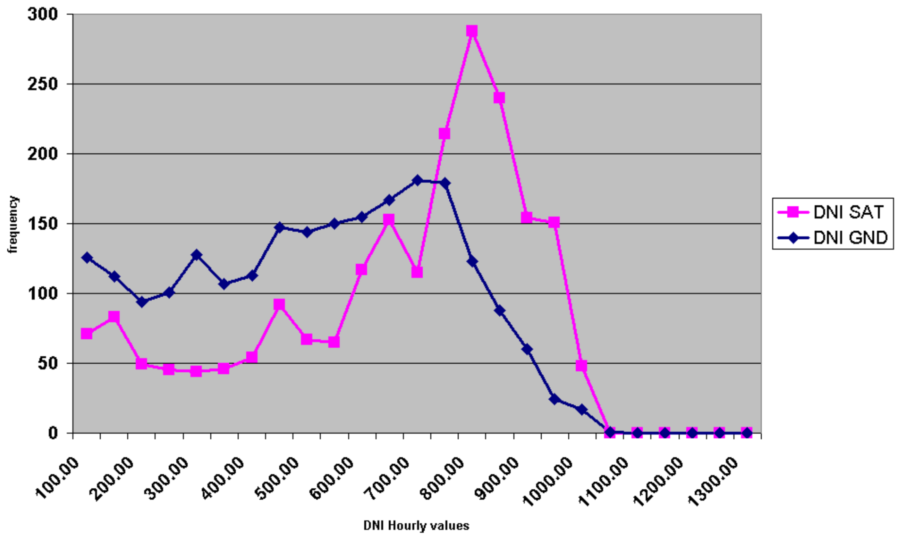
+ spatial coverage
+ long-term data *(more than 20 years)*
+ effectively no failures
+ no soiling
+ no ground site necessary
+ low costs

Disadvantages

- lower time resolution
- low accuracy at high time resolution

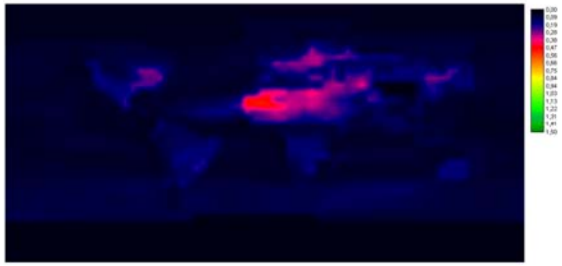
Simple Model

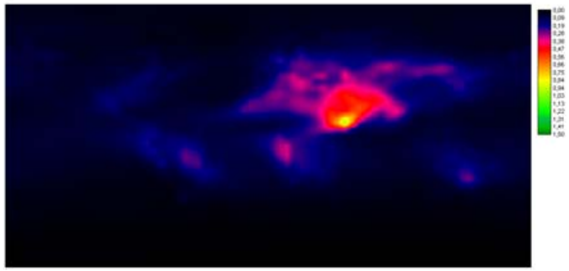
- GACP Aerosols and Simple Cloud Function
- Bias 12%, RMSD 47%
- Comparing ground and satellite data frequency distribution function shows a problem:

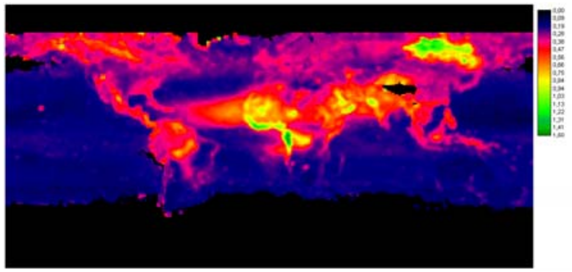


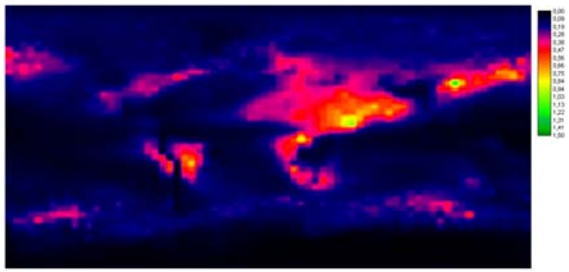
- over-estimate of frequency of high DNI

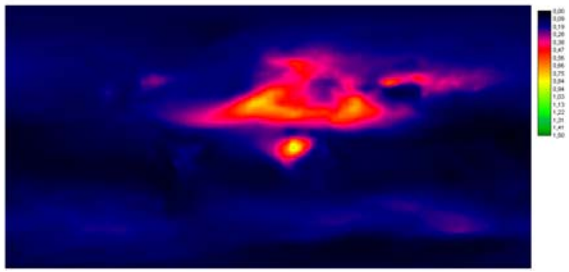
Inaccuracy of Aerosol Data

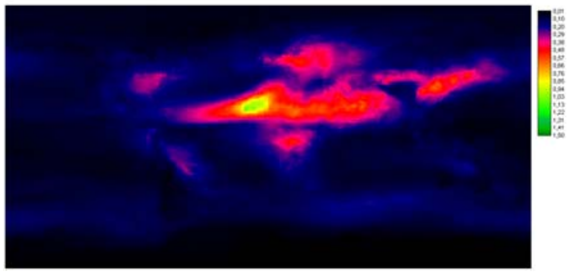

GADS


NASA GISS v1 / GACP


Toms

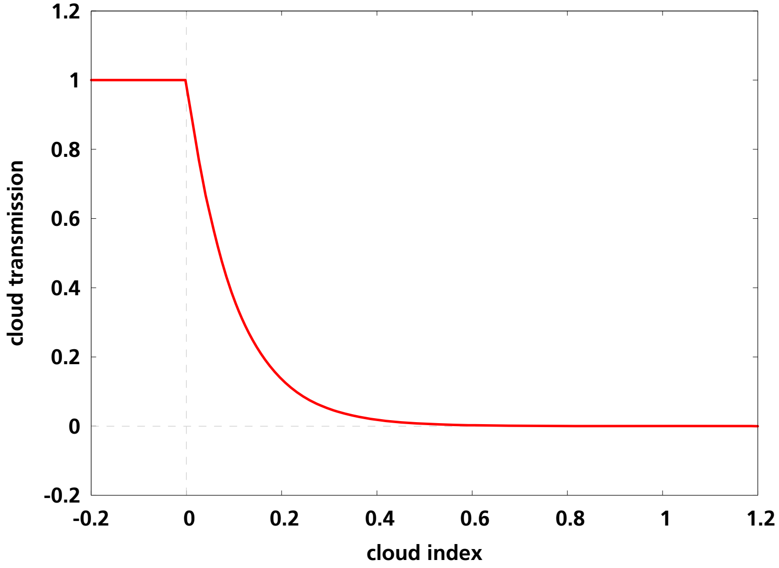

NASA GISS v2 1990

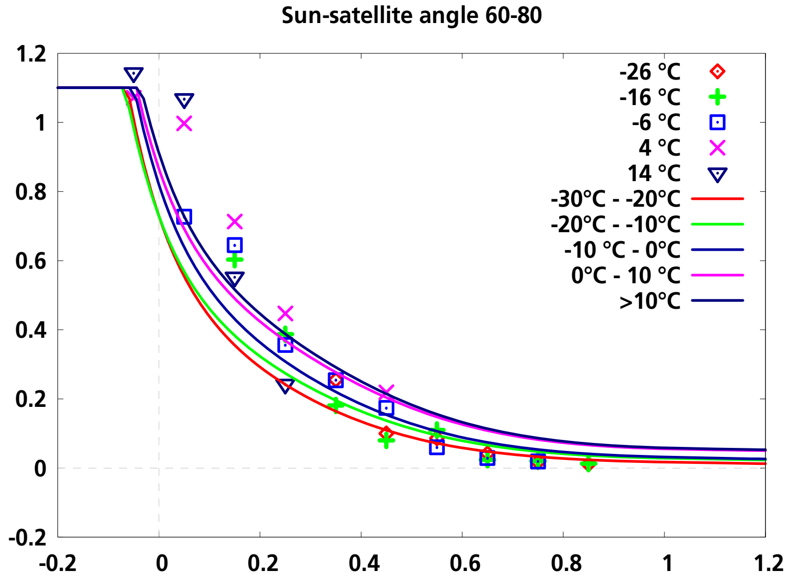

GOCART


AeroCom

- all for July
- all same scale (0 – 1.5)

Inaccuracy of Cloud Transmission Function





Simple Cloud Function $\tau = e^{-10*ci}$

Complex Cloud Function:
Different exponential funktions for different geometries and brightness temperatures

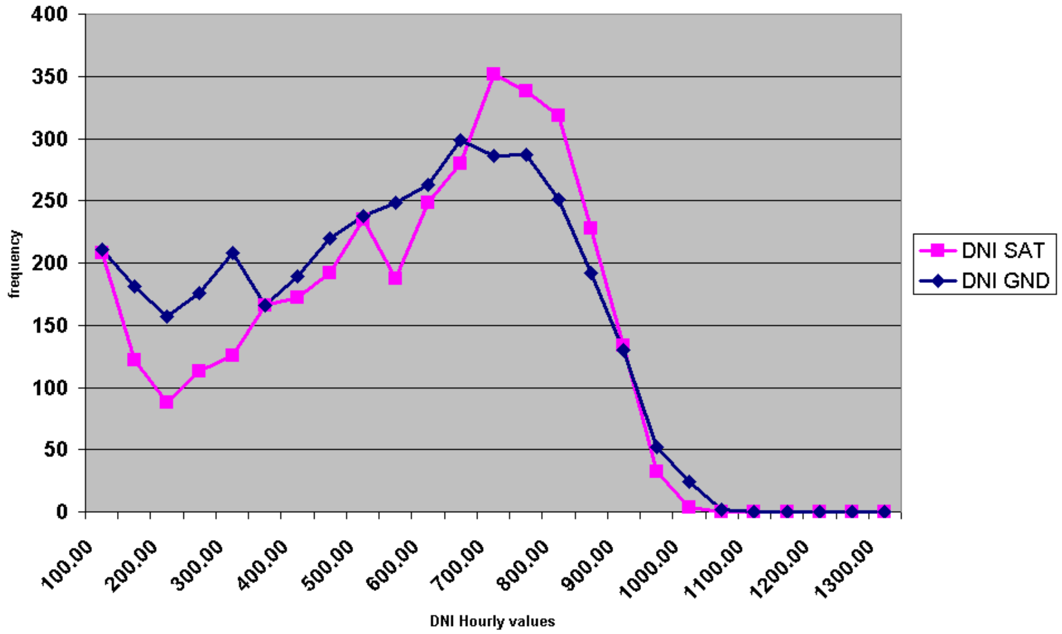
Combining Ground and Satellite Assessments

- 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

Enhanced Model

- MATCH Aerosol, v37 complex cloud transmission function.
- Bias 2%, RMSD 33 %
- enhanced distribution function



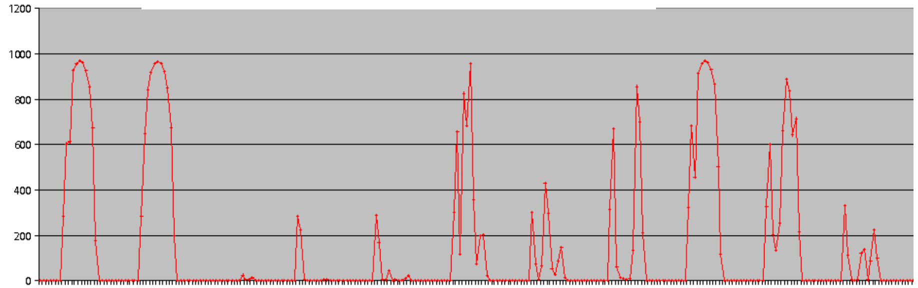
Good Solar Resource Assessments

- 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, overlap necessary).

