Part 3: Renewable Energy Resources

Franz Trieb

MBA Energy Management, Vienna, September 12-13, 2012

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

Solar Resource Assessment

Solar Energy Resources

Fixed Non-Concentrating PV

➔ Global (Direct+Diffuse) Irradiation on a Surface tilted towards Equator with latitude angle (GTI)

Sun-Tracking Non-Concentrating PV

➔ Global Normal (Perpenticular) Irradiation on a Surface Tracking the Sun (GNI)

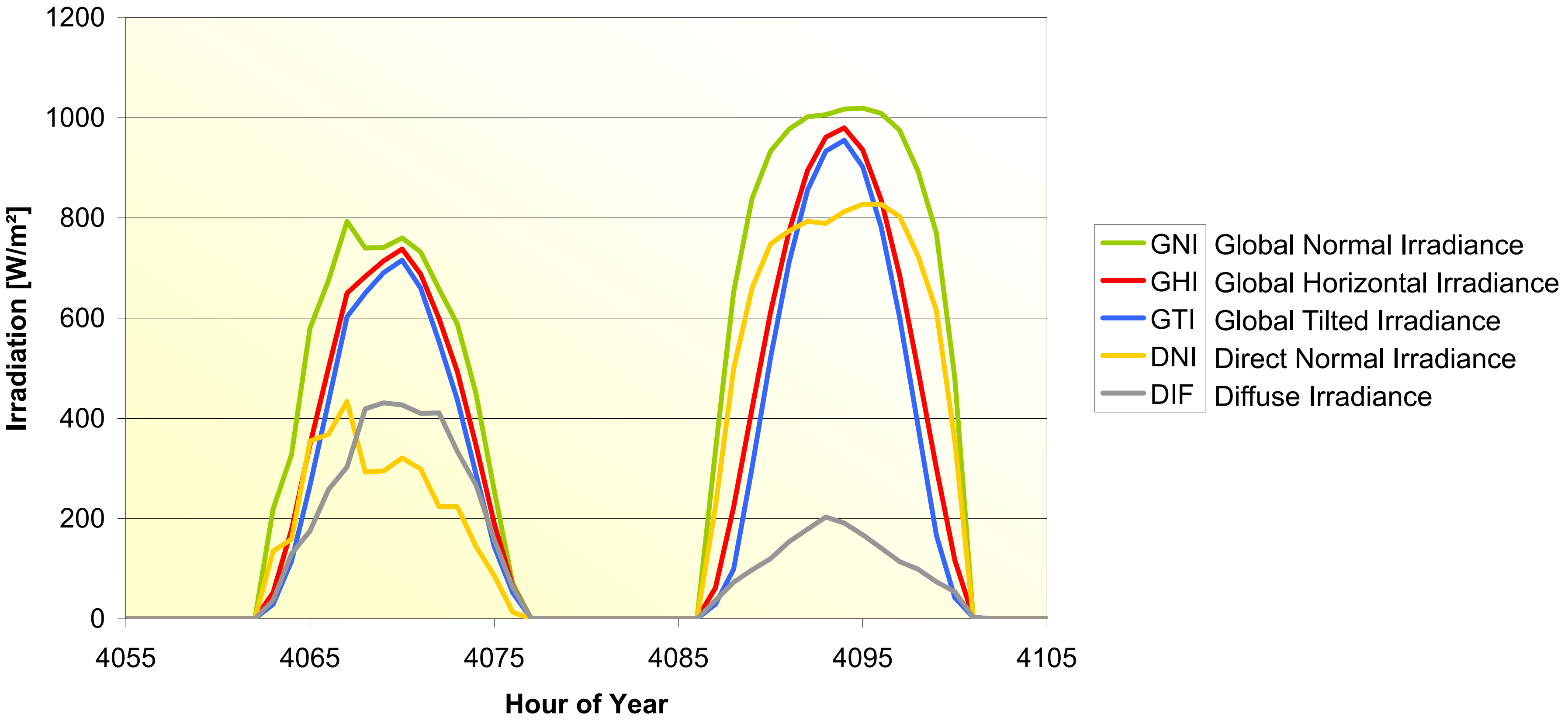
Sun-Tracking Concentrating PV and CSP

➔ 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: Airport Almeria, Spain; data: meteonorm

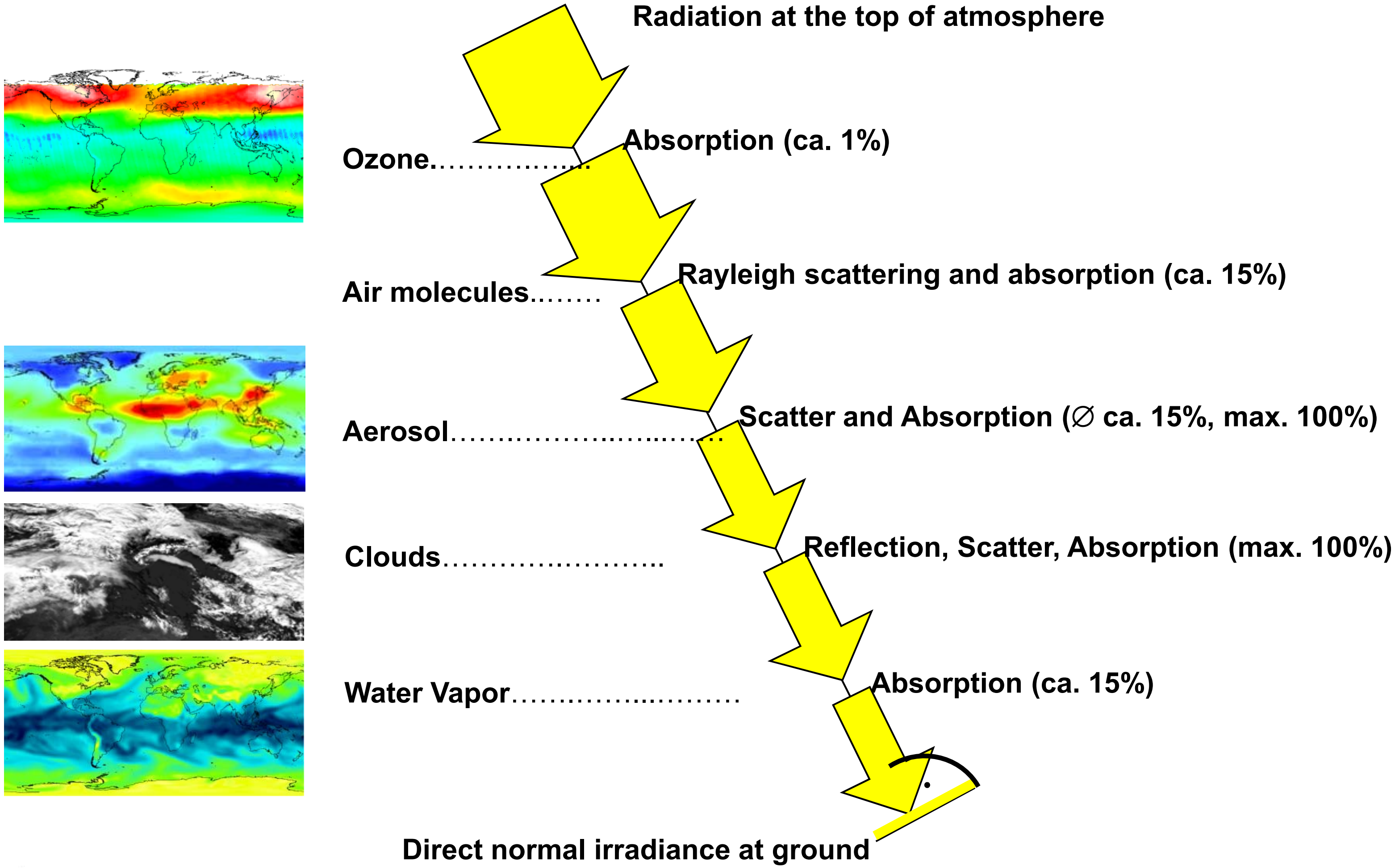
Solar Energy Resources Annual Sums

Month	GHI	GTI	DNI	GNI	DIF	Unit
Jan	82	136	119	168	34	kWh/m²/month
Feb	101	148	132	181	35	kWh/m²/month
Mar	147	183	168	235	50	kWh/m²/month
Apr	181	193	184	262	61	kWh/m²/month
May	199	187	169	270	84	kWh/m²/month
Jun	227	203	214	313	77	kWh/m²/month
Jul	223	204	203	303	80	kWh/m²/month
Aug	195	197	171	268	78	kWh/m²/month
Sep	153	179	161	232	54	kWh/m²/month
Oct	115	152	121	185	49	kWh/m²/month
Nov	86	135	115	165	35	kWh/m²/month
Dec	73	124	107	150	30	kWh/m²/month
Annual Total	**1778**	**2041**	**1865**	**2733**	**666**	**kWh/m²/year**

site: Airport Almeria, Spain; data: meteonorm

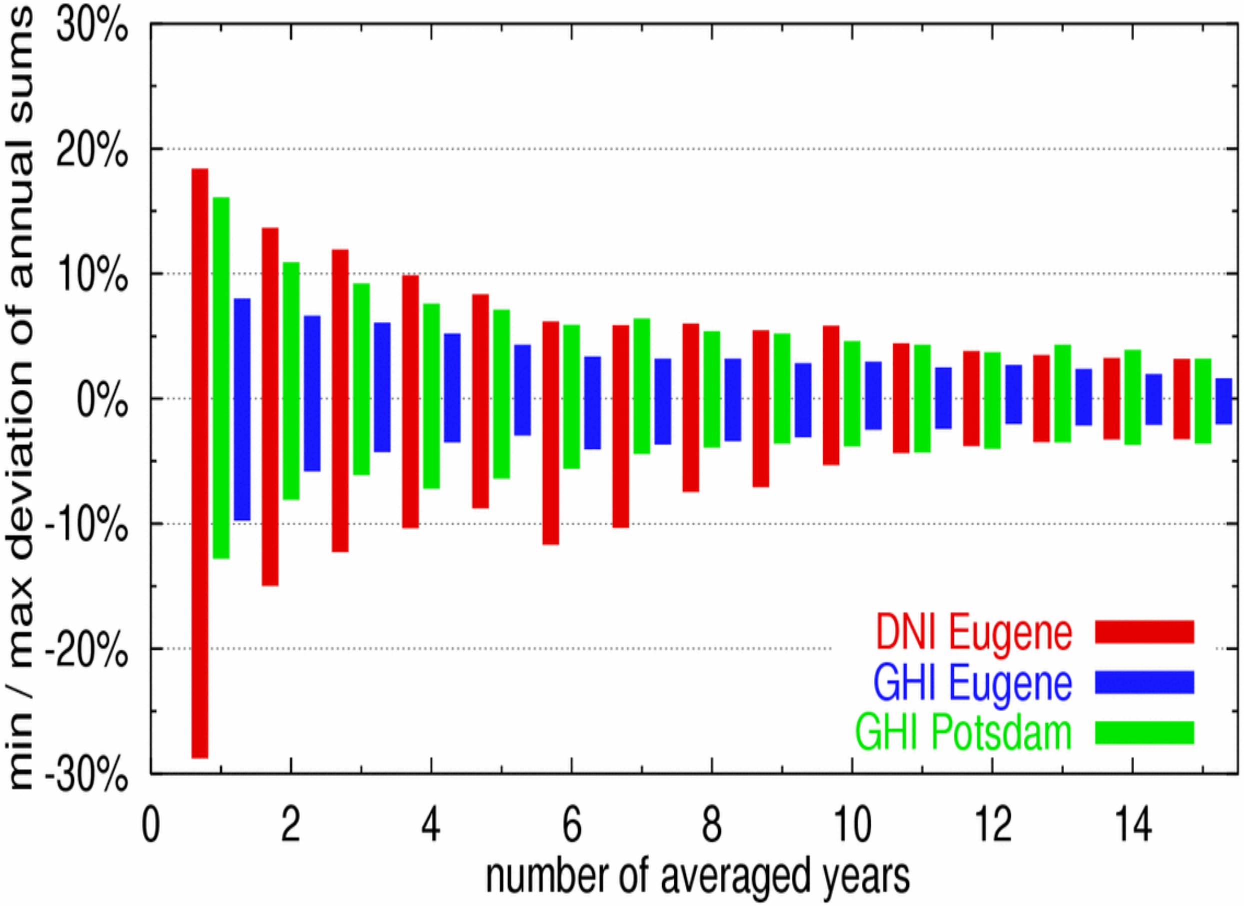
DNI from Satellite Data

Properties of Solar Radiation



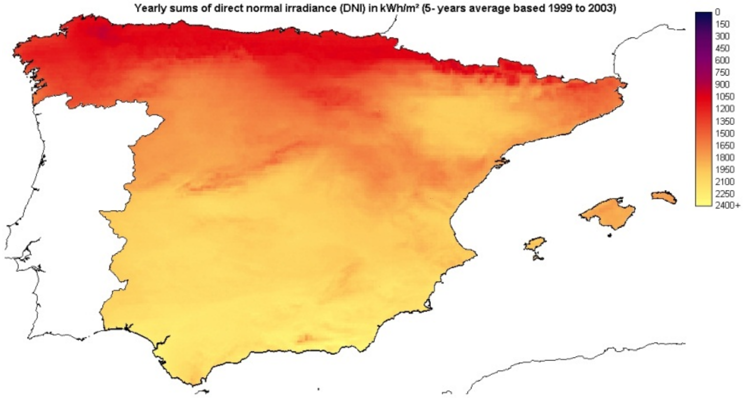
Long-term Variability of Solar Irradiance