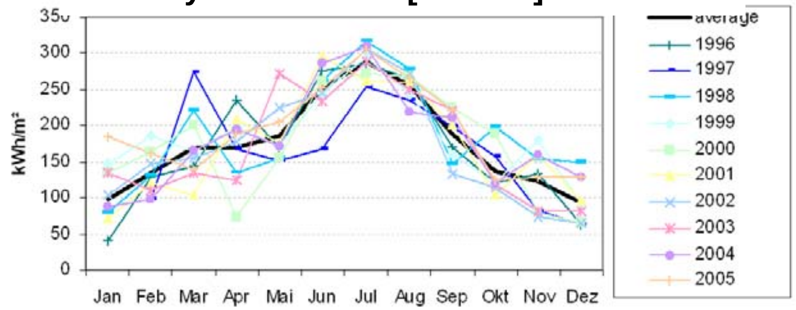
Resource Assessment for Site Performance Modelling

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

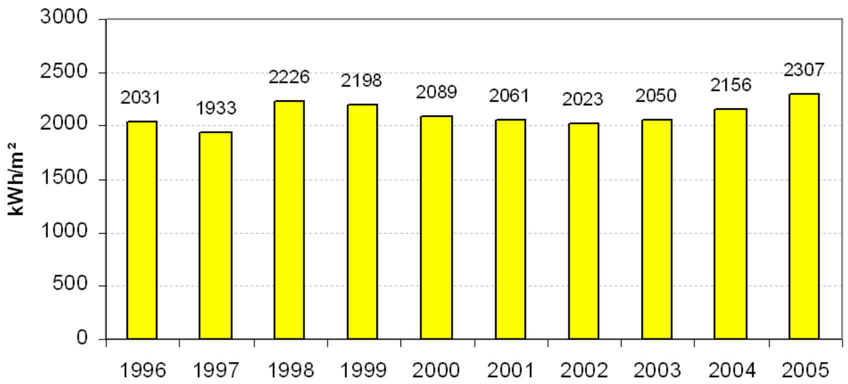
Hourly DNI [Wh/m²] for one site



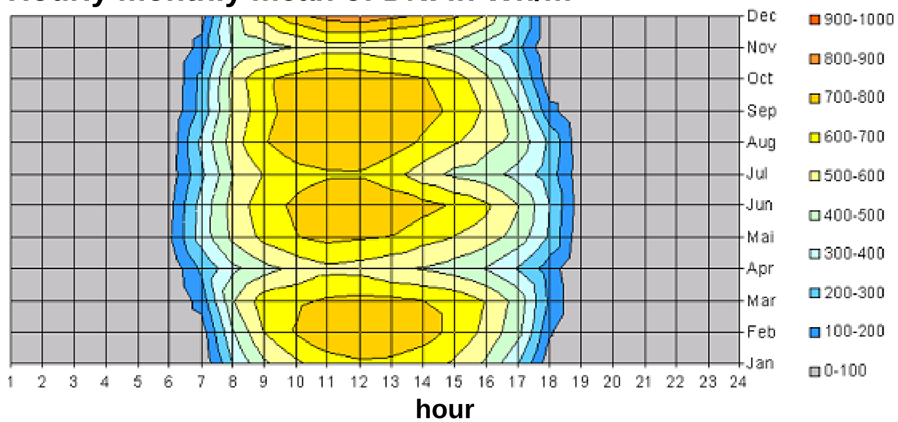
Monthly sums of DNI [kWh/m²] for one site



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

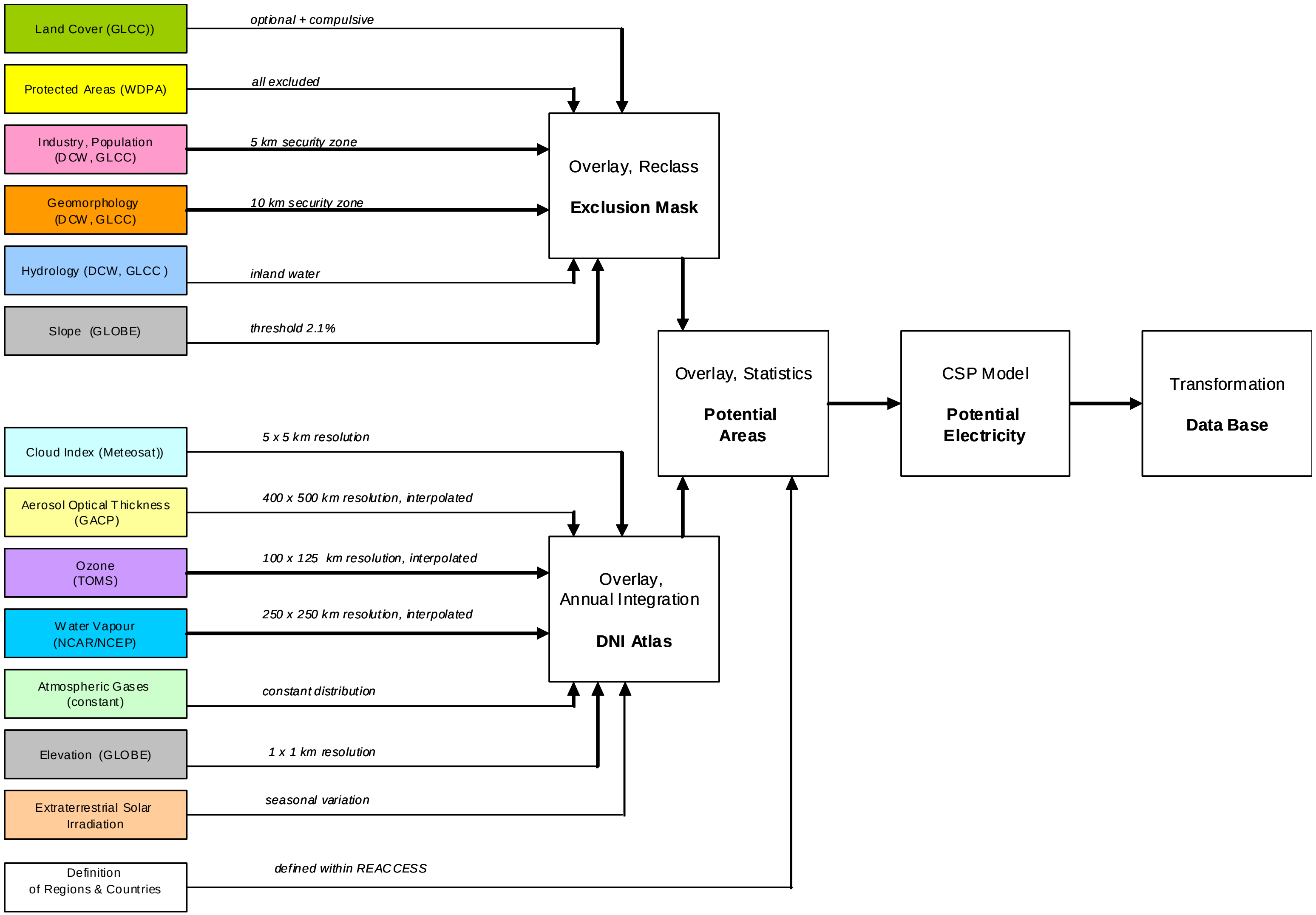


Hourly monthly mean of DNI in Wh/m²



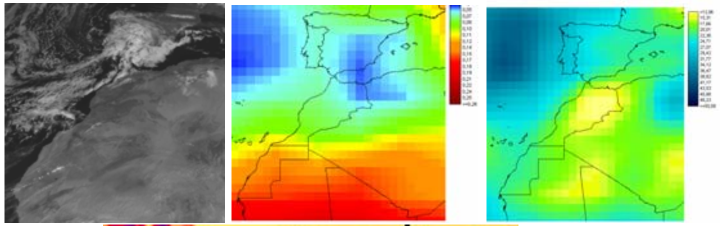
Assessment of CSP Potentials

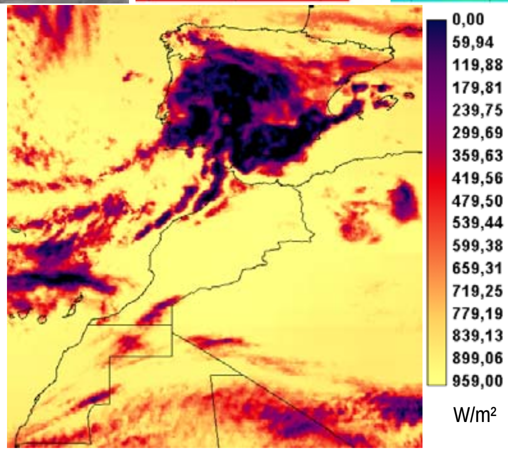
Methodology of Solar Power Potential Assessment



Solar Energy Resource Assessment

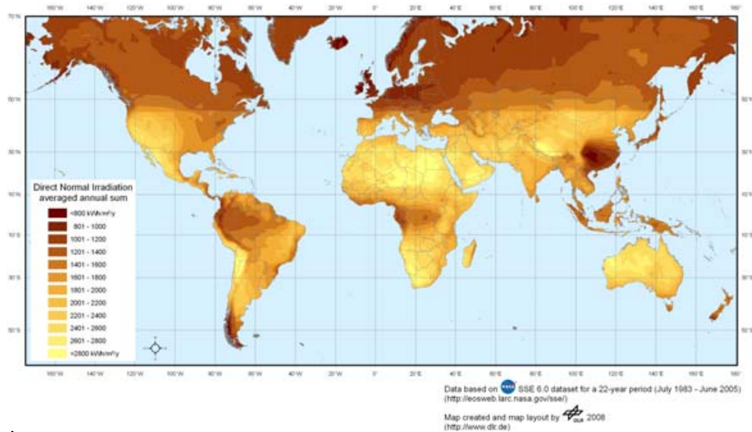
Clouds + Dust + Vapour + Ozone + Atmosphere ....