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

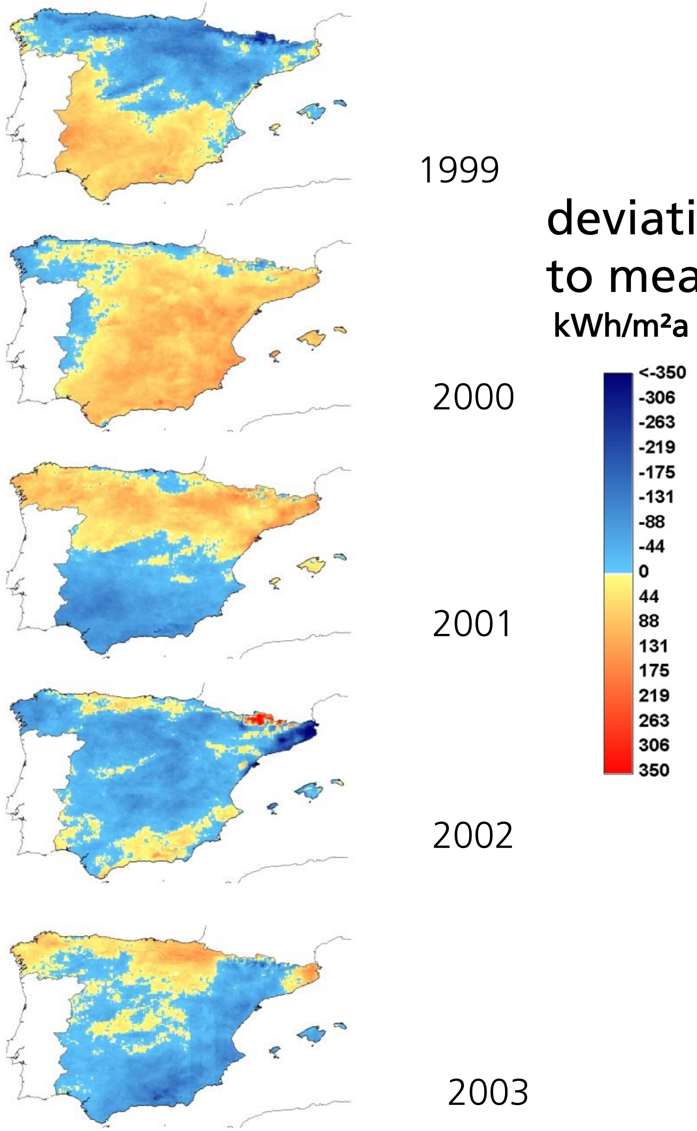


Inter-Annual Variability

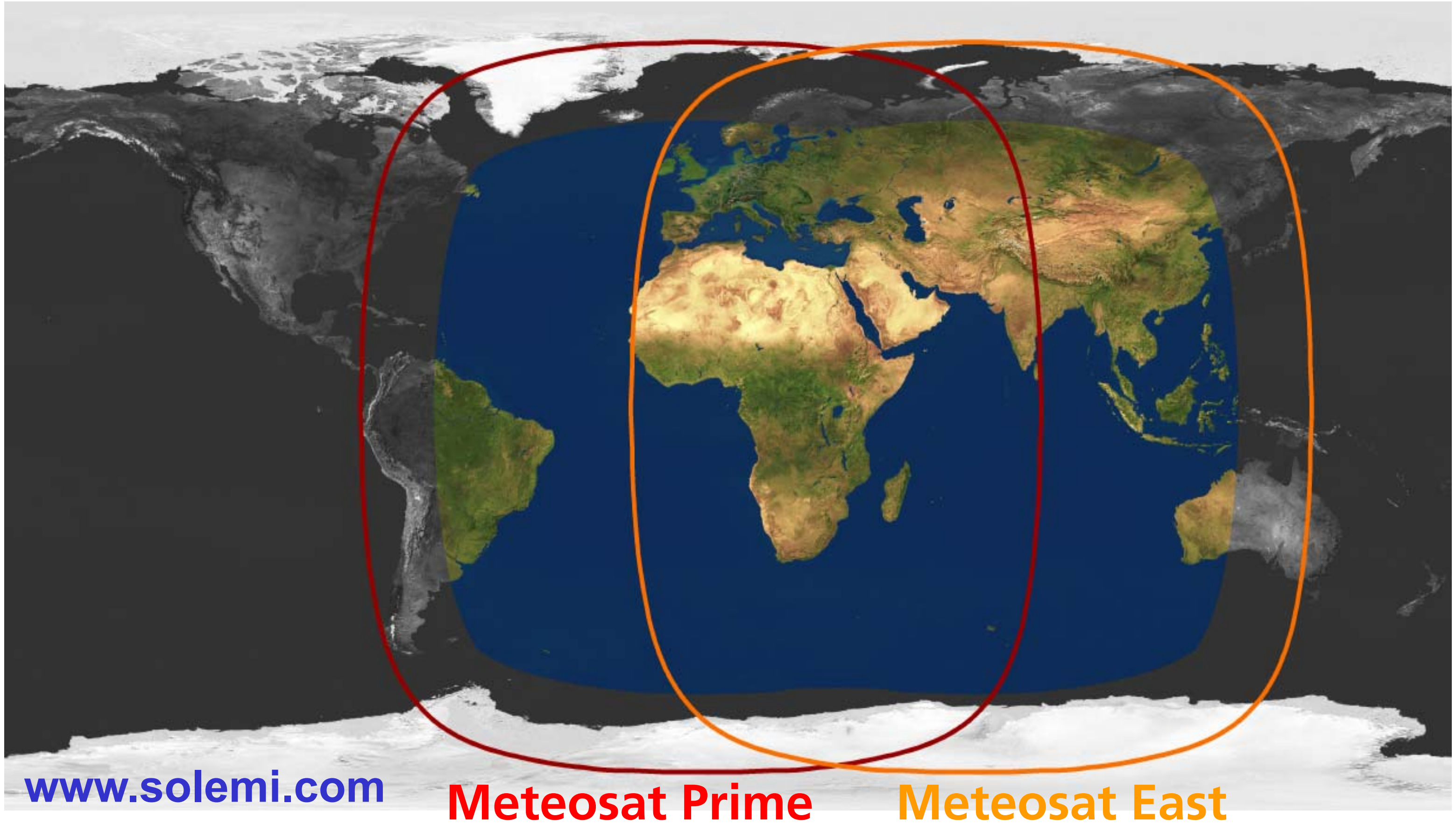
- Strong inter-annual and regional variations



Average of the direct normal irradiance from 1999-2003

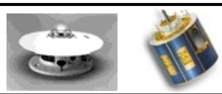
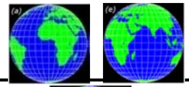
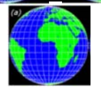
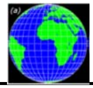


Satellite Data: SOLEMI – Solar Energy Mining (DLR)



- 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	coverage	period	provider
NASA SSE	ISCCP	World	1983-2005	NASA
Meteonorm		World	1981-2000	Meteotest
Solemi			since 1991	DLR
Helioclim			since 1985	Ecole de Mines
EnMetSol			since 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

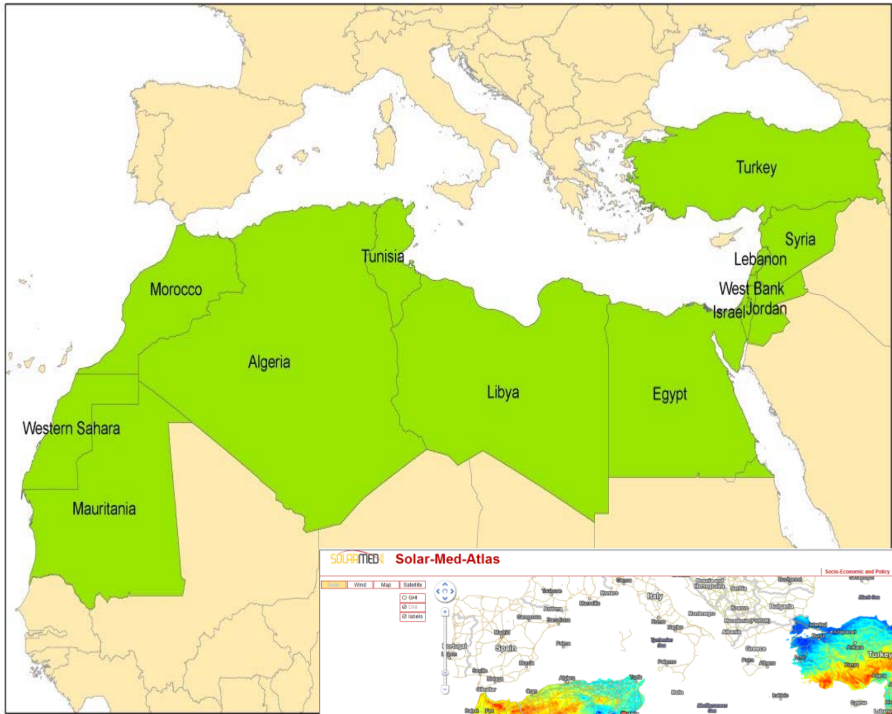
product	input	time resolution	spatial resolution
NASA SSE	ISCCP	averag. daily profile	100 km
Meteonorm	 	synthetic hourly/min	1 km (+SRTM)
Solemi		1h	1 km
Helioclim		15min/30min	30 km // 3-7 km
EnMetSol		15min/1h	3-7 km // 1-3 km
Satel-light		30min	5-7 km
PVGIS Europe		averag. daily profile	1 km (+ SRTM)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

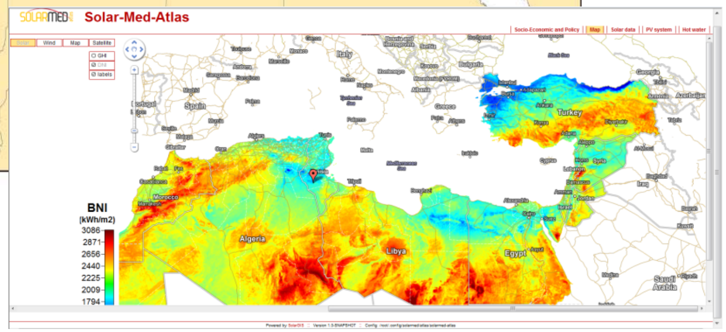
□ synthetic high resolution values □measured high resolution values

Solar Atlas for the Mediterranean (BMU-IKI)

- Solar Atlas for the south and east Mediterranean Countries
- 20 year DNI and GHI maps accessible by public internet portal
- Sponsored by BMU IKI
- European Consortium
- Start 2010 - End 2012
- Coordinated by DLR

Countries of the Solar Atlas for the Mediterranean

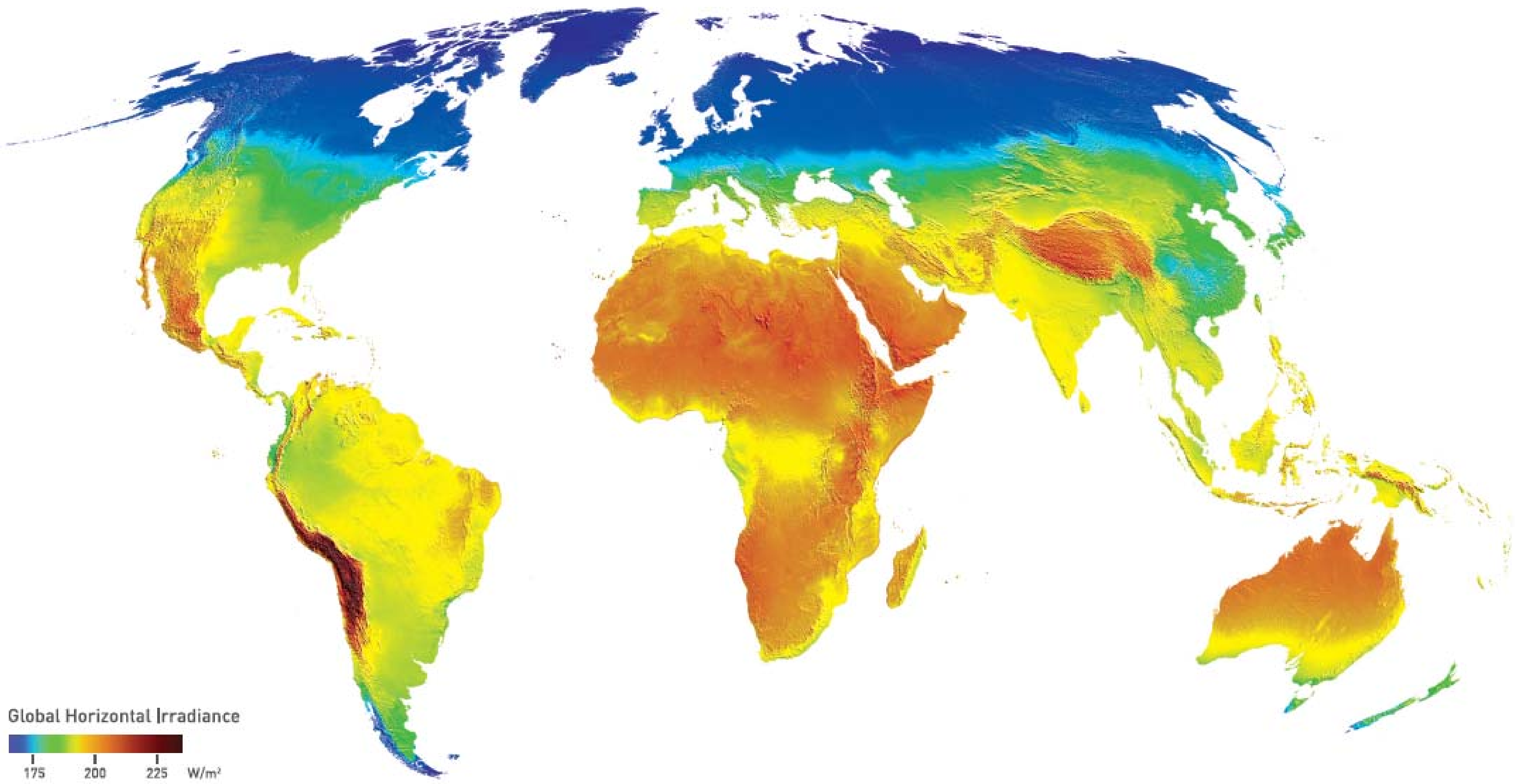




www.solar-med-atlas.org

Global Mean Solar Irradiance

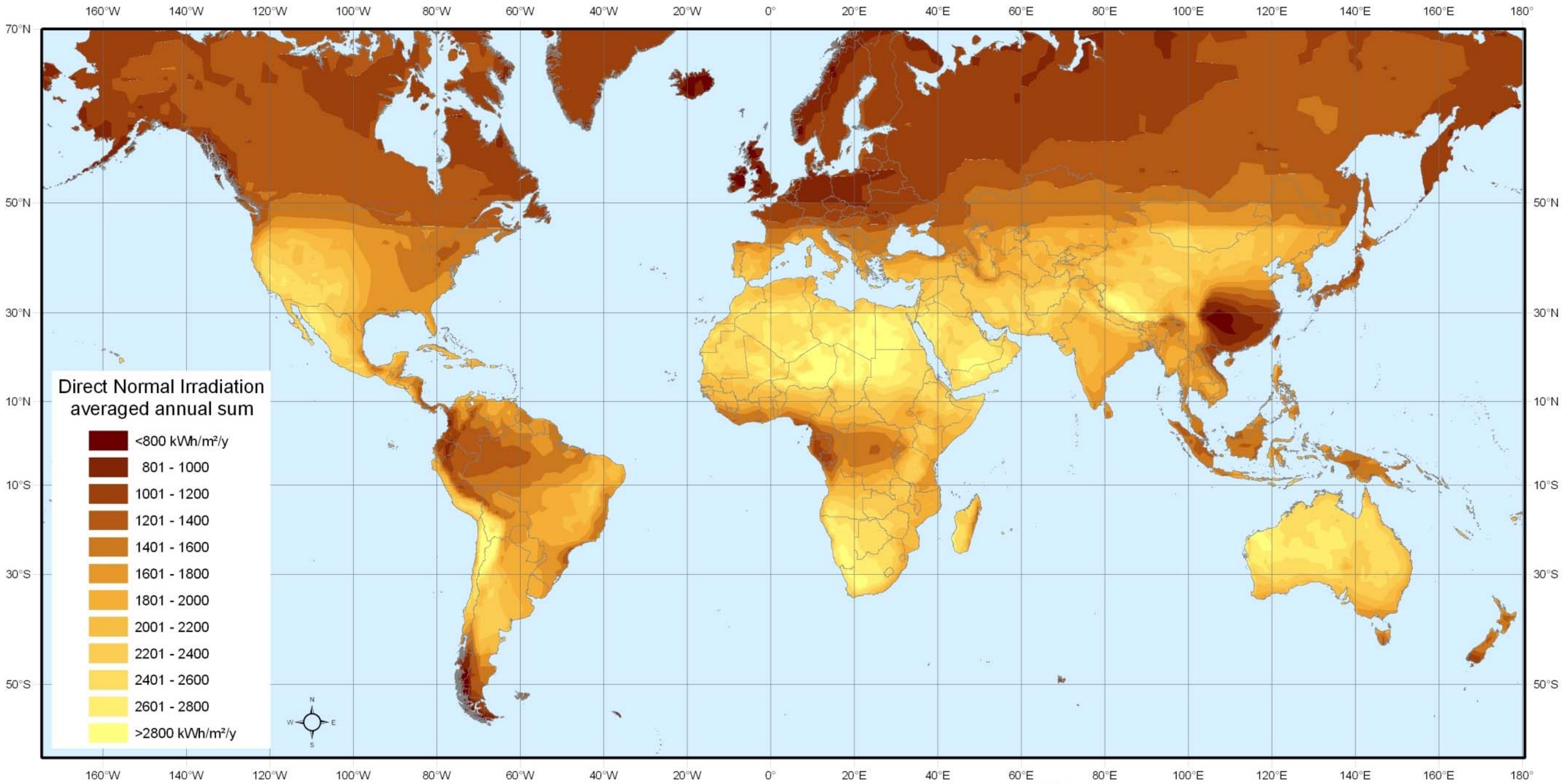
3TIER



Map developed by 3TIER | www.3tier.com | © 2011 3TIER Inc.