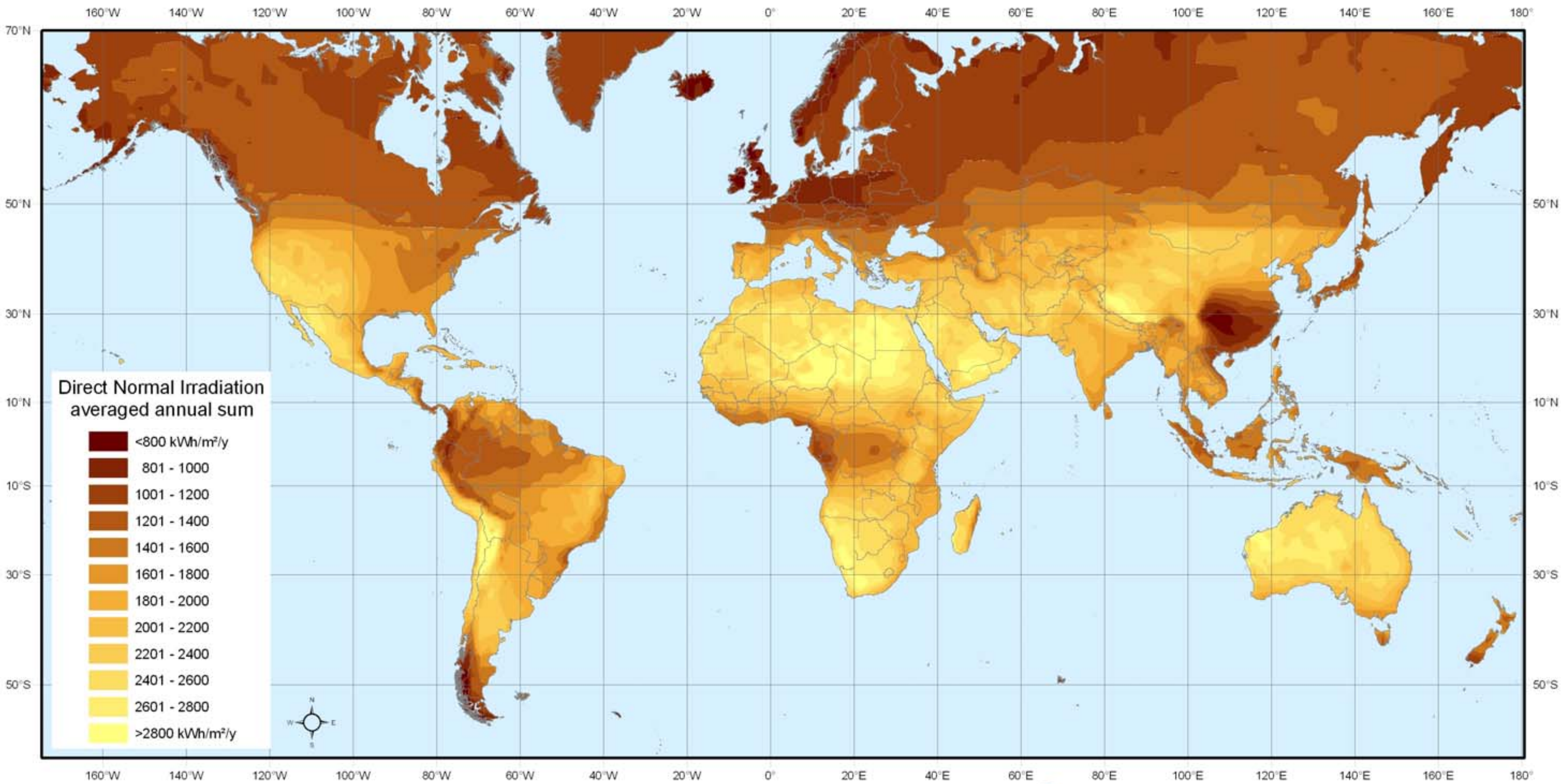
Direct Normal Irradiation (DNI)

repeat for 8760 h/y



Long Term Average Annual Direct Normal Irradiation Map

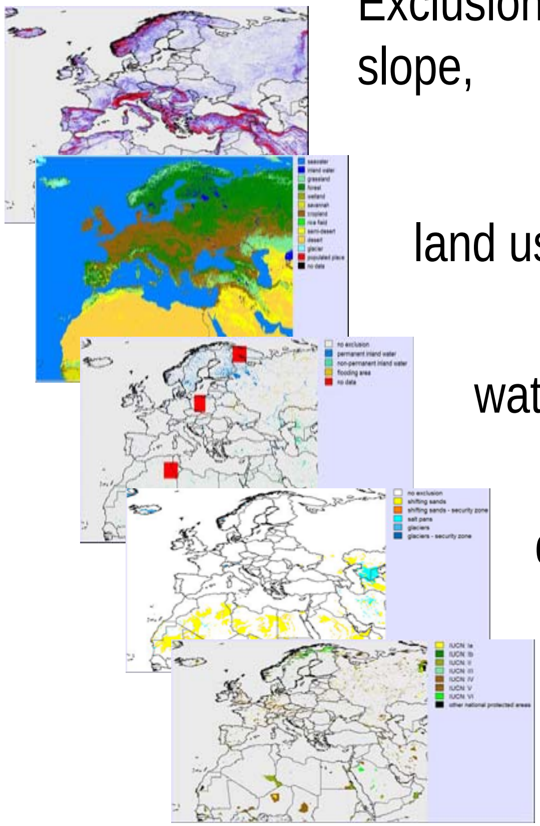
Solar Energy Resource Assessment



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,

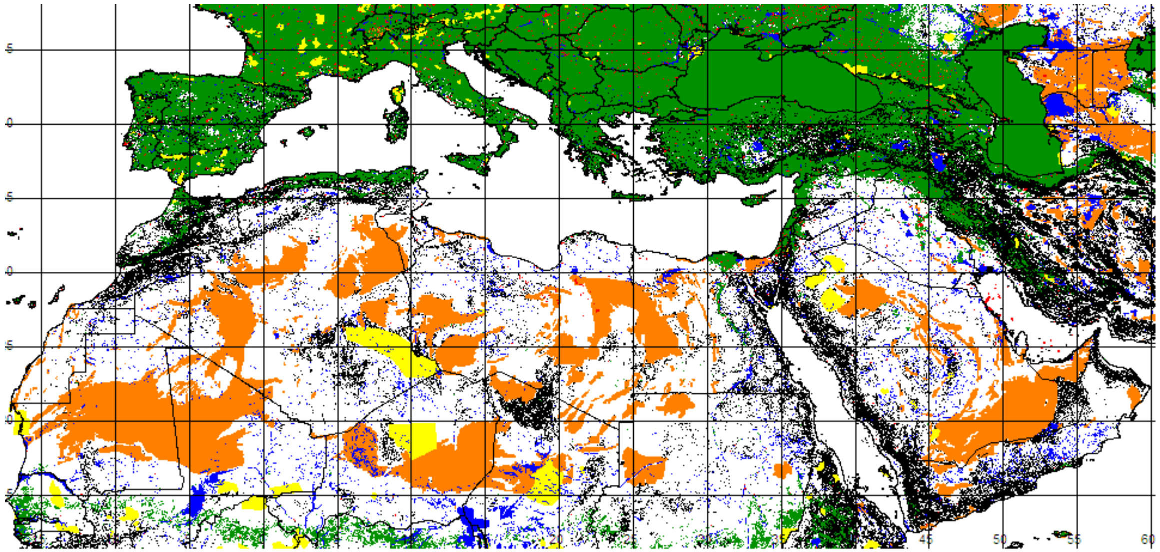
land use,

water,

dunes,

national parks,
infrastructure,

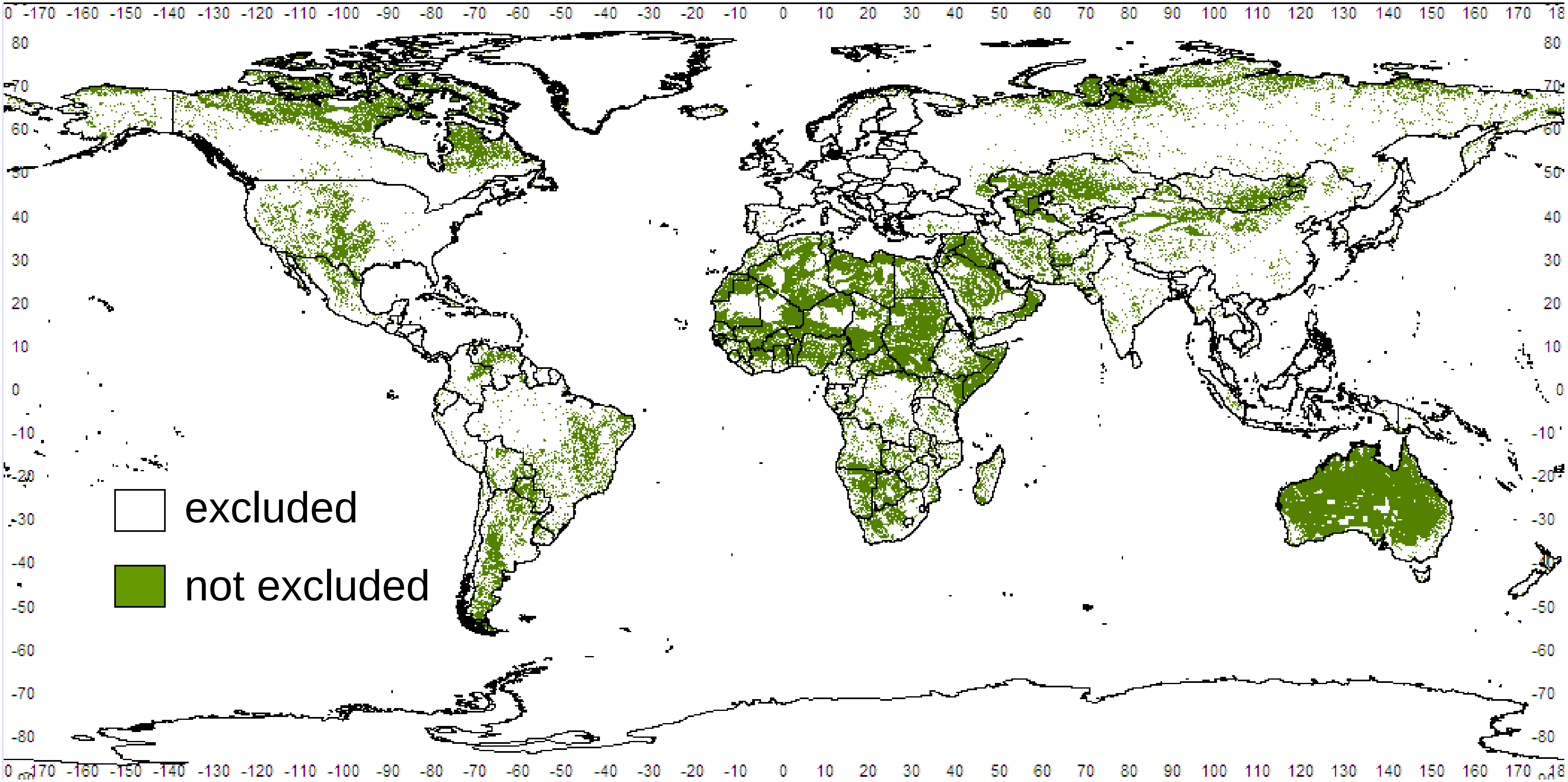
etc....



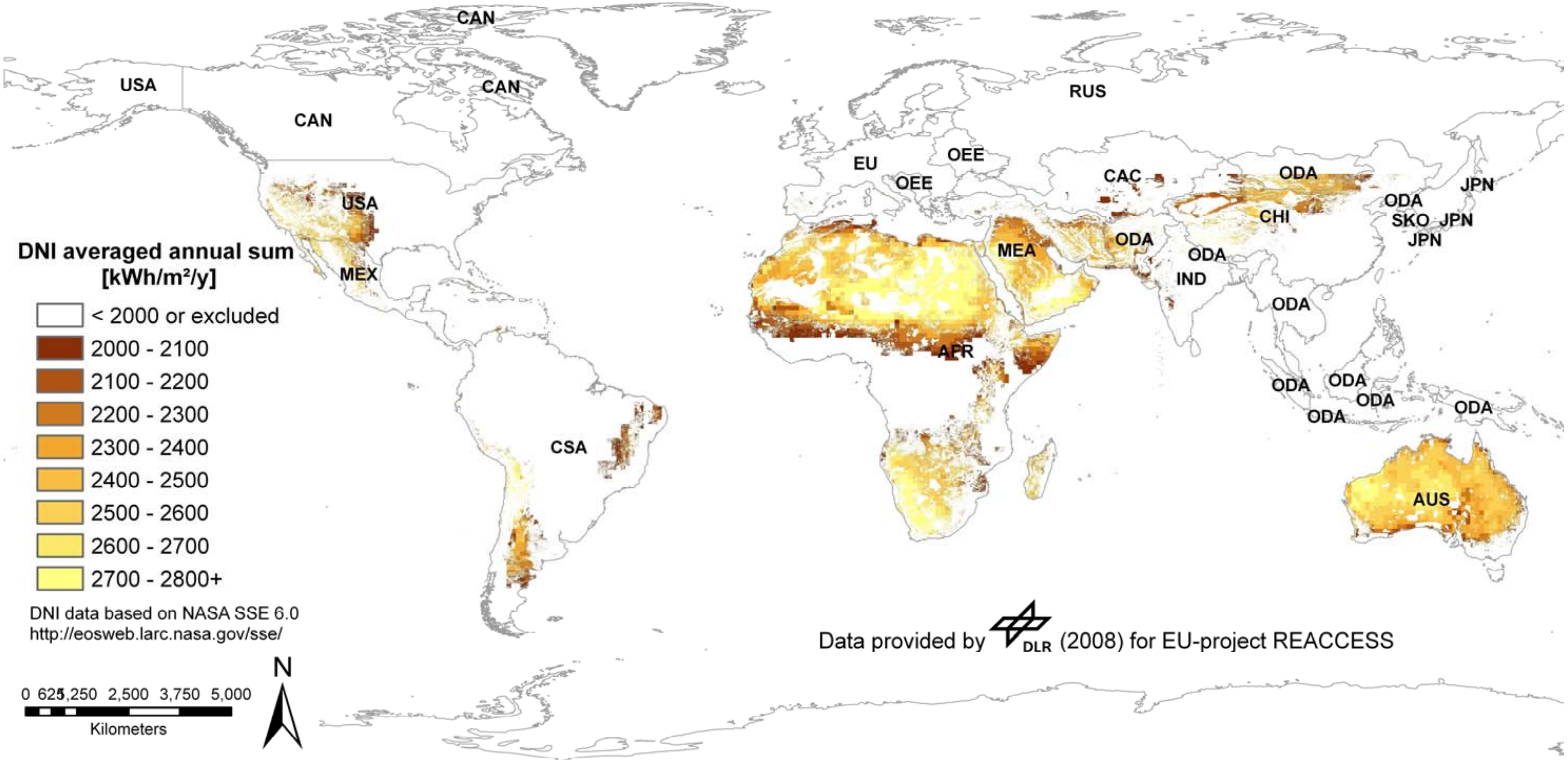
add all layers

- no exclusion
- urban or industrial
- hydrography
- protected area
- land cover
- geomorphology
- topography

Site Exclusion for Concentrating Solar Power Plants (Trough)



Global Annual DNI > 2000 kWh/m²/y after Site Exclusion



see slide 8 for abbreviations

CSP Performance Model

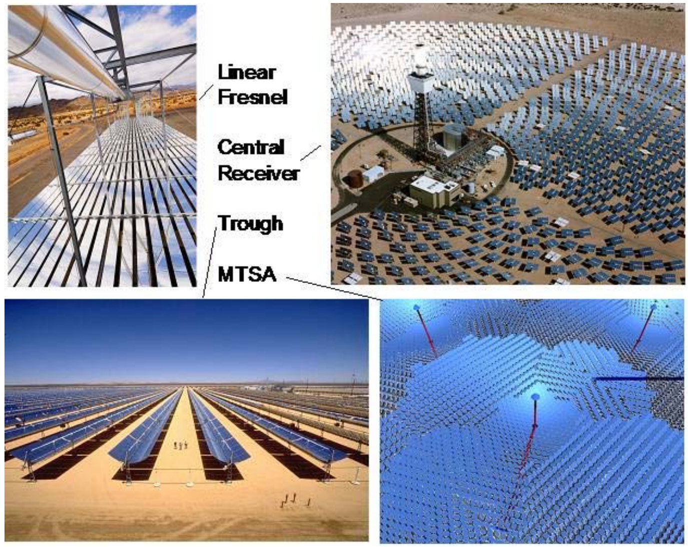
Average Land Use Efficiency (LUE)

= Solar-Electric-Efficiency (12%)

x Land Use Factor (37%)

= 4.5% for parabolic trough steam cycle

with dry cooling tower



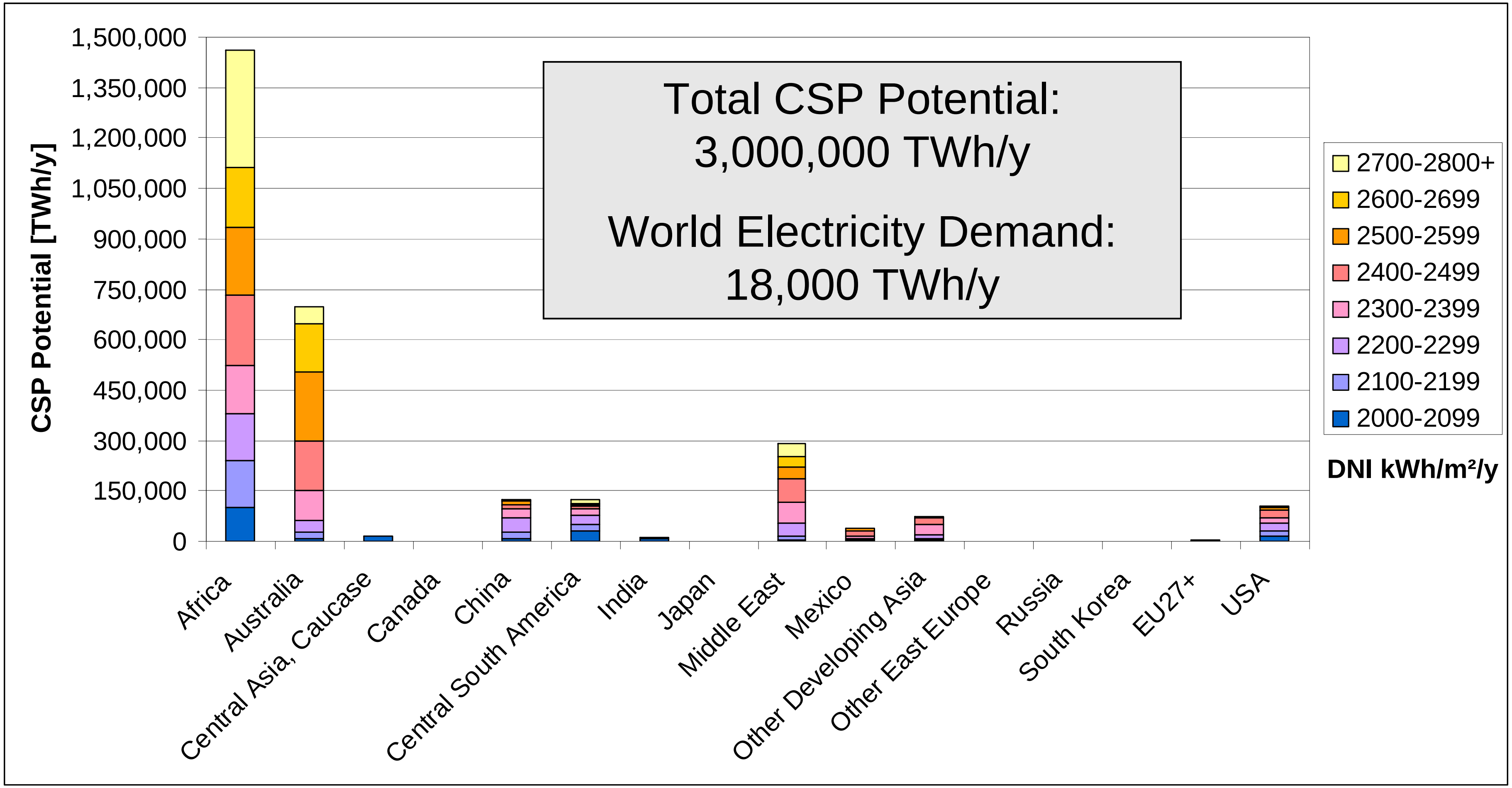
Collector & Power Cycle Technology	Solar-Electric Aperture Related Efficiency	Land Use Factor	Land Use Efficiency
Parabolic Trough Steam Cycle	11 - 16%	25 - 40%	3.5 - 5.6%
Central Receiver Steam Cycle	12 - 16%	20 – 25%	2.5 – 4.0%
Linear Fresnel Steam Cycle	8 - 12%	60 - 80%	4.8 - 9.6%
Central Receiver Combined Cycle*	20 - 25%	20 - 25%	4.0 – 6.3%
Multi-Tower Solar Array Steam or Combined Cycle*	15 - 25%	60 - 80%	9.0 – 20.0%

Global CSP Potentials by DNI Classes and Regions (4.5% LUE)

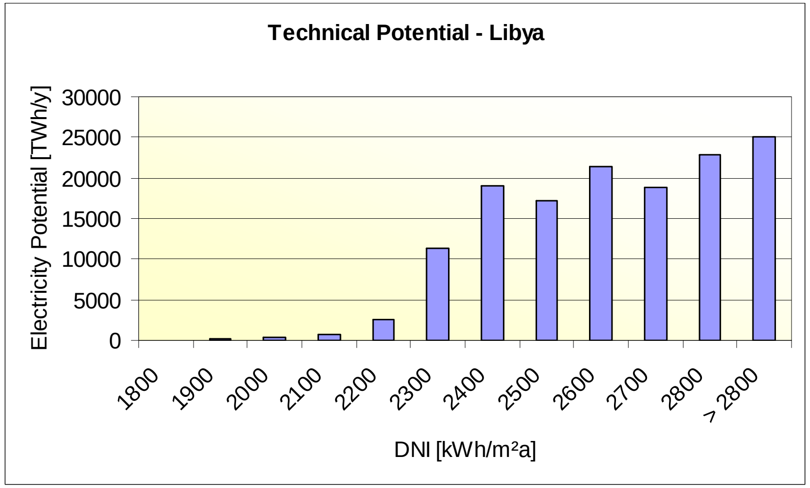
DNI Class kWh/m²/y	Africa TWh/y	Australia TWh/y	Central Asia, Caucase TWh/y	Canada TWh/y	China TWh/y	Central South America TWh/y	India TWh/y	Japan TWh/y
2000-2099	102,254	6,631	14,280	0	8,332	31,572	7,893	0
2100-2199	138,194	18,587	300	0	18,276	20,585	1,140	0
2200-2299	139,834	36,762	372	0	43,027	24,082	550	0
2300-2399	141,066	87,751	177	0	28,415	20,711	774	0
2400-2499	209,571	148,001	64	0	11,197	6,417	426	0
2500-2599	203,963	207,753	0	0	11,330	3,678	13	0
2600-2699	178,480	142,490	0	0	2,180	5,120	119	0
2700-2800+	346,009	49,625	0	0	3,079	11,827	15	0
Total [TWh/y]	**1,459,370**	**697,600**	**15,193**	**0**	**125,835**	**123,992**	**10,928**	**0**