http://www.3tier.com/en/support/resource-maps/

Example Result: Global Annual Direct Normal Irradiation Map



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)

DNI Ground Measurements

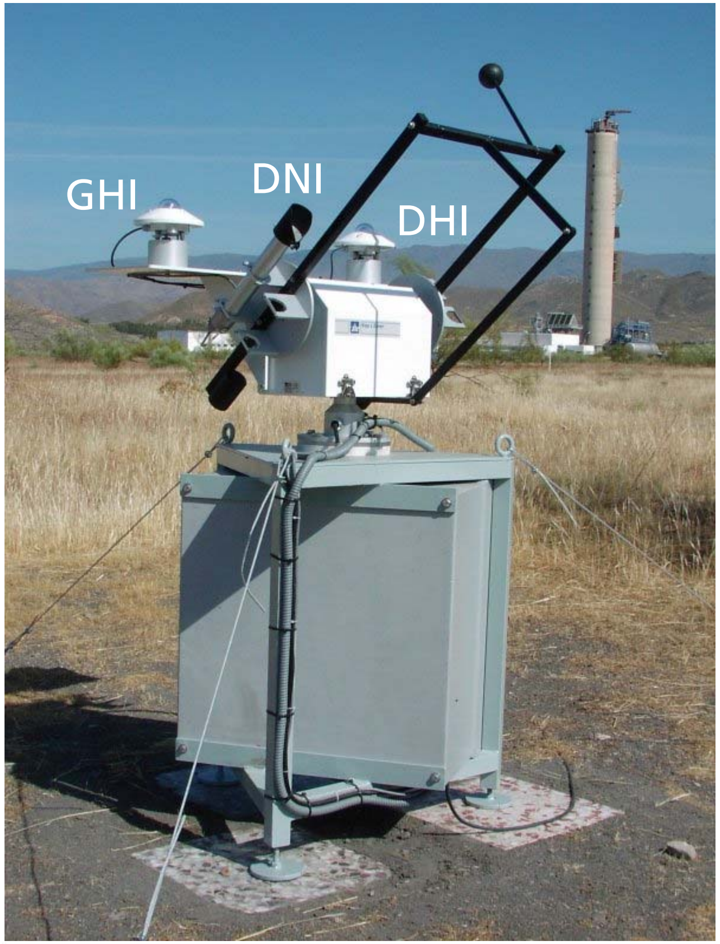
Solar Radiation Instruments

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)*

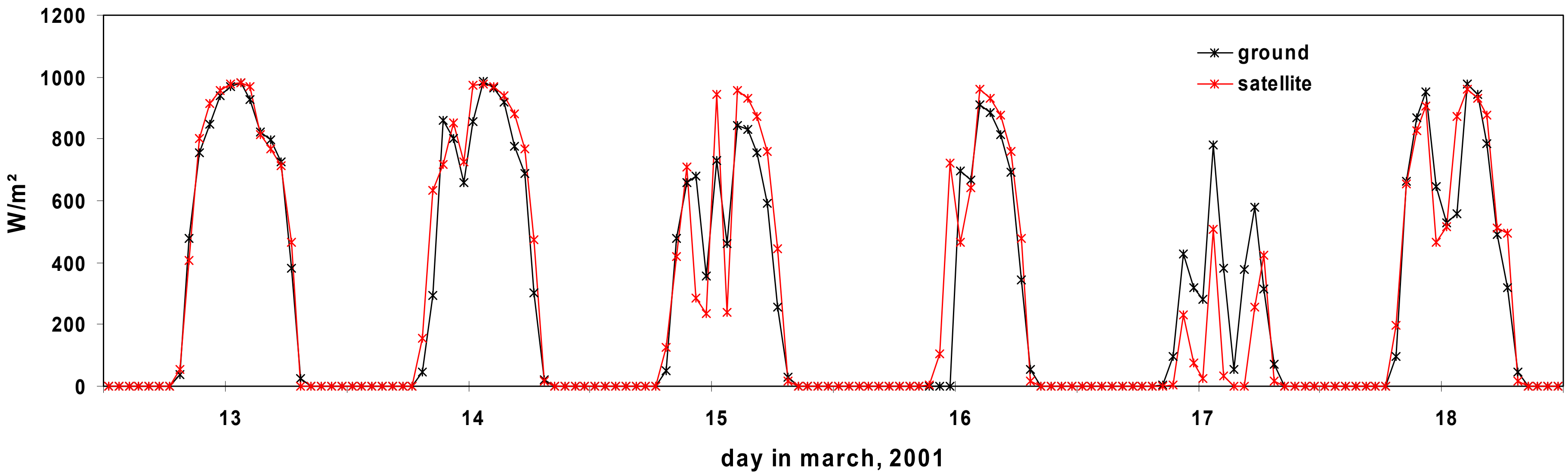
Availability of Ground Measured Data

long term measurements at meteorological stations

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

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

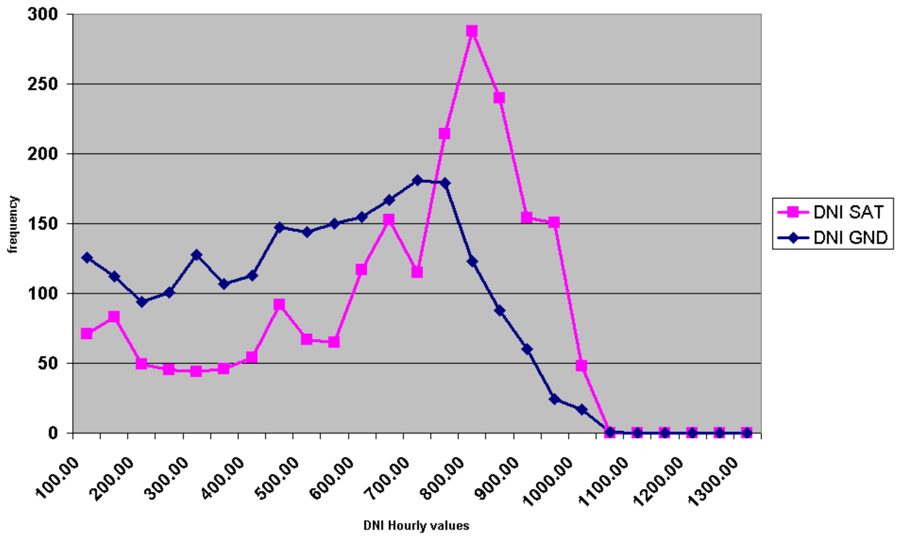
+ spatial coverage
+ long-term data *(more than 20 years)*
+ effectively no failures
+ no soiling
+ no ground site necessary
+ low costs

Disadvantages

- lower time resolution
- low accuracy at high time resolution

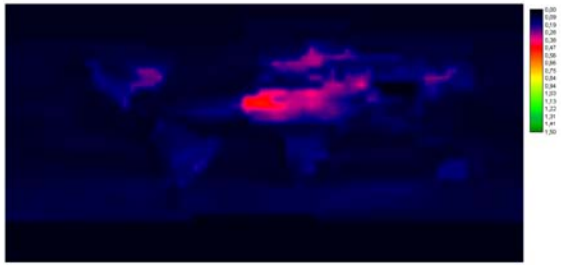
Simple Model

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

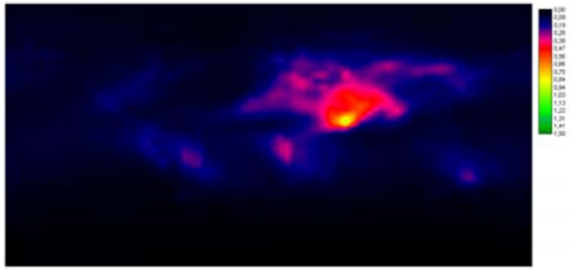


- over-estimate of frequency of high DNI

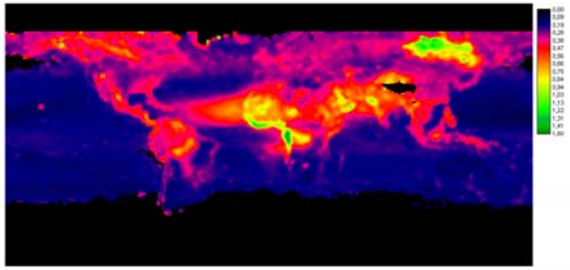
Inaccuracy of Aerosol Data



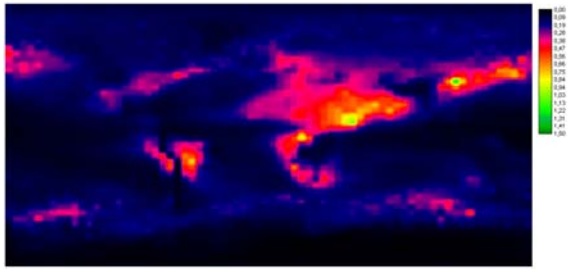
GADS



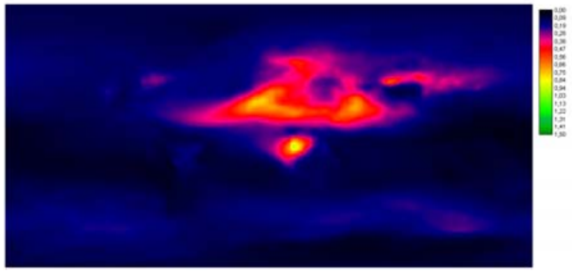
NASA GISS v1 / GACP



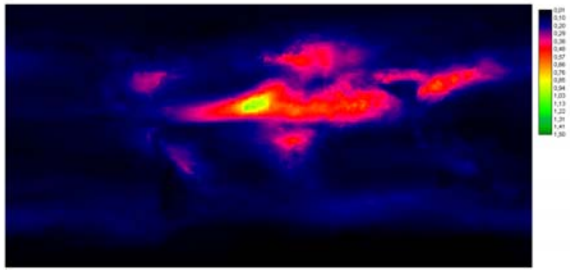
Toms



NASA GISS v2 1990



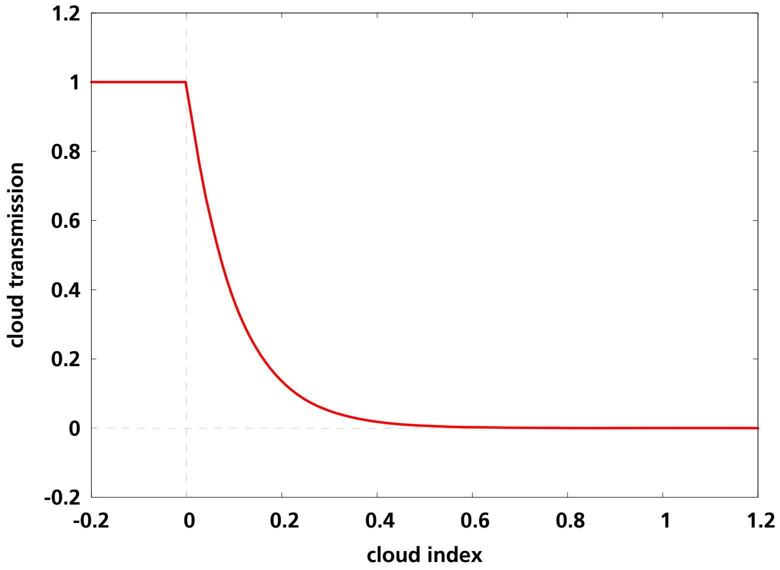
GOCART

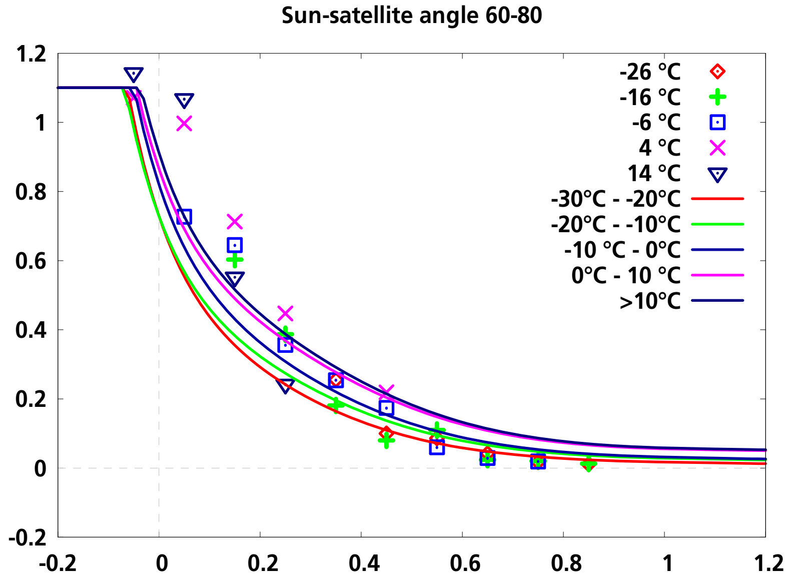


AeroCom

- 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 functions for different geometries and brightness temperatures