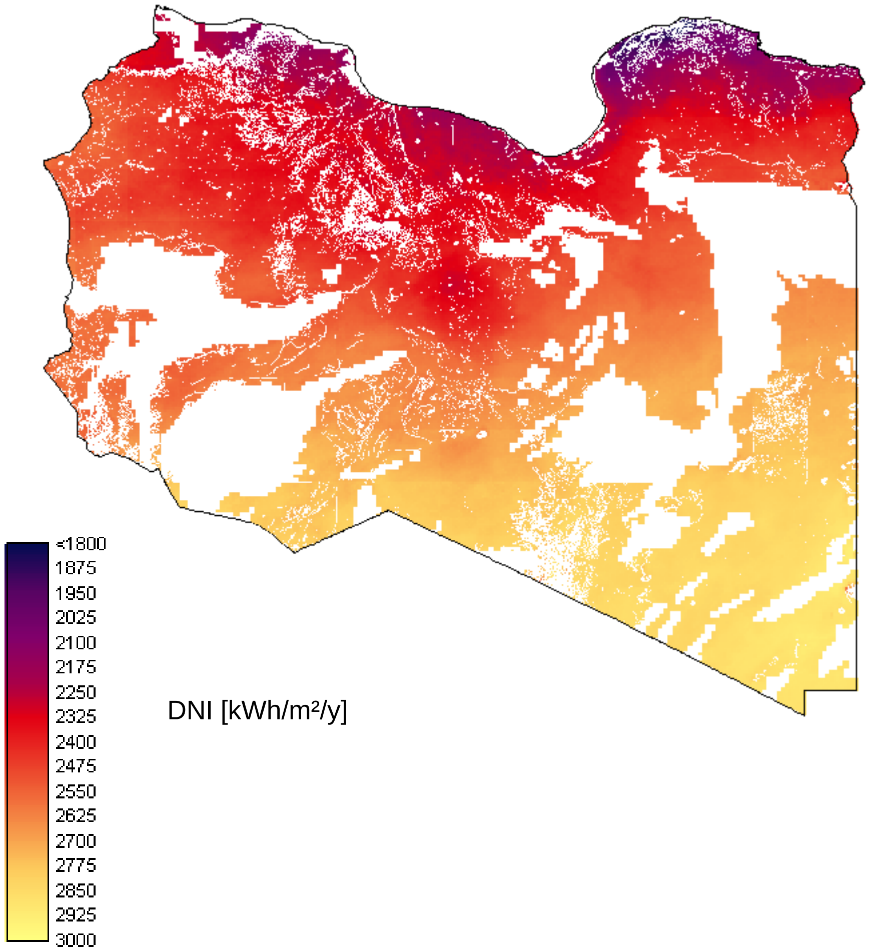
DNI Class kWh/m²/y	Middle East TWh/y	Mexico TWh/y	Other Developing Asia TWh/y	Other East Europe TWh/y	Russia TWh/y	South Korea TWh/y	EU27+ TWh/y	USA TWh/y
2000-2099	3,432	1,606	4,491	6	0	0	866	14,096
2100-2199	12,443	3,378	5,174	13	0	0	497	17,114
2200-2299	39,191	3,650	10,947	2	0	0	660	21,748
2300-2399	60,188	5,807	30,776	0	0	0	162	16,402
2400-2499	71,324	15,689	19,355	0	0	0	90	23,903
2500-2599	34,954	7,134	4,429	0	0	0	69	8,116
2600-2699	32,263	1,534	253	0	0	0	31	2,326
2700-2800+	36,843	1,878	136	0	0	0	34	0
Total [TWh/y]	**290,639**	**40,675**	**75,561**	**21**	**0**	**0**	**2,409**	**103,704**

Global CSP Potentials by DNI Classes and Regions (4.5% LUE)



Solar Thermal Electricity Generating Potentials in Libya





Wind Resource Assessment

Outline

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

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

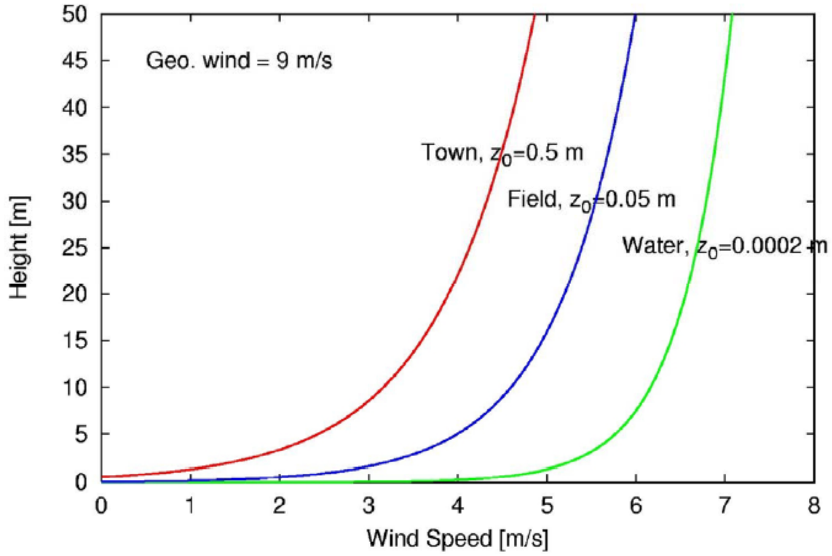
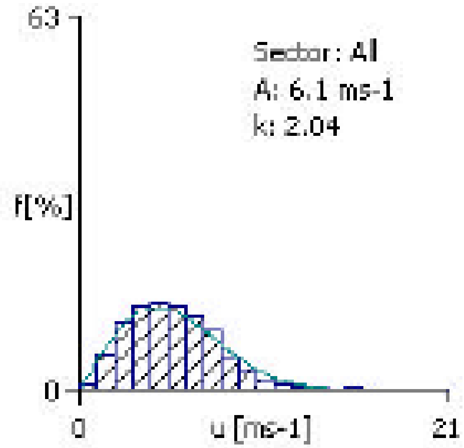


Image source: RISØ/DTU

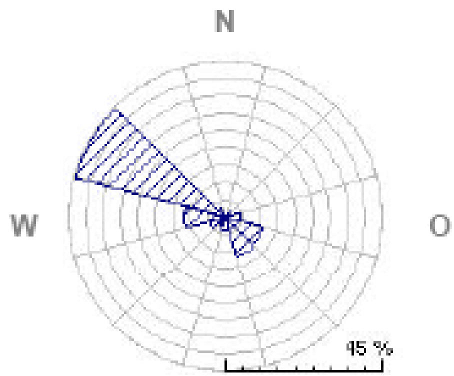
Site specific wind resource assessment

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.

What are local effects?

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

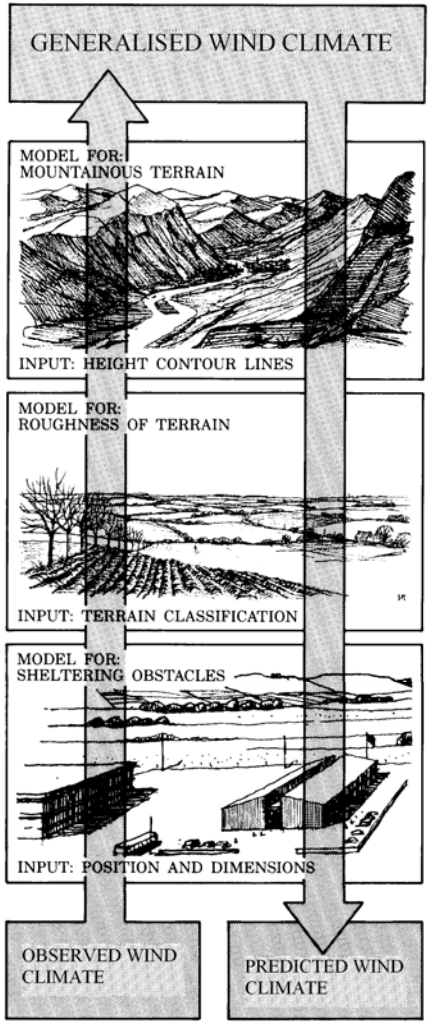


Image source: RISØ/DTU

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.

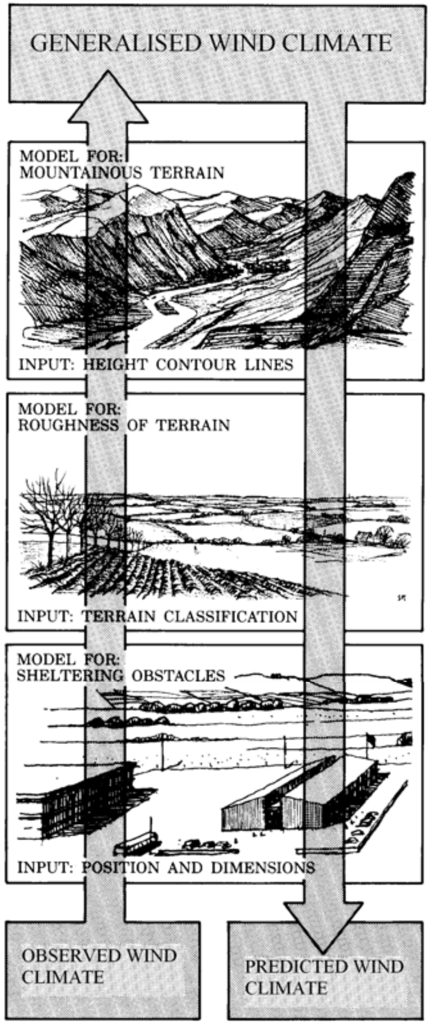
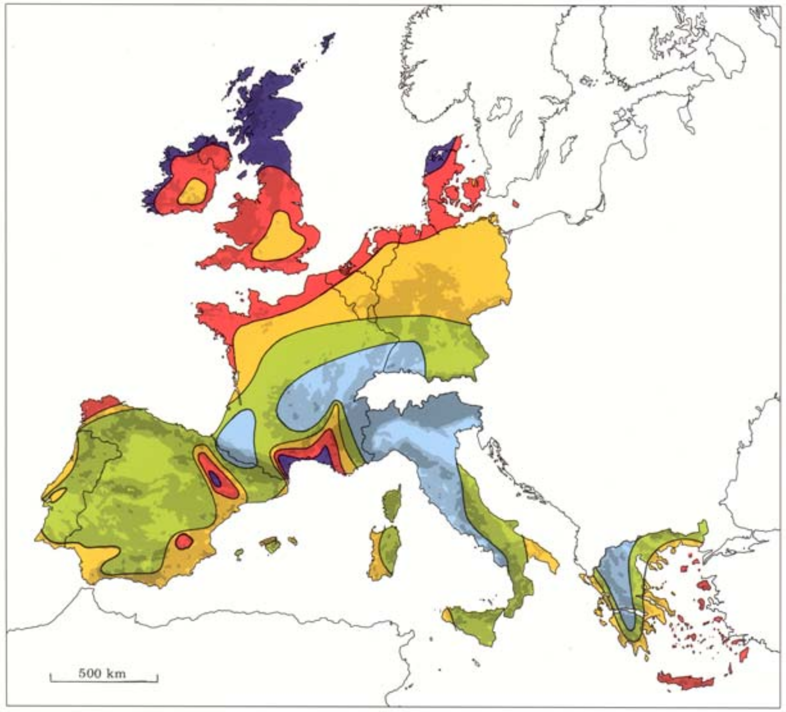