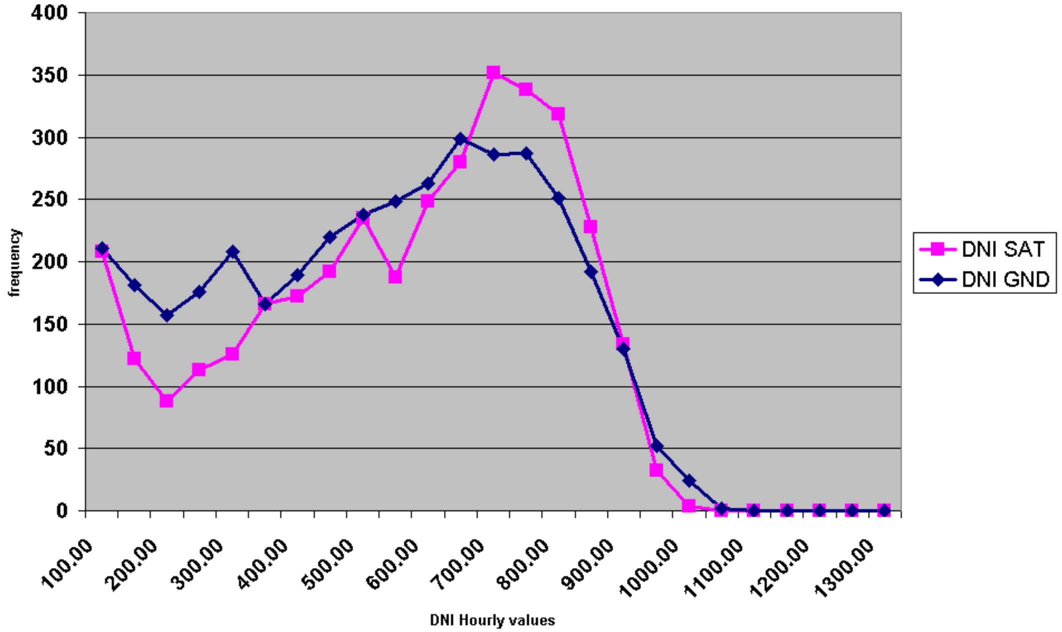
Combining Ground and Satellite Assessments

- Satellite data
  - Long term average over several decades can be obtained
  - Year to year variability can be assessed over a long period
  - Regional assessment for large areas is possible

- Ground data
  - Site specific data
  - High temporal resolution possible
    (up to 1 min to model transient effects)
  - Good distribution function

Enhanced Model

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



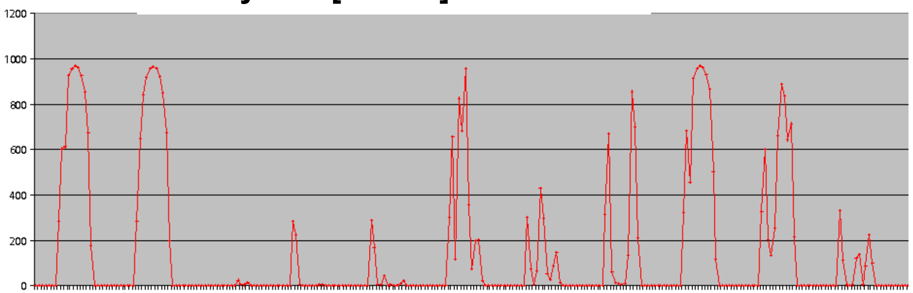
Good Solar Resource Assessments

- Based on long term data
- Site specific, high spatial resolution
- Sufficient temporal resolution for the specific 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).

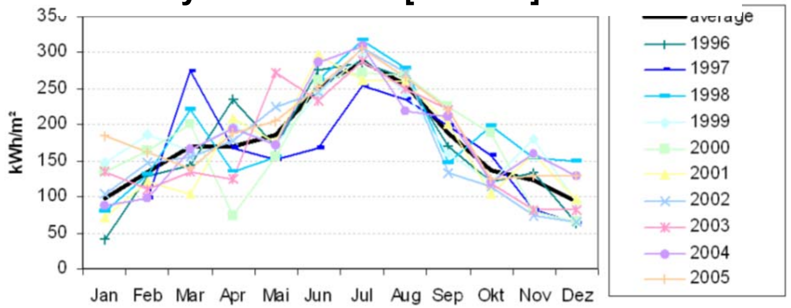
Resource Assessment for Site Performance Modelling

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

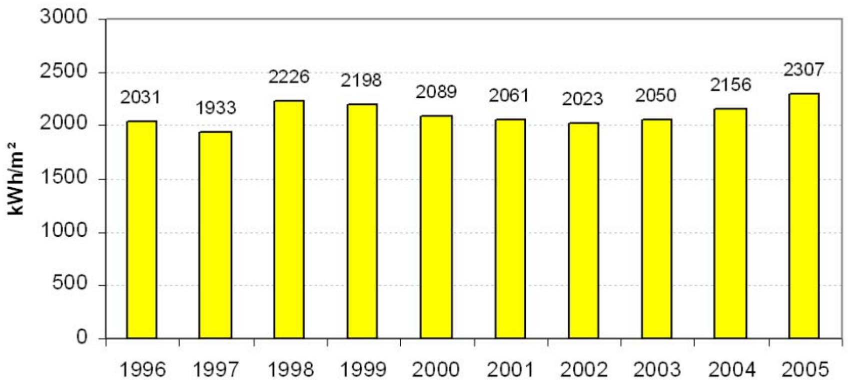
Hourly DNI [Wh/m²] for one site



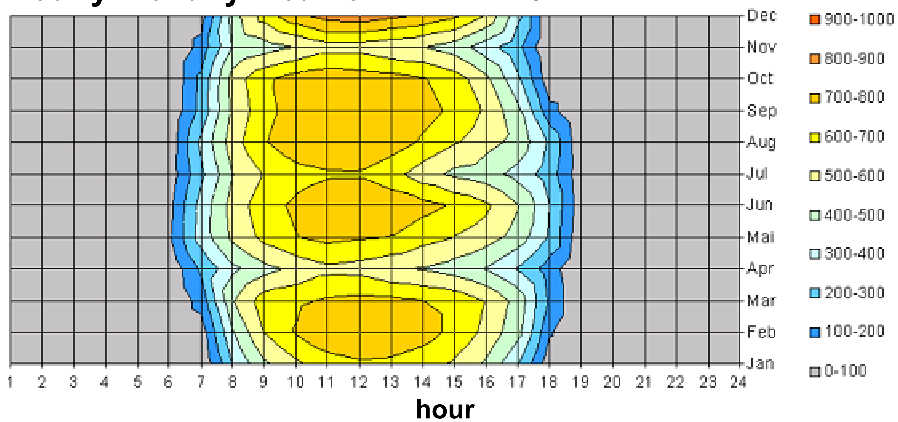
Monthly sums of DNI [kWh/m²] for one site



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

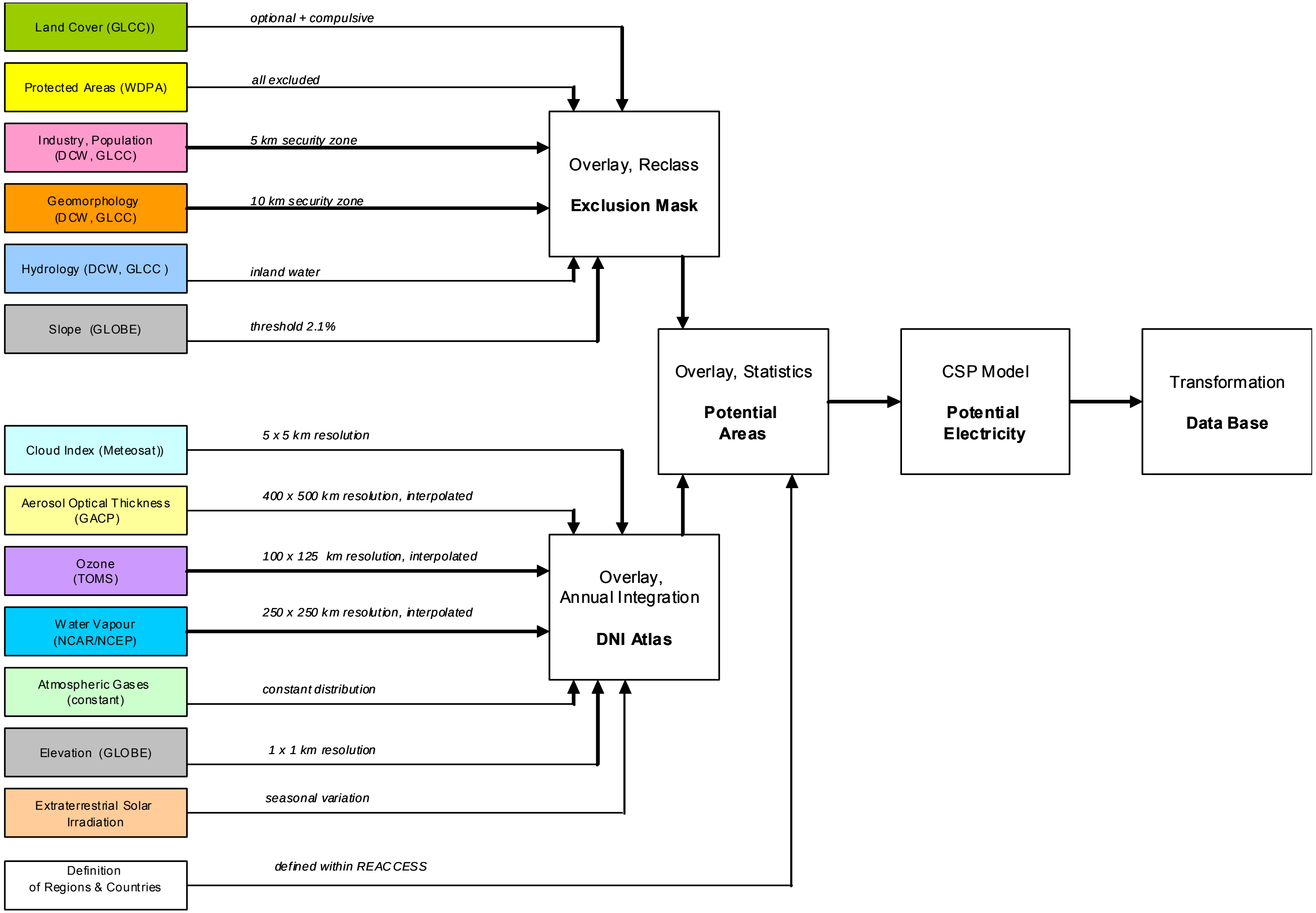


Hourly monthly mean of DNI in Wh/m²



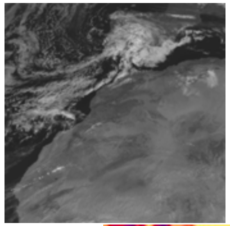
Example: Assessment of CSP Potentials

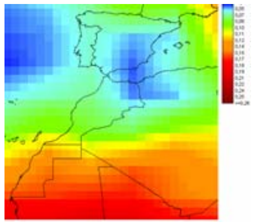
Methodology of Solar Power Potential Assessment

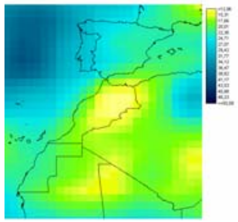


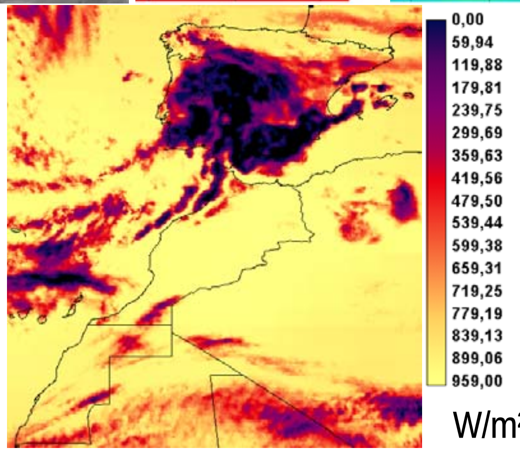
Solar Radiation Resource Assessment

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





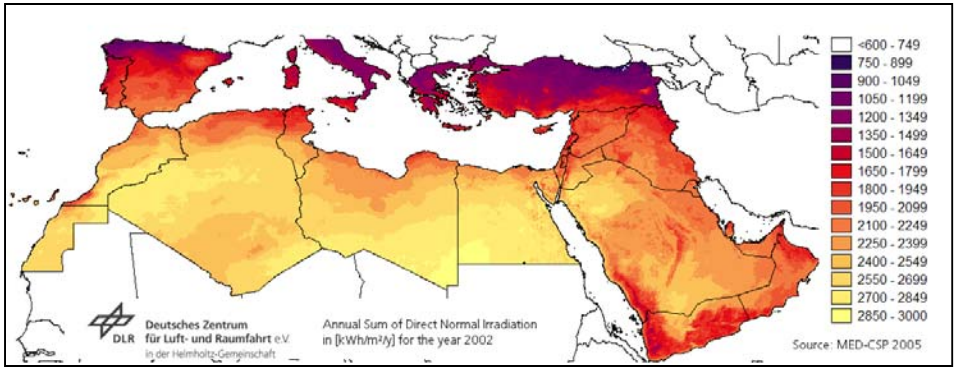




W/m²

Direct Normal Irradiation (DNI)

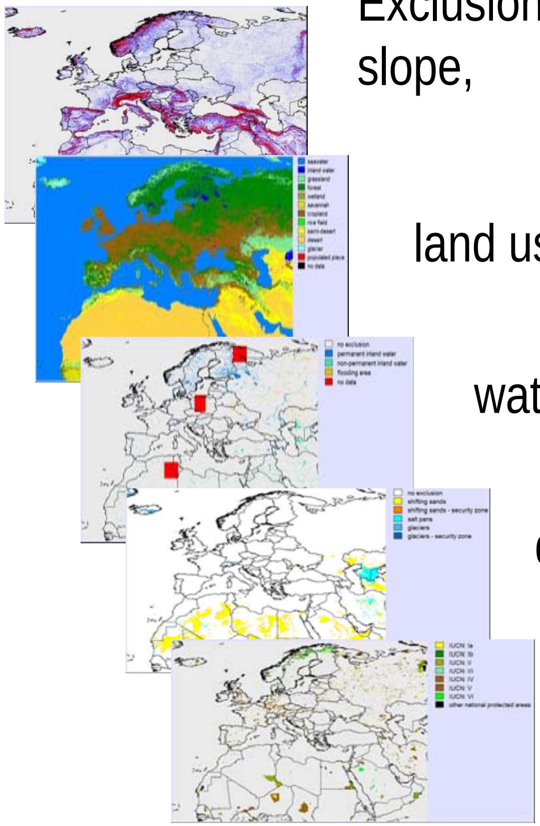
repeat for 8760 h/y



Long Term Average Annual Direct Normal Irradiation Map

www.dlr.de/tt/csp-resources

Land Area Resource Assessment



Exclusion of:
slope,

land use,

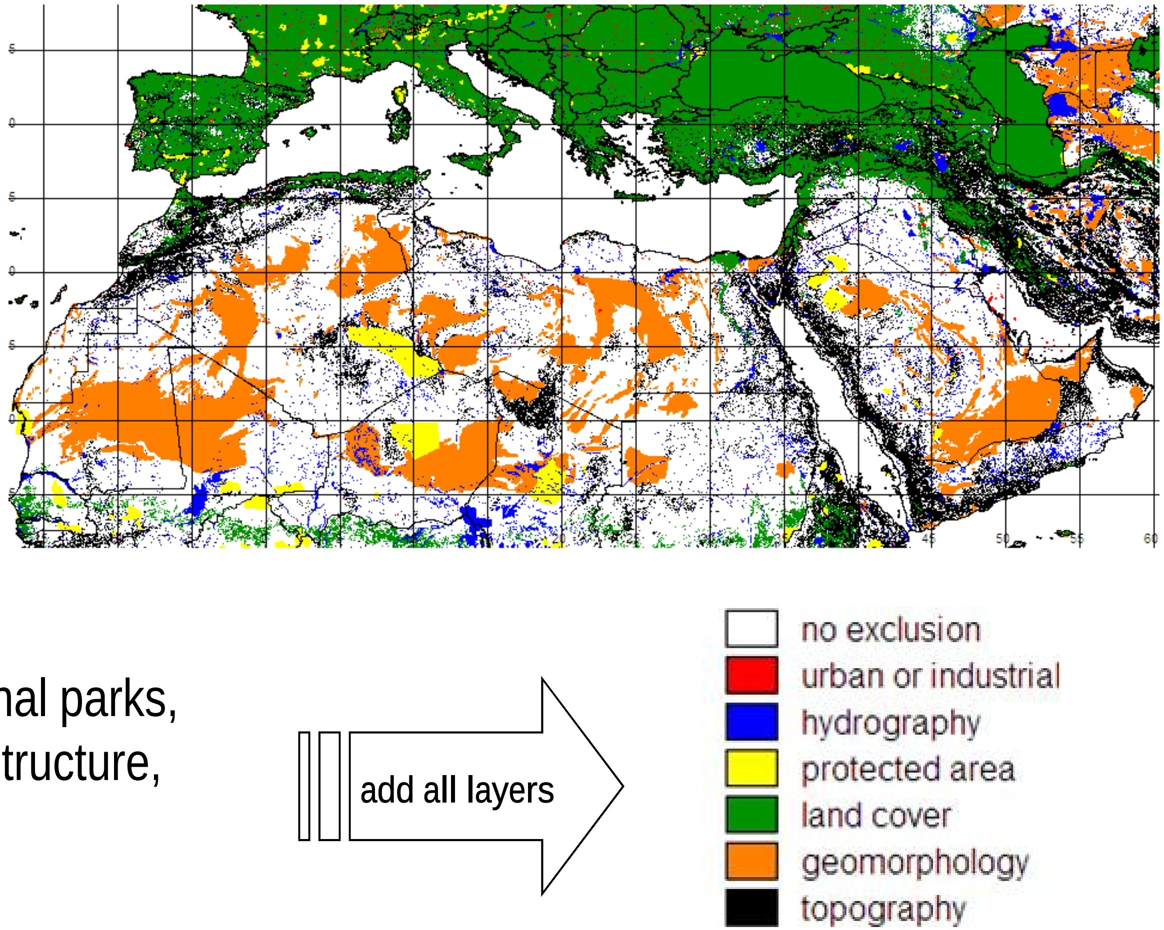
water,

dunes,

national parks,
infrastructure,

etc....

add all layers



www.dlr.de/tt/med-csp

CSP Performance Model

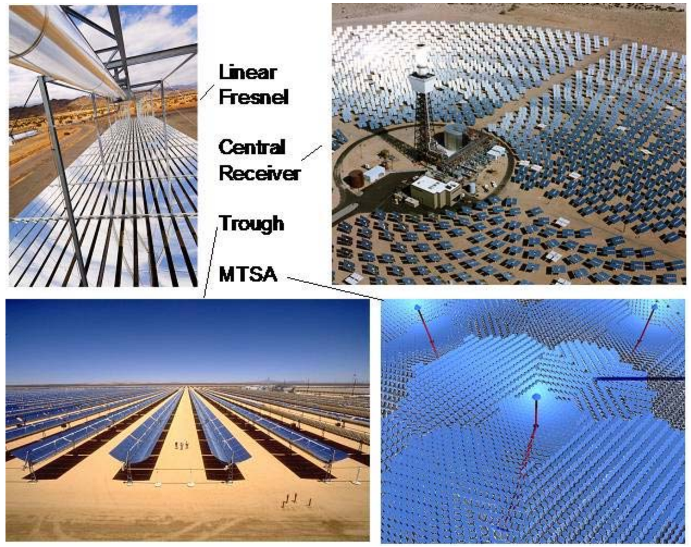
Average Land Use Efficiency (LUE)

= Solar-Electric-Efficiency (12%)

x Land Use Factor (37%)

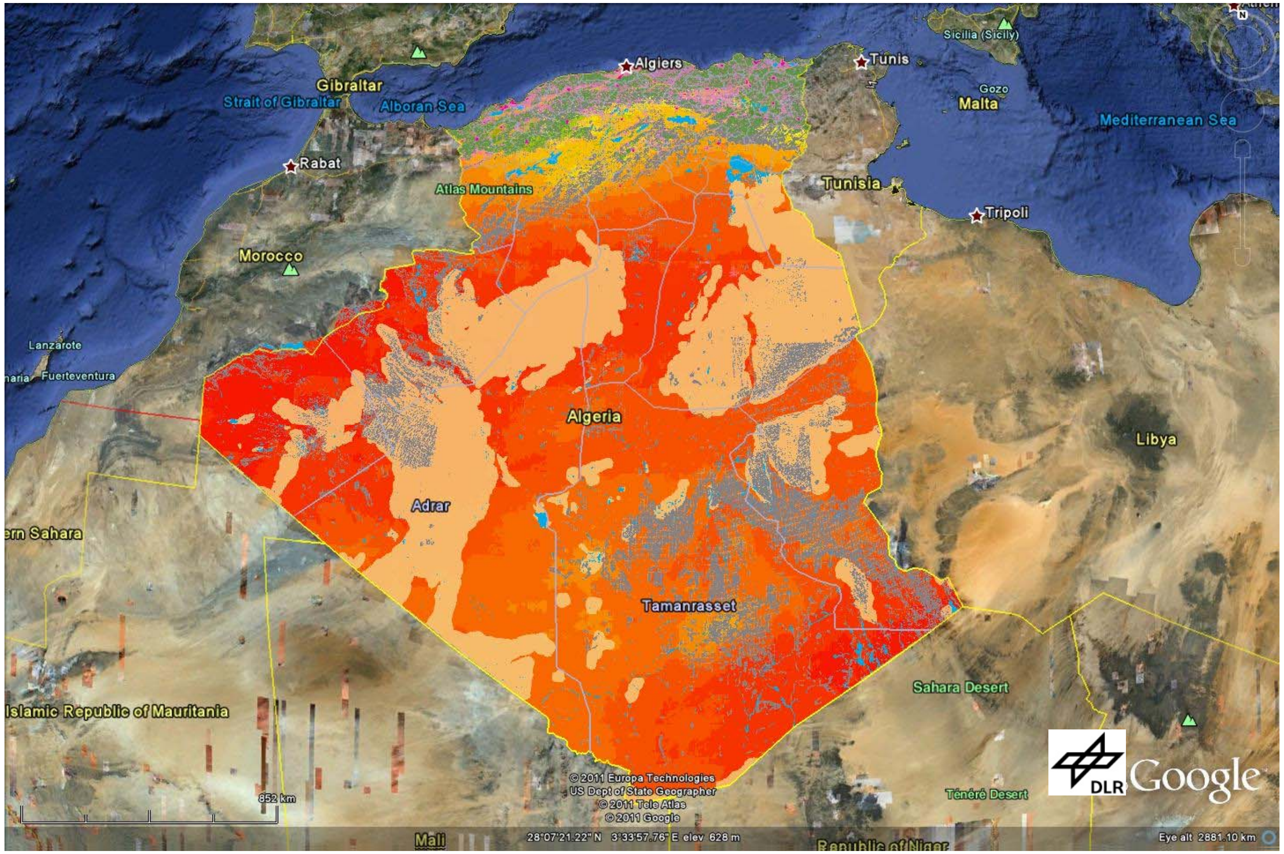
= 4.5% for parabolic trough steam cycle

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%

Analyse du potentiel des centrales thermosolaires en Algérie



DNI kWh/m²/y]

- 2,000
- 2,100
- 2,200
- 2,300
- 2,400
- 2,500
- 2,600
- 2,700
- 2,800
- 2,900

Critère d'exclusion

- Zones urbaines
- Densité de population
- Couverture terrestre
- Hydrographie
- Géomorphologie
- Inclinaison

www.dlr.de/tt/menawater

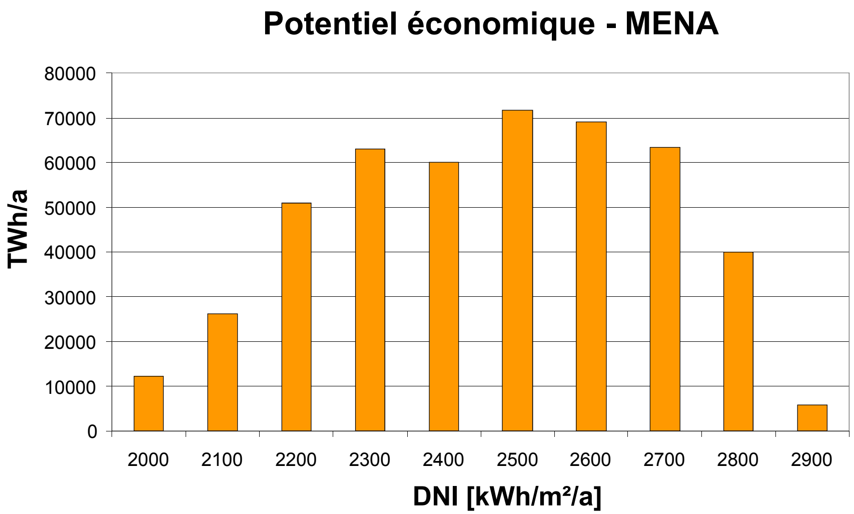
Potentiel de production d'électricité des centrales thermosolaires

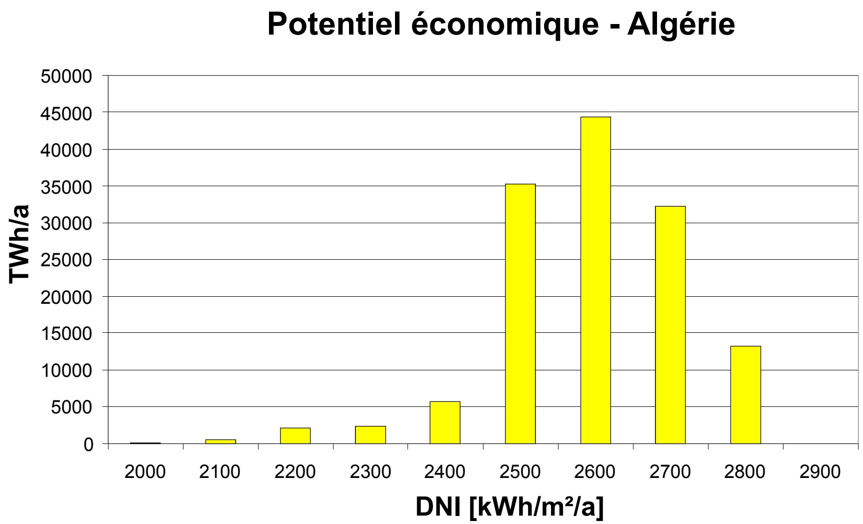
MENA

- besoin d'énergie:
  - 2010: ~ 1145 TWh/a
  - 2050: ~ 2870 TWh/a
- potentiel des centrales thermosolaires:
  - ~ 462000 TWh/a

Algérie

- besoin d'énergie :
  - 2010: ~ 39 TWh/a
  - 2050: ~ 190 TWh/a
- potentiel des centrales thermosolaires :
  - ~ 135771 TWh/a





www.dlr.de/tt/menawater

www.dlr.de/tt/med-csp

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

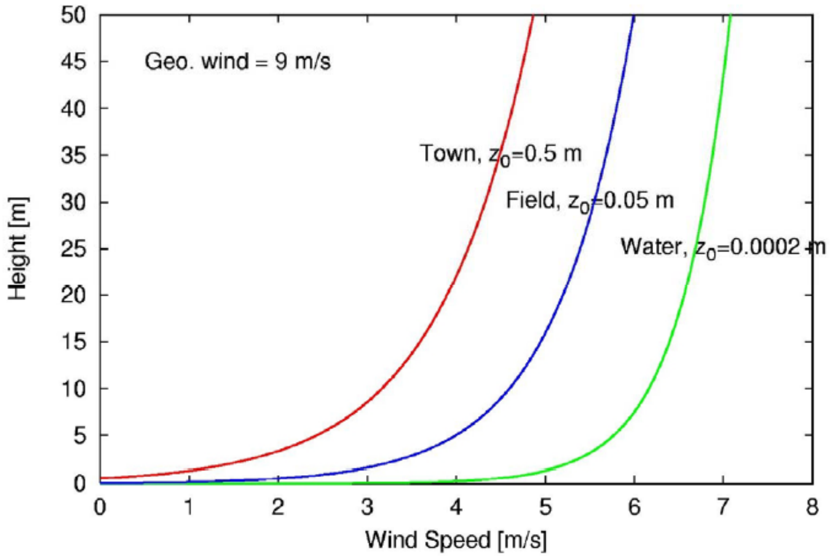


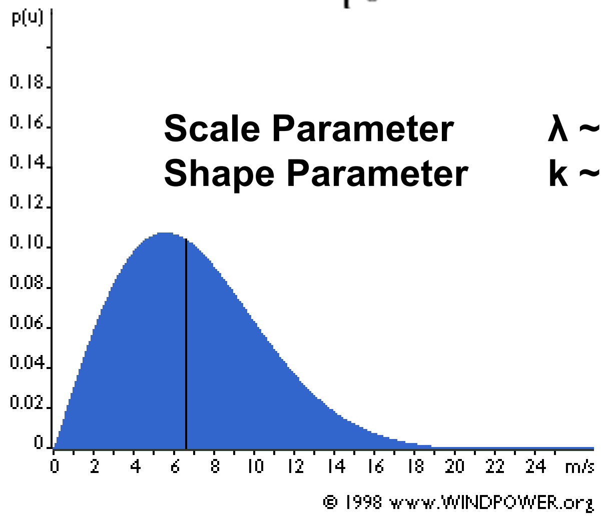
Image source: RISØ/DTU

Site specific wind resource assessment

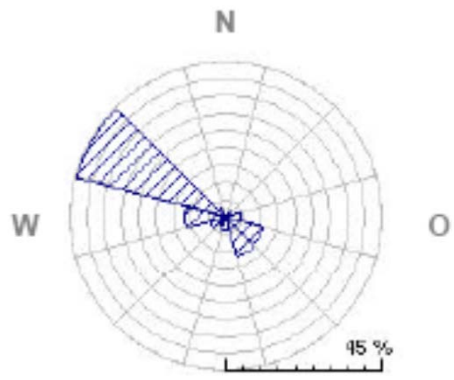
$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0, \\ 0 & x < 0, \end{cases}$$

Important information is:

- **Distribution of wind speed x**
  (can be approximated by a Weibull distribution with parameters λ 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 limited 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

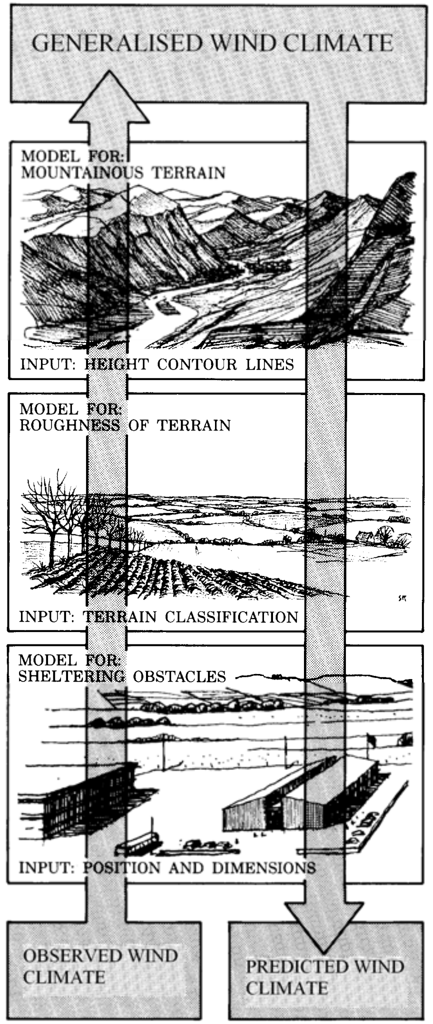


Image source: RISØ/DTU

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.