Image source: RISØ/DTU

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}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	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
	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
	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
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Image source: RISØ/DTU

Offshore

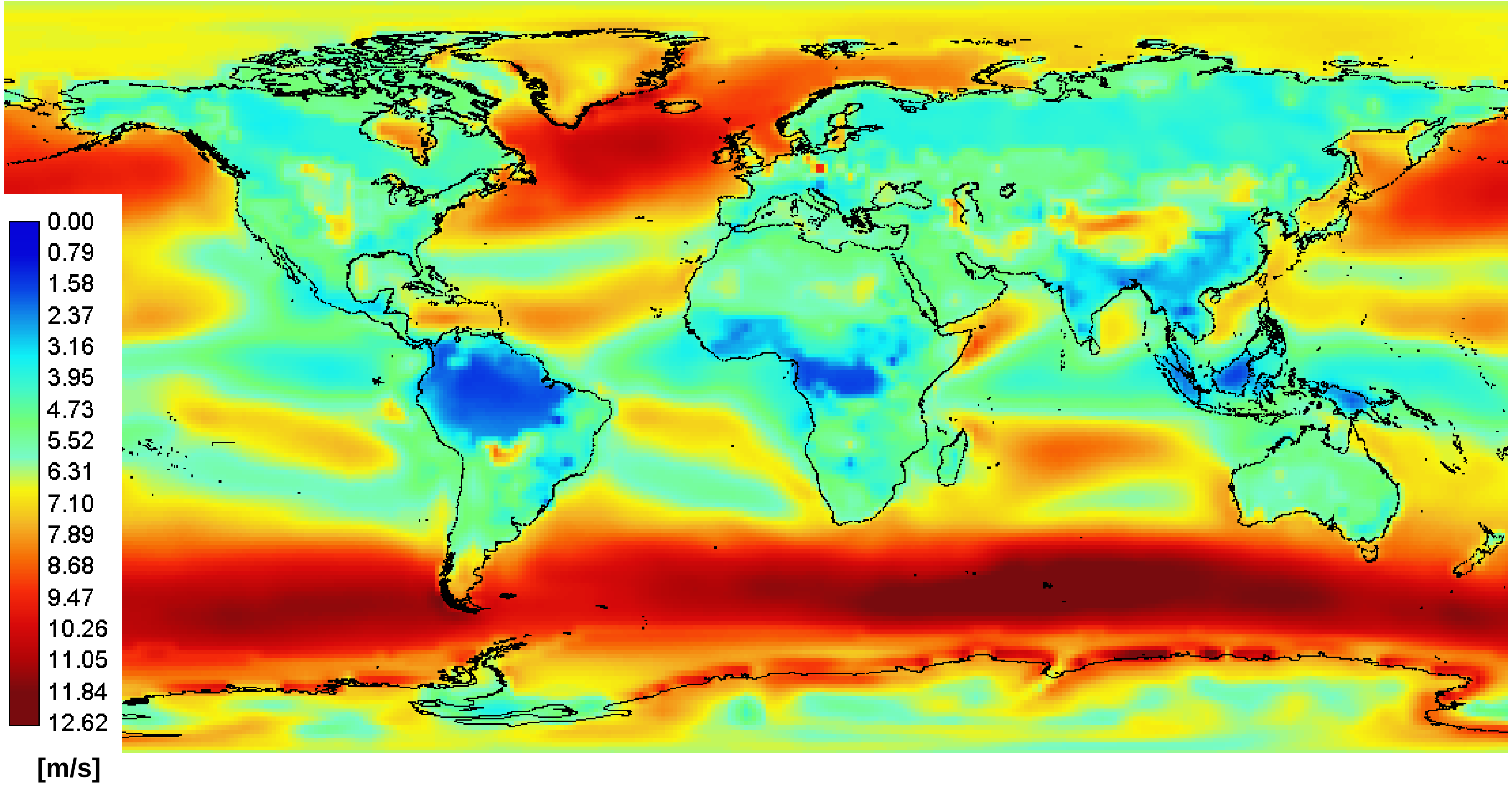
- The wind profile is more complex due to
  - larger thermal inertia of the water
  - wind and wave interactions
  - time lag of wave development
- Nearly no measurements, very few platforms e.g. in front of the Danish or German coast
- But: Wind speed can be assessed by measuring the wave height with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