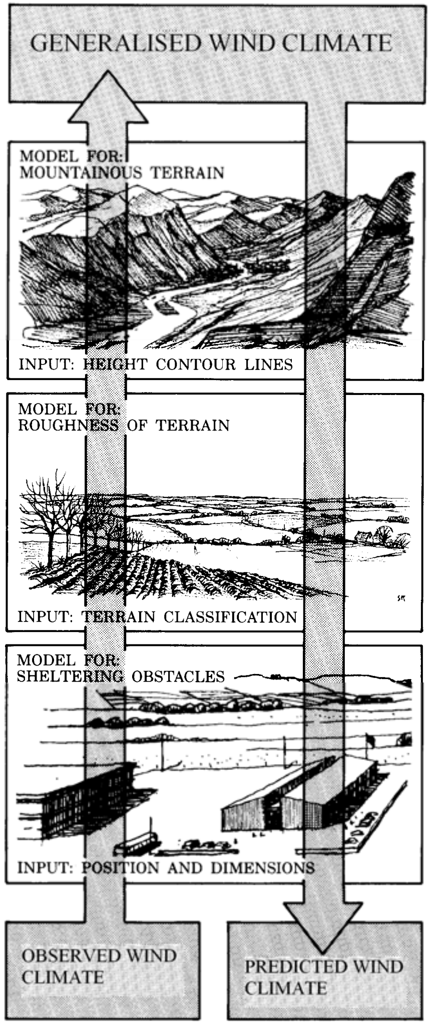
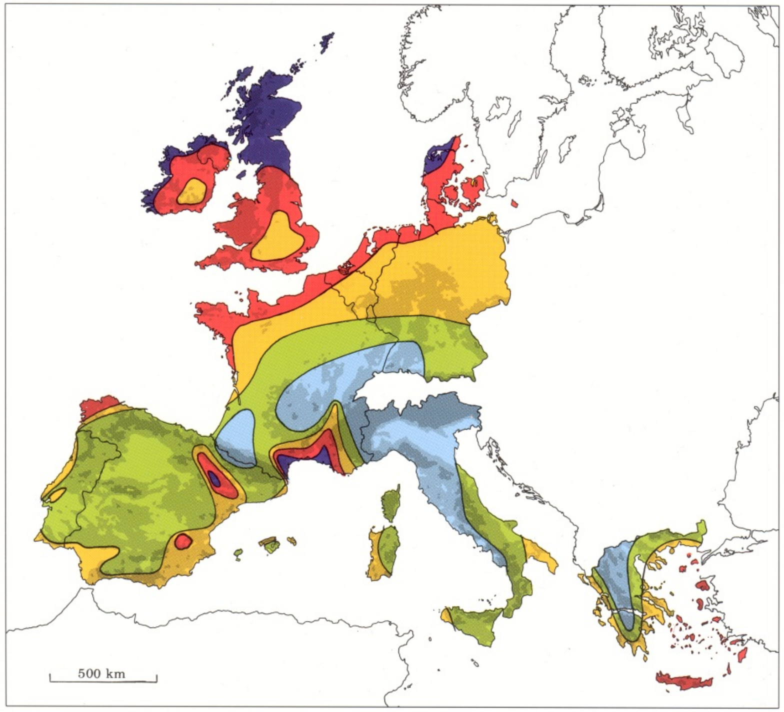


Image source: RISØ/DTU

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

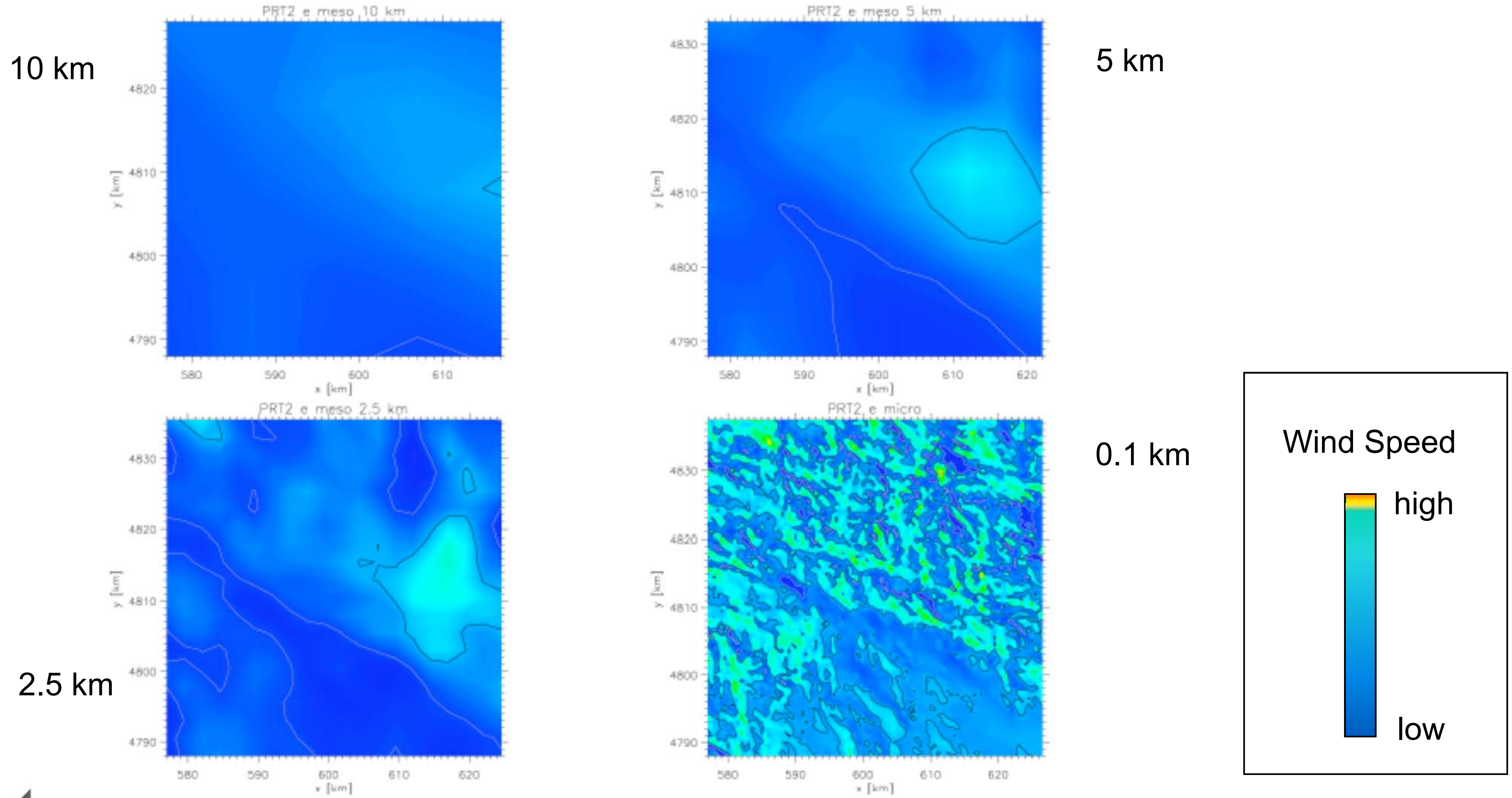


Wind resources[1] at 50 metres above ground level for five different topographic conditions

	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

Quality of Wind Potential Assessment is very Sensible to Geographical Resolution



Offshore

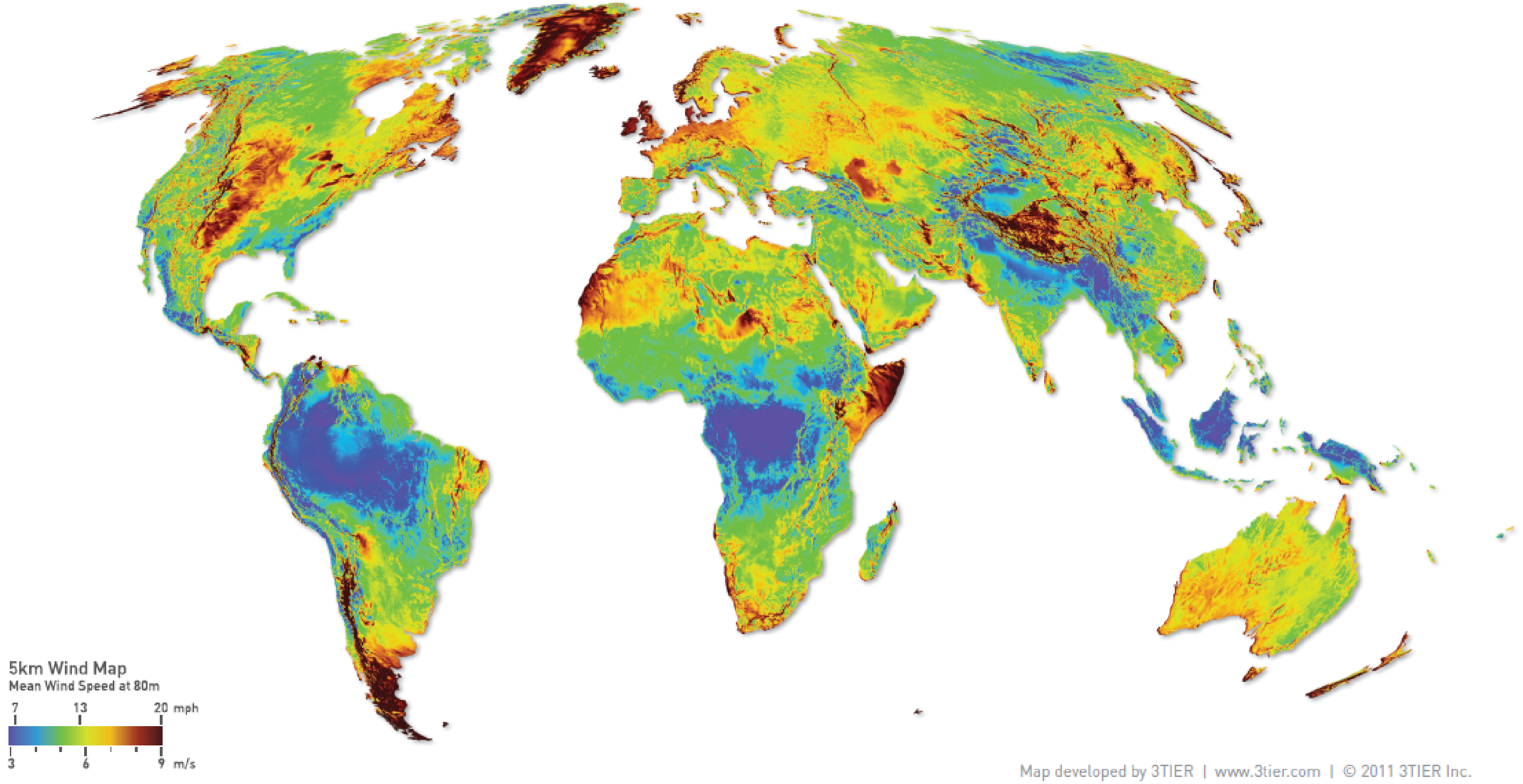
- The wind profile is more complex due to
  - larger thermal inertia of the water
  - wind and wave interactions
  - time lag of wave development
- Nearly no measurements, very few platforms e.g. in front of the Danish or German coast
- But: Wind speed can be assessed by measuring the wave height with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

Data sources

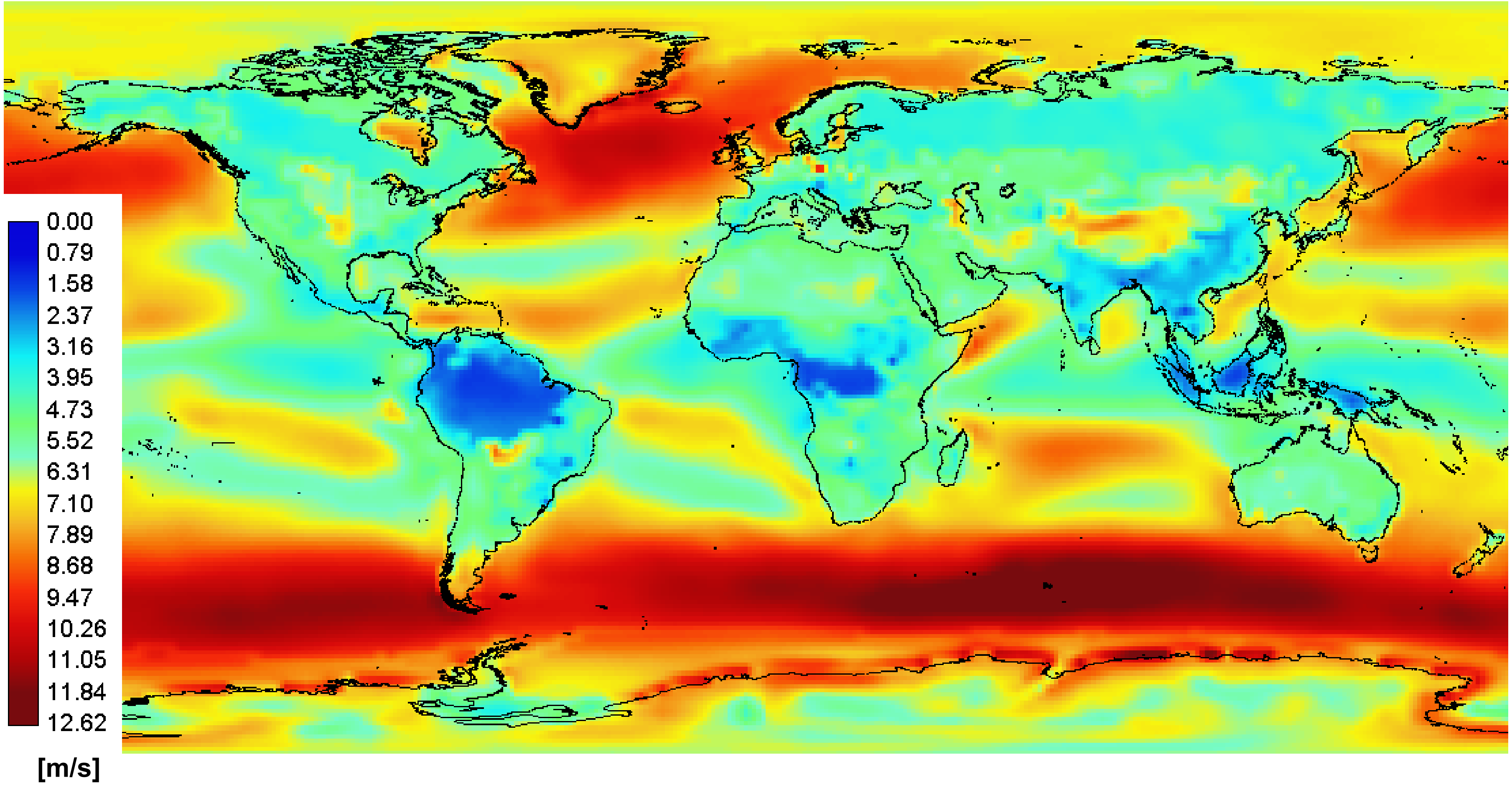
- Wind Atlases of RISØ/DTU: www.windatlas.dk
- SWERA: http://swera.unep.net

- Wind resource assessment is a commercial business
- Some companies/institutions are:
  - AWS Truewind
  - 3tier
  - Garrad Hassan
  - Cener
  - NREL
  - National Met Offices

Global Mean Wind Speed at 80m



Annual Average Wind Speed at 50 m Height

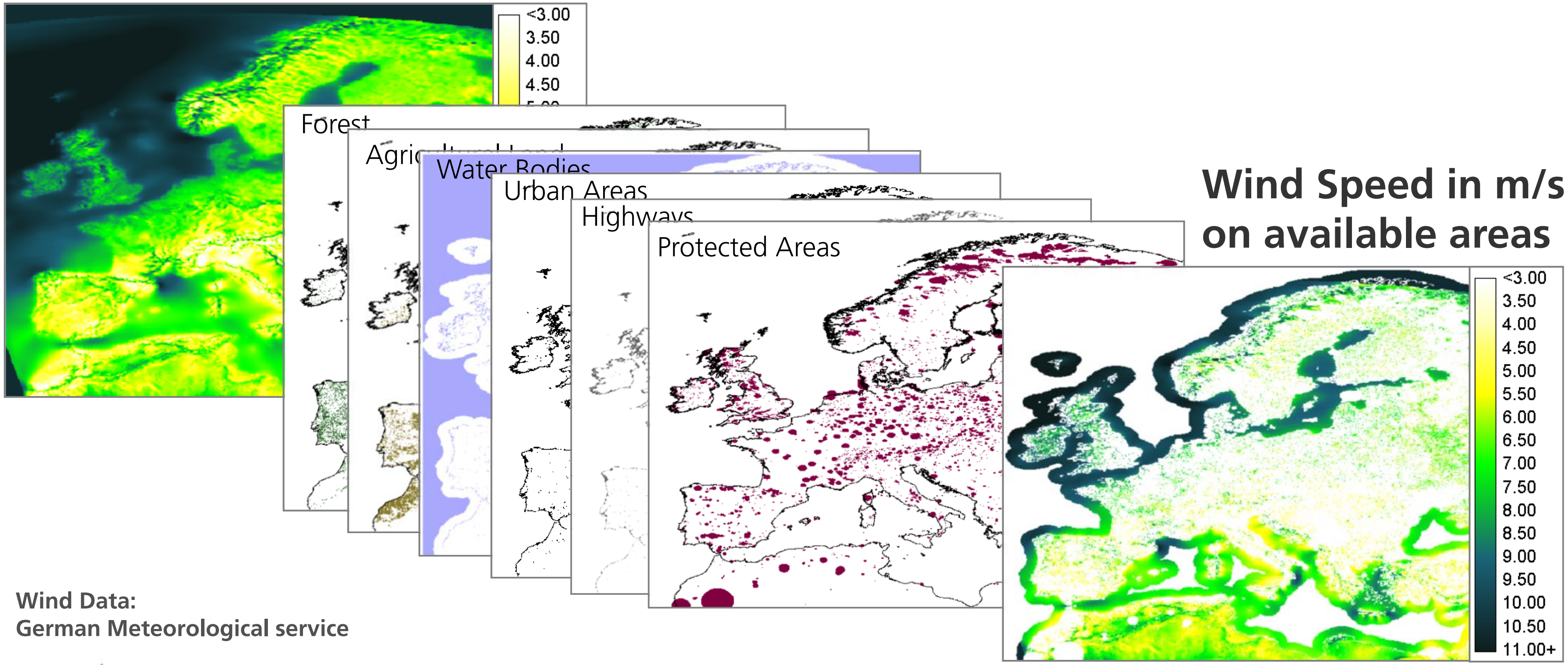


Example:
Wind Cost-Potential Functions

Wind Power Potentials in Europe

Resource and Land Availability

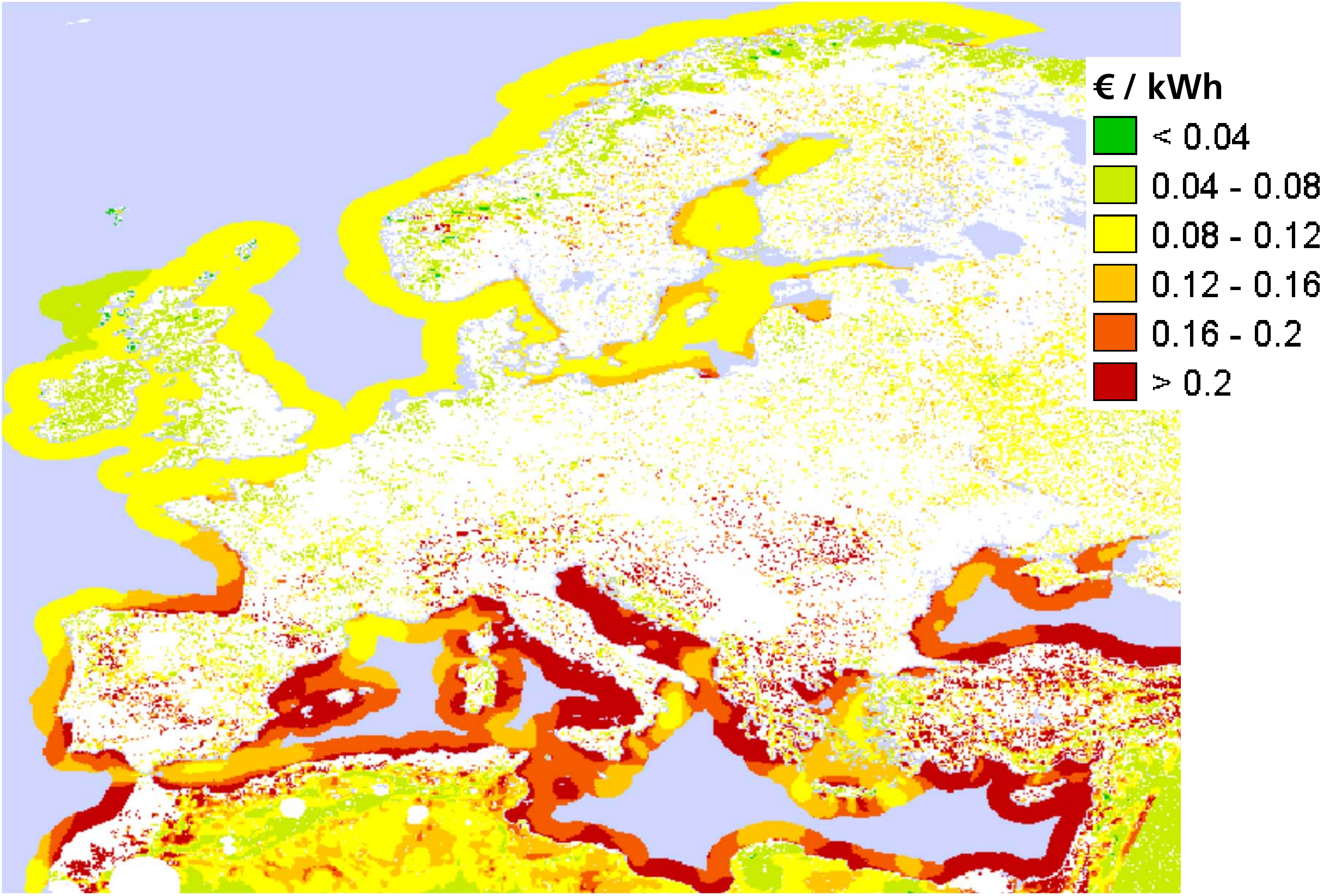
Wind Speed in m/s



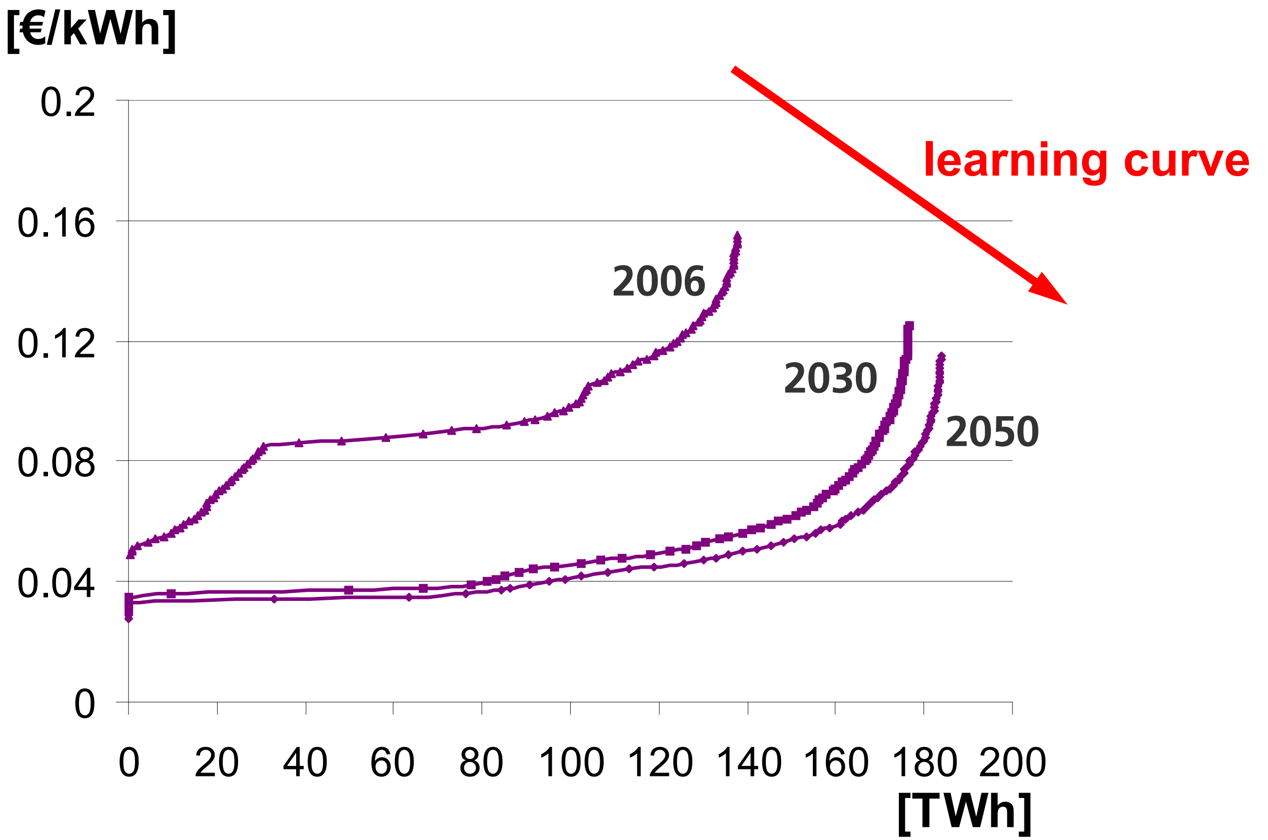
Wind Speed in m/s on available areas

Wind Data:
German Meteorological service

Wind Electricity Cost: Technology and Cost Status 2006

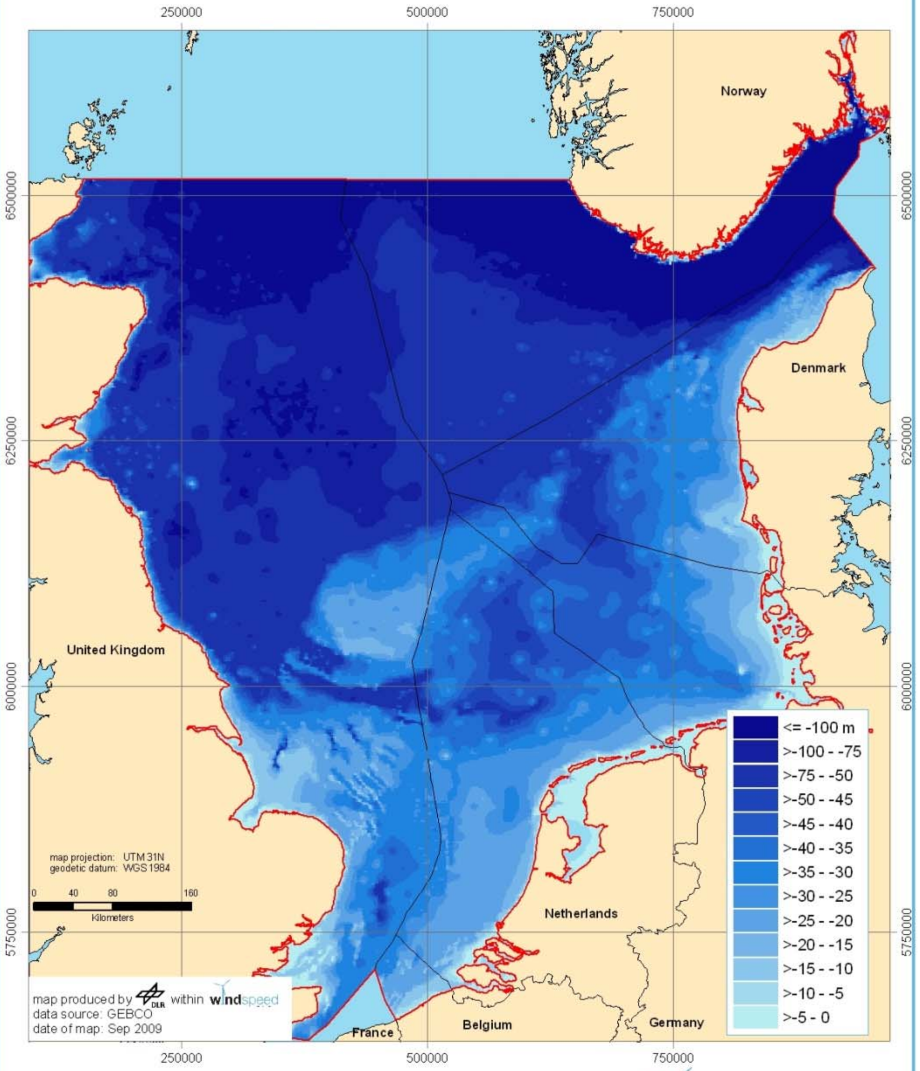


Cost Potential Functions for Wind Power in Germany



Example: Offshore Wind Potentials

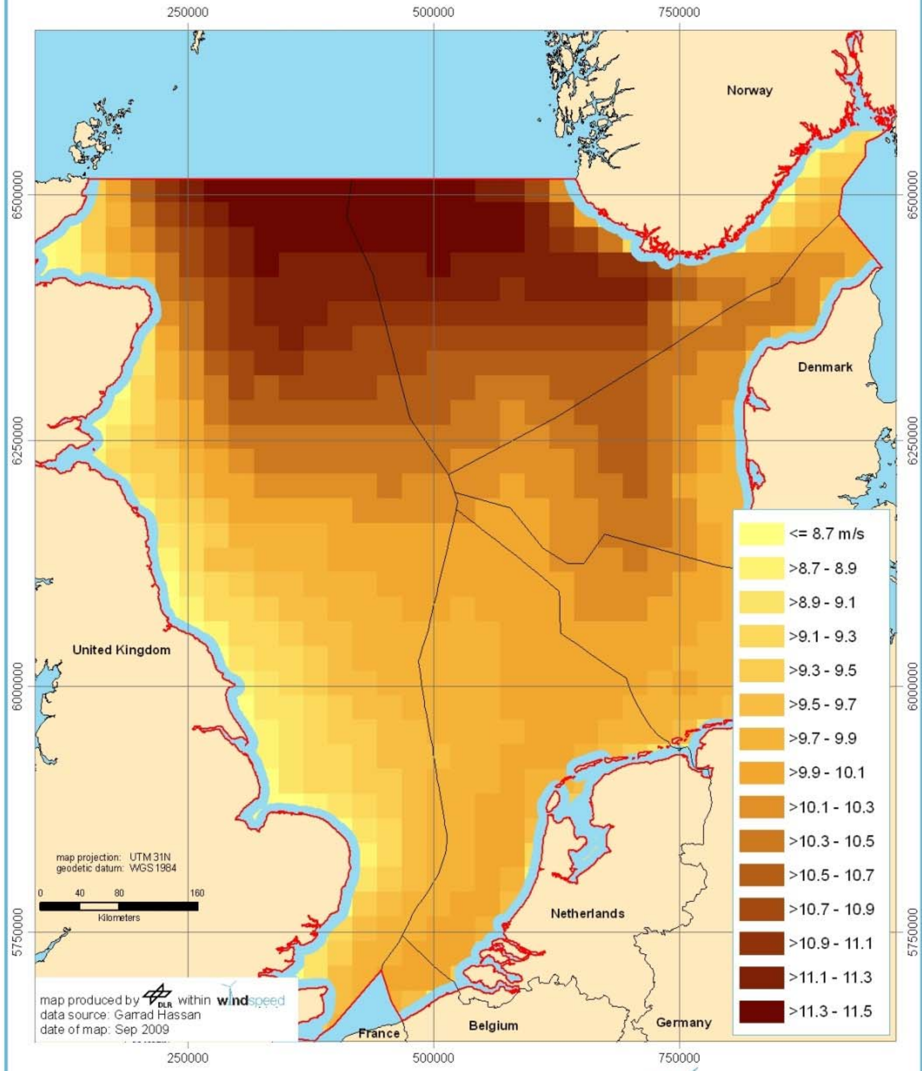
Sea Depth (Bathymetry) [m]



windspeed