Annual Average Wind Speed at 50 m Height

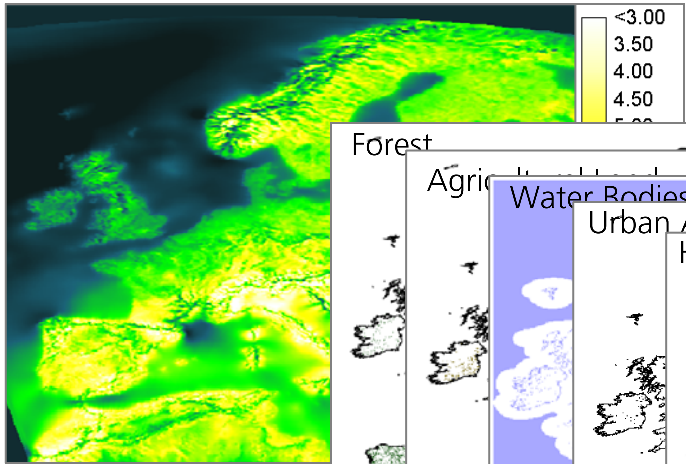


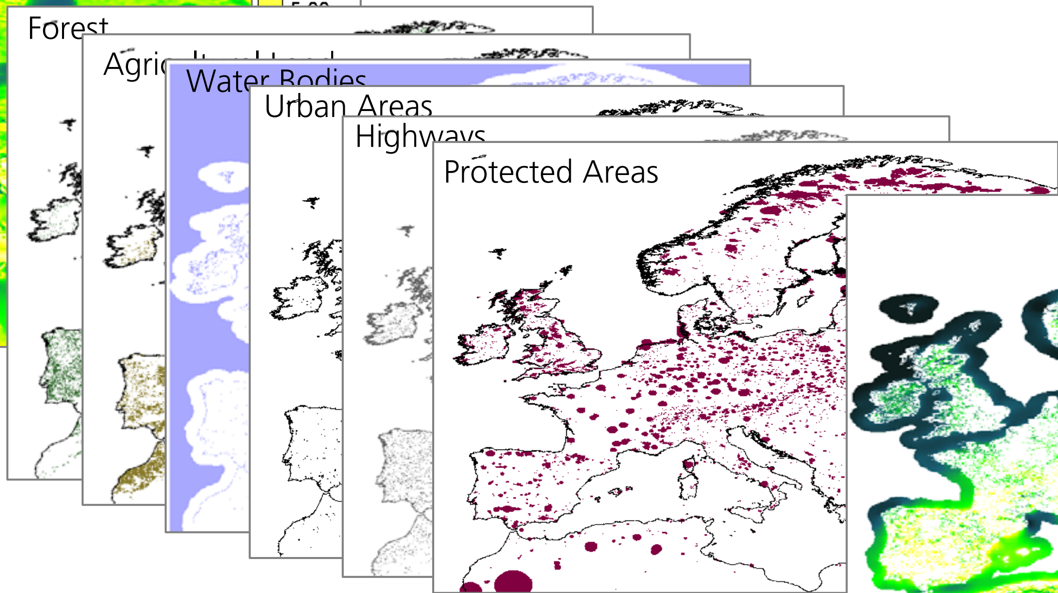
Example: Wind Cost Potential Functions

Wind Power Potentials in Europe

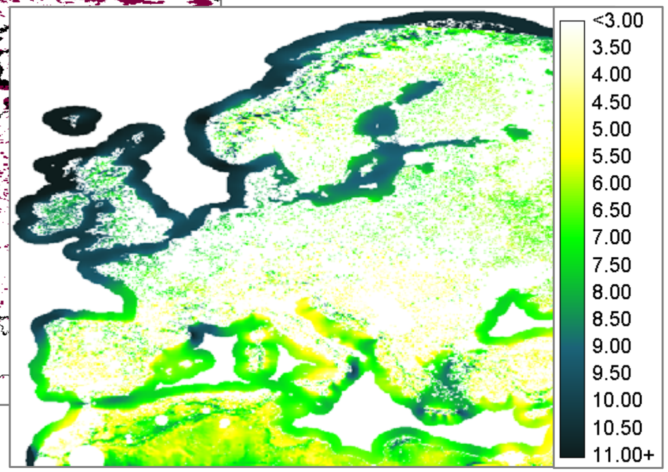
Resource and Land Availability

Wind Speed in m/s



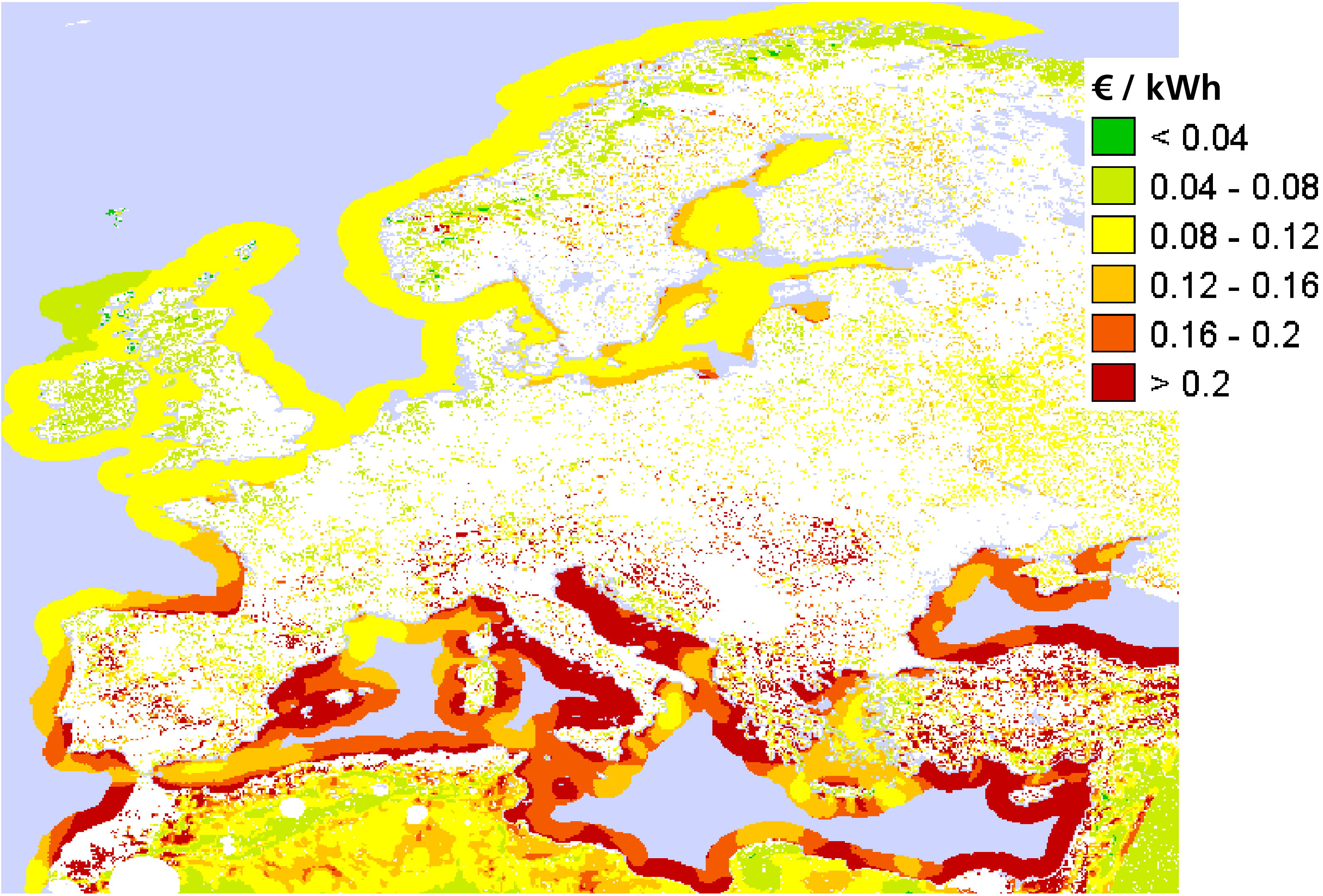


Wind Speed in m/s on available areas

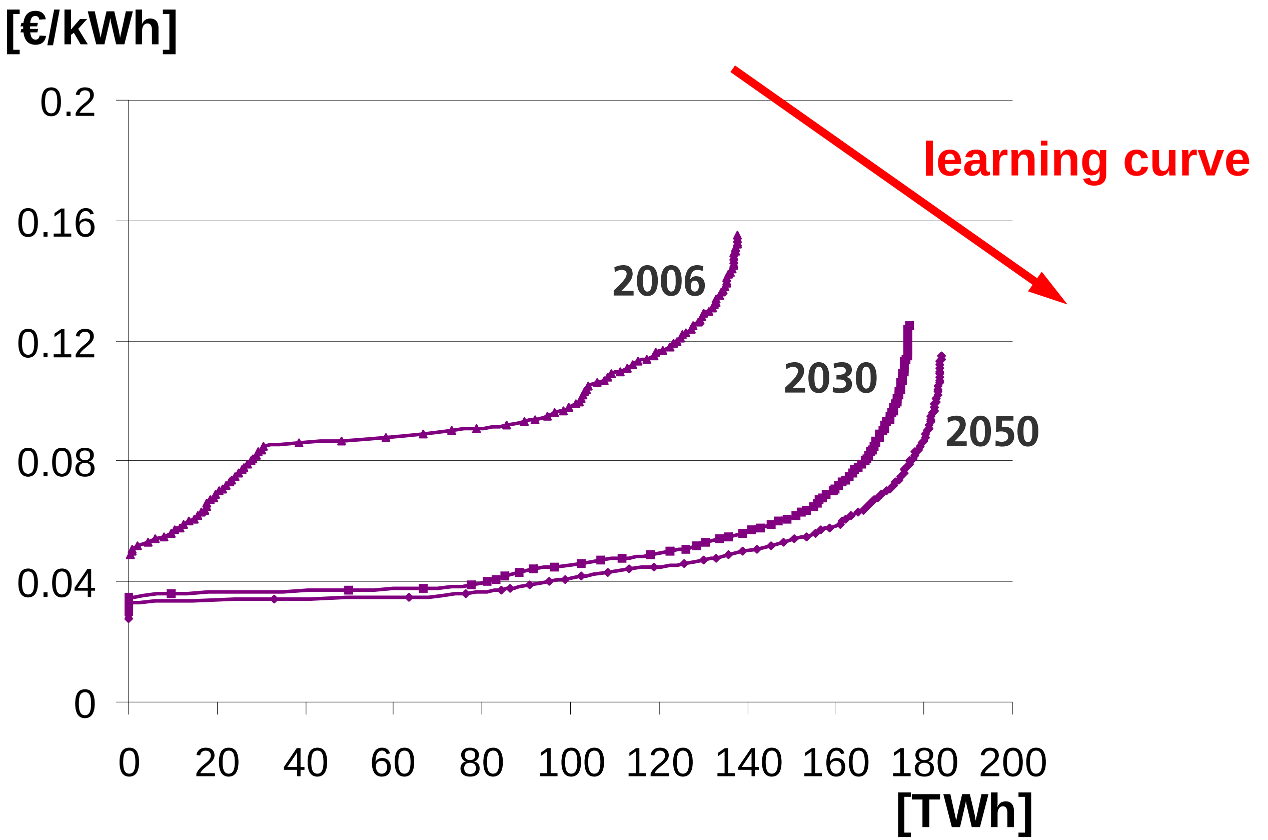


Wind Data:
German Meteorological service

Wind Electricity Cost: Technology and Cost Status 2006

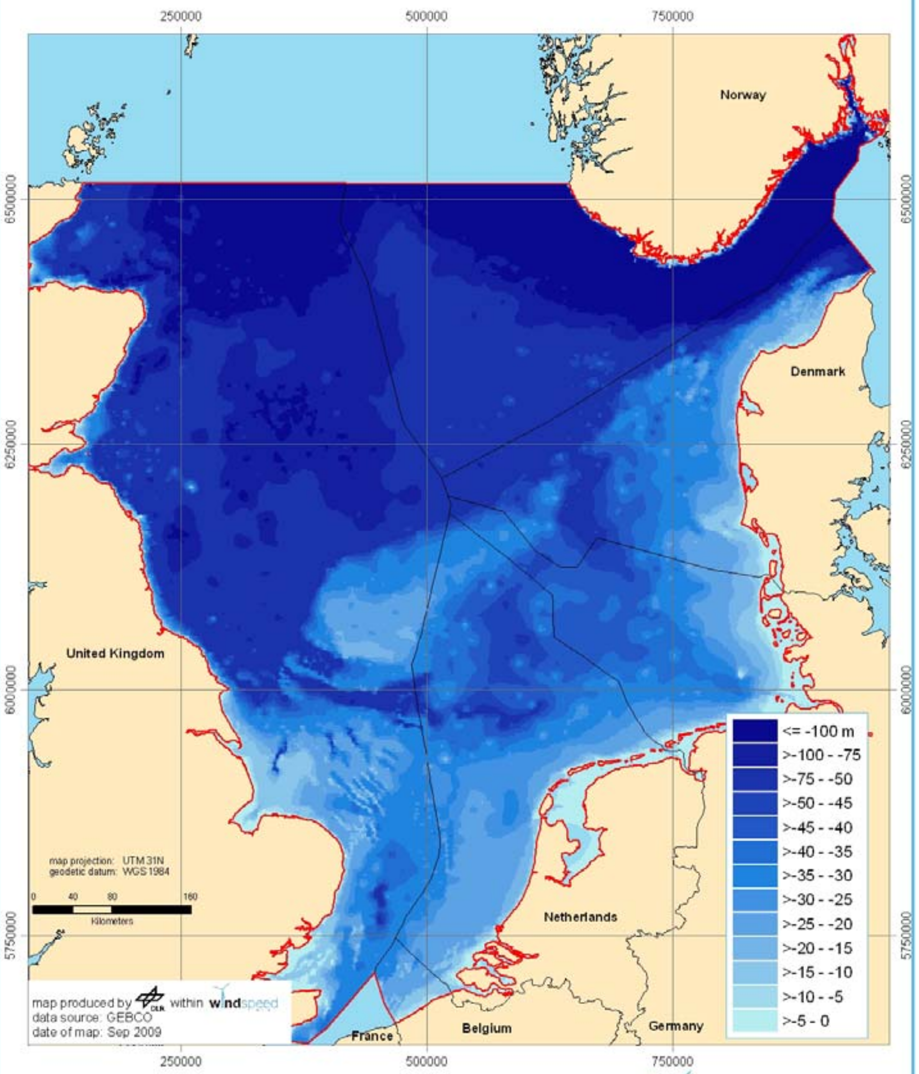


Cost Potential Functions for Wind Power in Germany

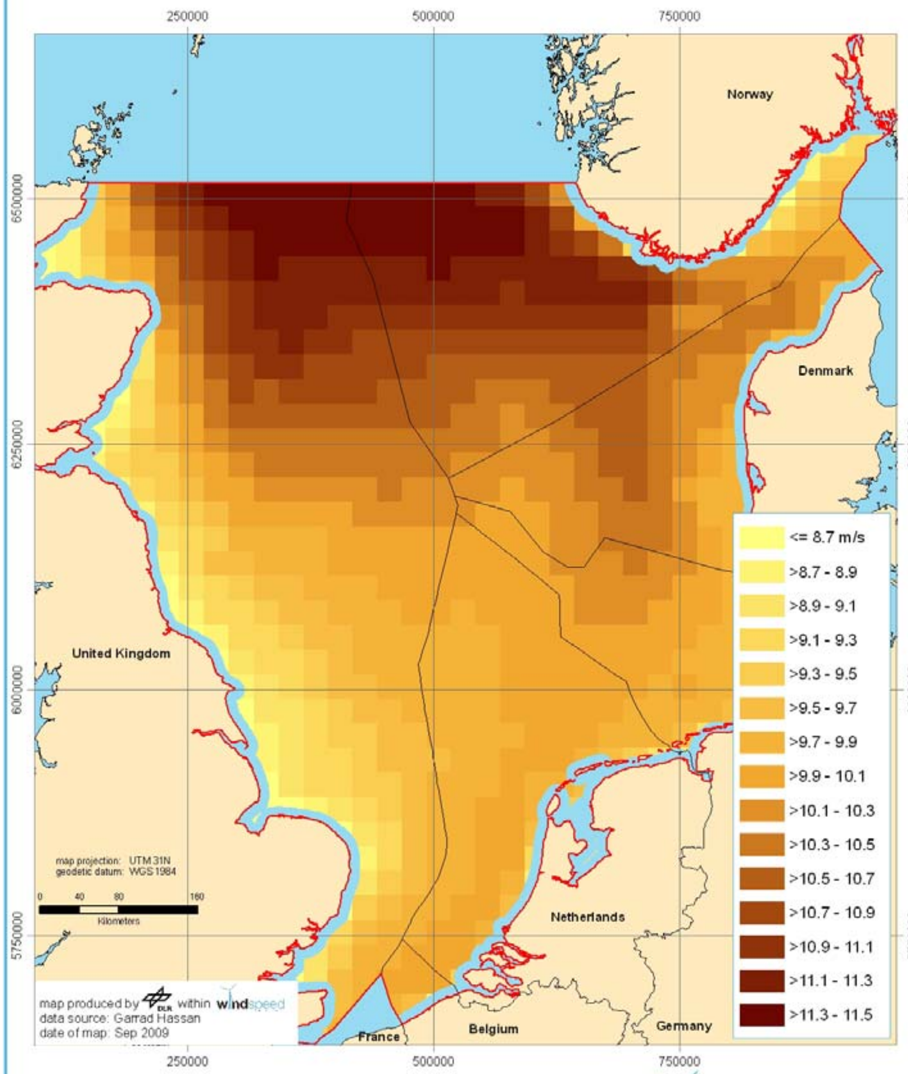


Example: Offshore Wind Potentials

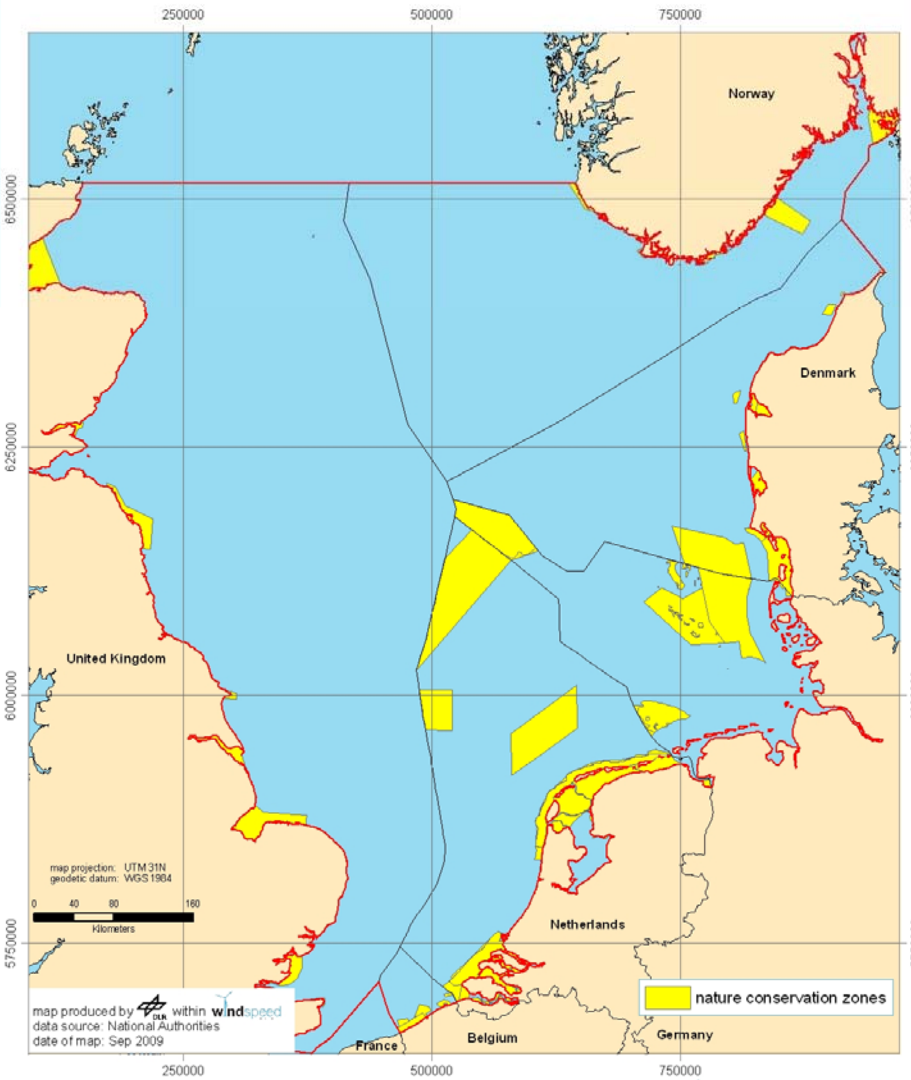
Sea Depth (Bathymetry) [m]



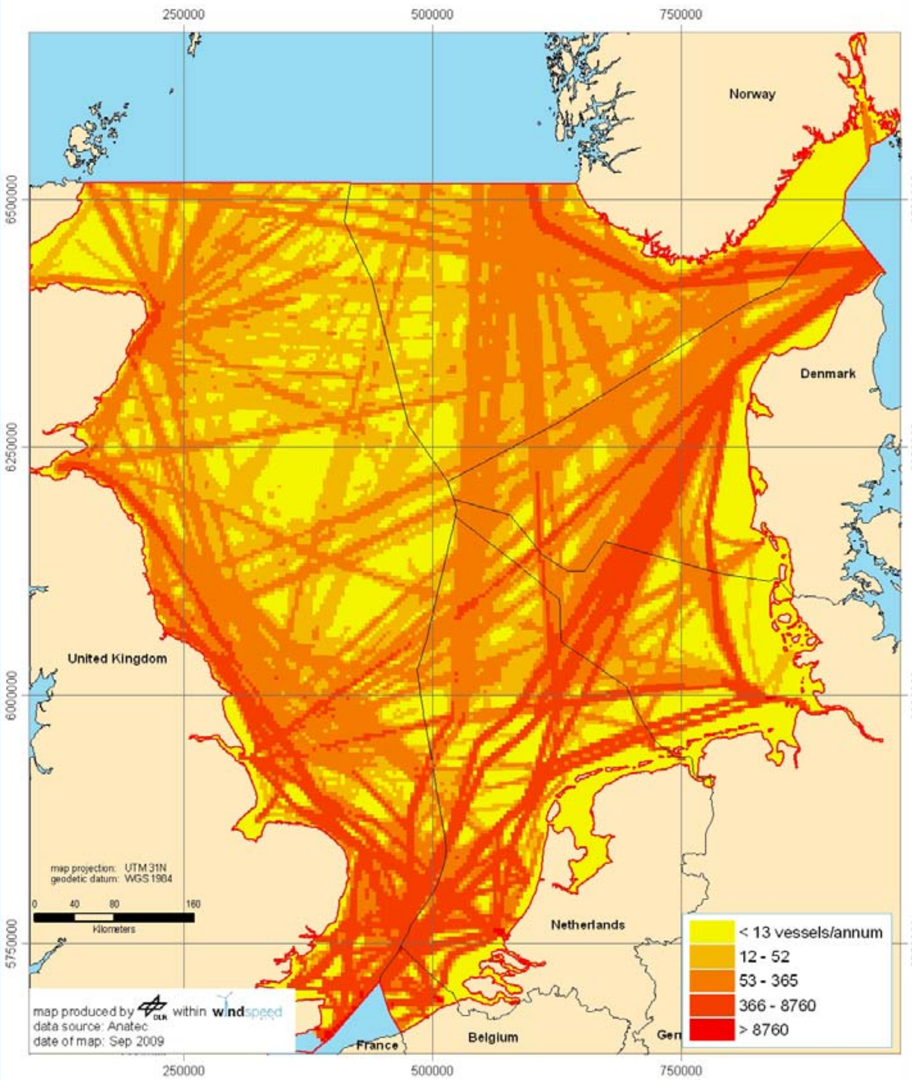
Windspeed at 90m hub height [m/s]



Marine Nature Conservation Zones

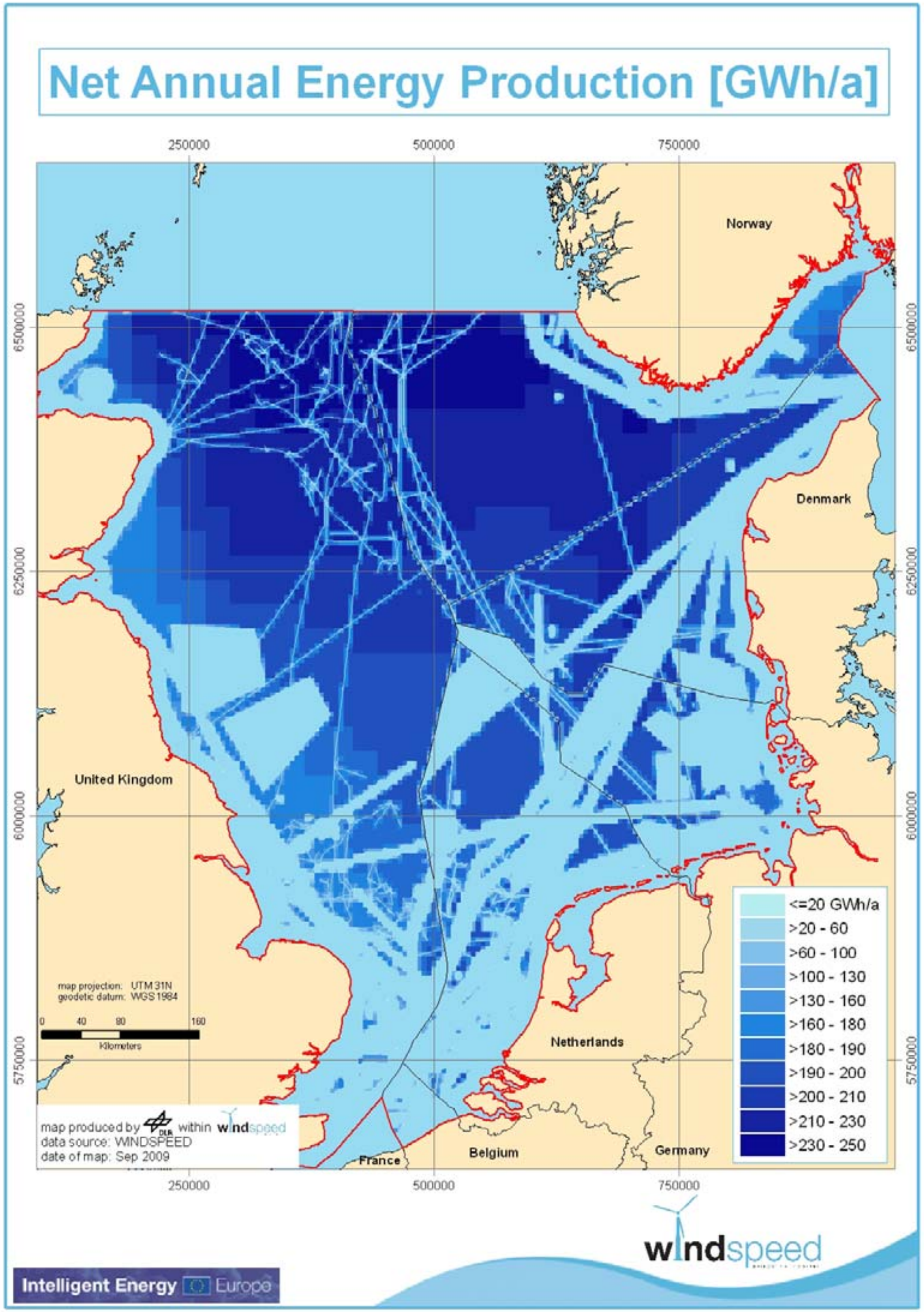


Shipping Density [vessels/annum]



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