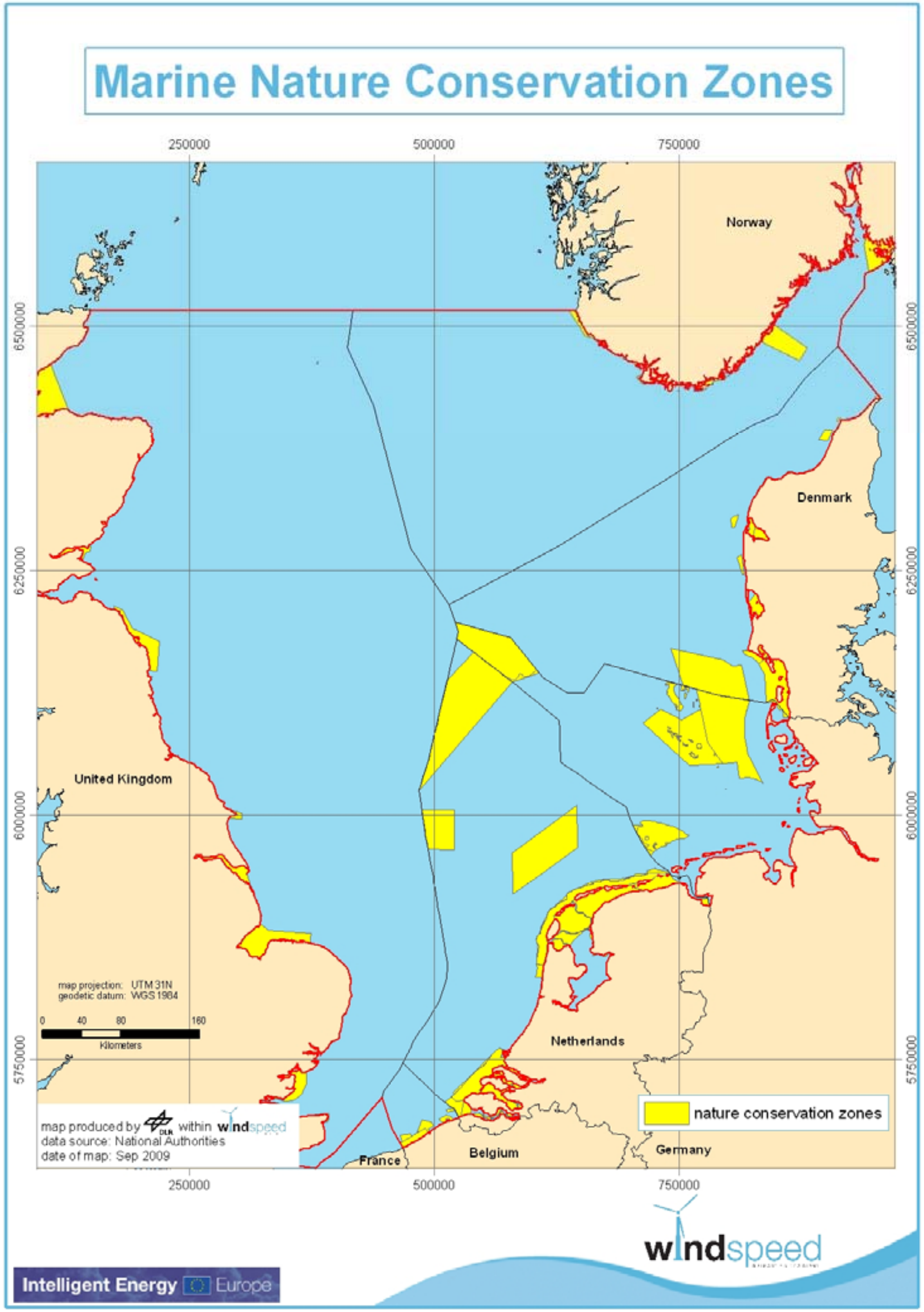
Intelligent Energy Europe

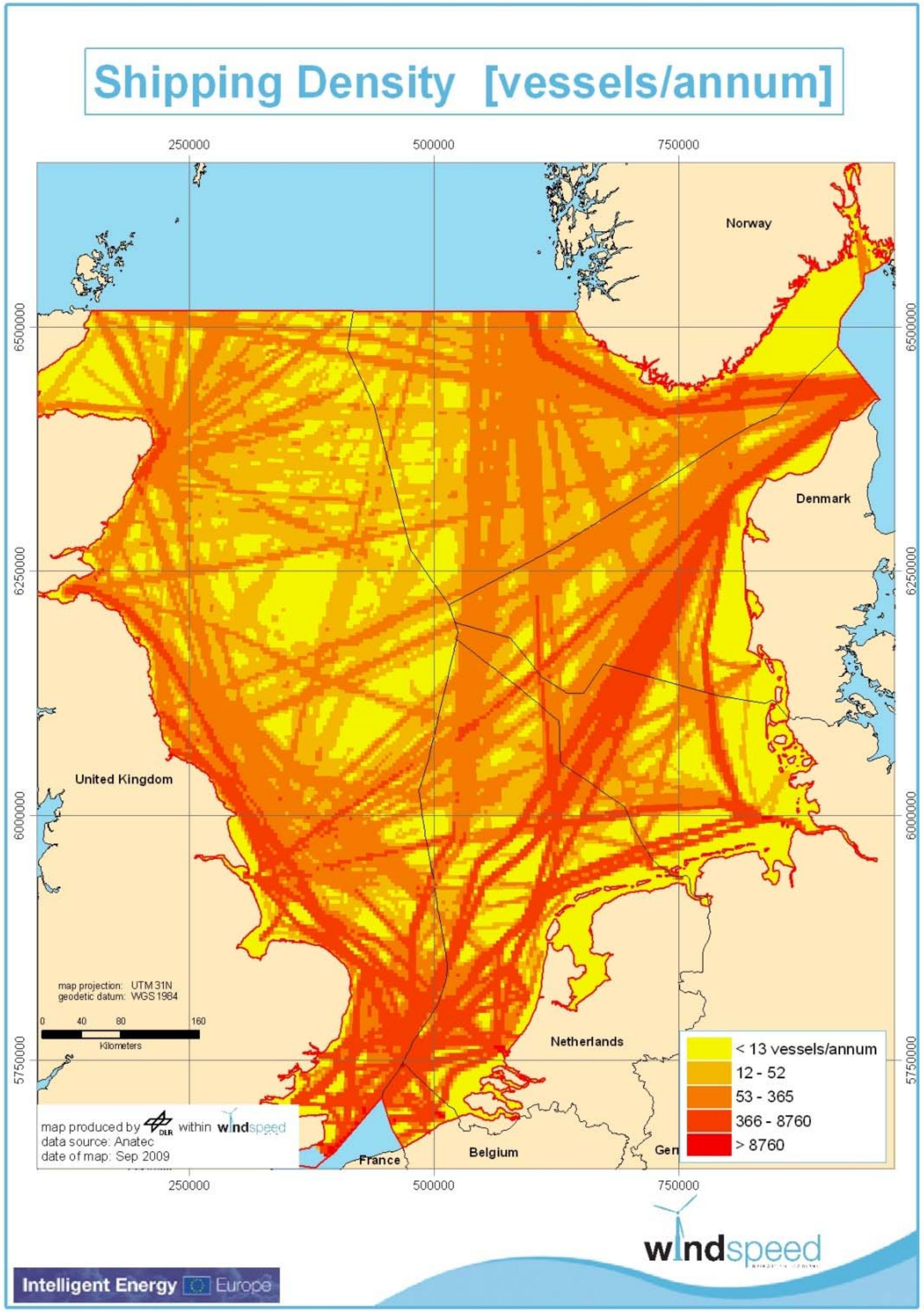
Windspeed at 90m hub height [m/s]



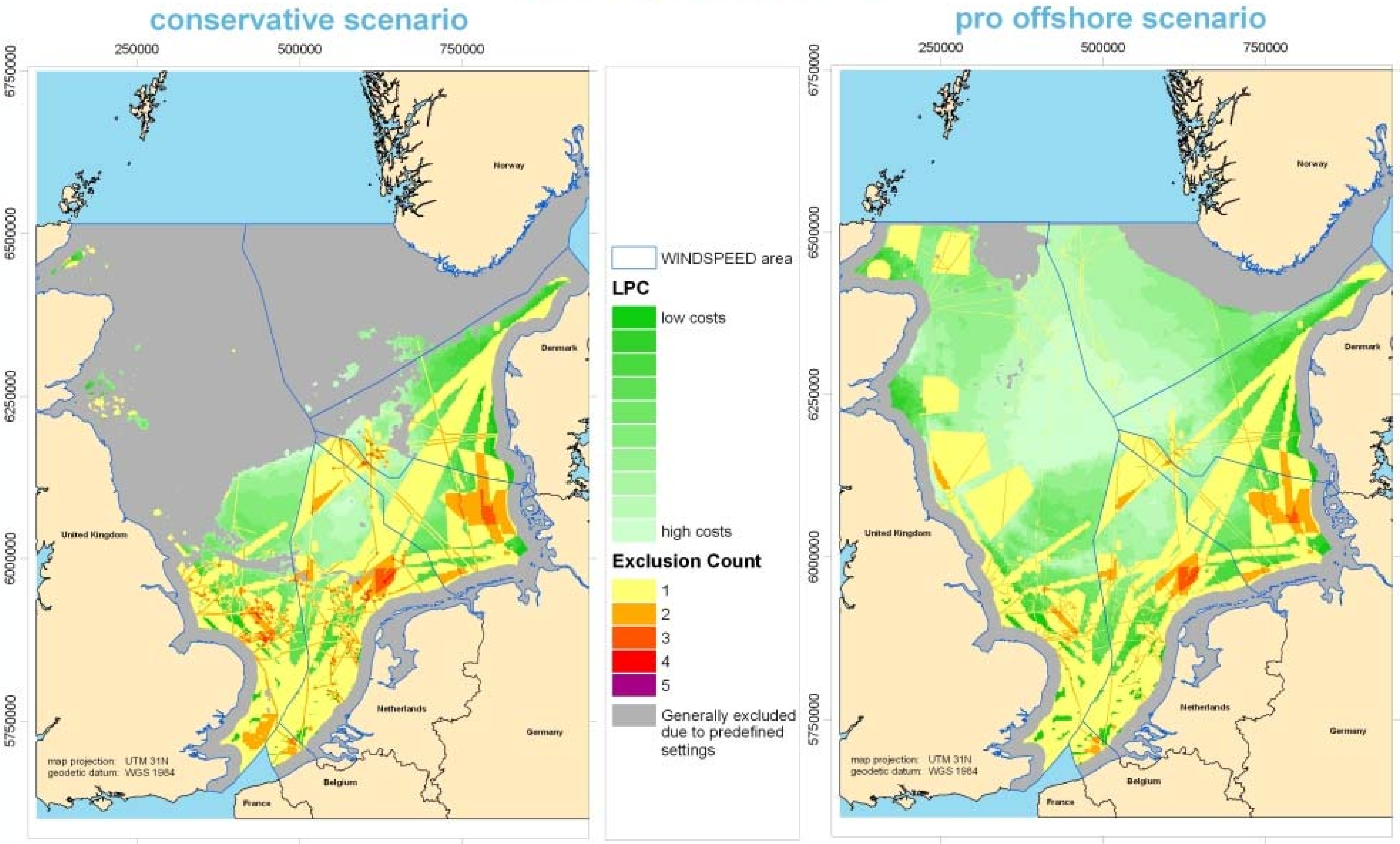
windspeed

Intelligent Energy Europe


Marine Nature Conservation Zones
Norway
Denmark
United Kingdom
Netherlands
Belgium
France
Germany
nature conservation zones
map projection: UTM 31N
geodetic datum: WGS 1984
Kilometers
map produced by DLR within windspeed
data source: National Authorities
date of map: Sep 2009
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
map projection: UTM 31N
geodetic datum: WGS 1984
Kilometers
map produced by DLR within windspeed
data source: Anatec
date of map: Sep 2009
windspeed
Intelligent Energy Europe

Example Results



Intelligent Energy Europe

map produced by DLR within windspeed
date of map: Mar 2010

windspeed