The True Task & Optimal Solutions

100% Renewable Electricity within a Trans-European Supergrid

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preliminary questions:

Is it possible to come to a totally renewable electricity supply?
(Potentials, Technology, Temporal Production Behavior)

YES

Can we afford that?
(Cost)

How could that work in an optimal case?

Utilisation of the renewable potentials for a common electricity supply interconnected within a strong international grid => affordable supply

Achieving goals of development policy & climate politics in a multilateral win-win strategy

Electricity Production with Hydropower

Storage Type

River Runoff Type

Photo source, VSE

Storage Hydro Power in Europe:

Rated Power, Storage Capacity and Annual Energy Production

Data of UCTE 1998	**Rated Power** of Reservoir and mixed pumped Storage	**Storage Capacity** of Reservoir and mixed pumped Storage	**Annual Energy Prod.** of Reservoir and mixed pumped Storage
	[GW]	**[TWh]**	**[TWh]**
Slovenia/Croatia	1,4	1,8	?
Swizerland	8,2	8,4	18,0
Serbia and Montenegro	2,0	2,0	?
Portugal	2,1	2,6	4,2
Austria	5,6	3,2	7,0
Luxemburg	0,0	0,0	0,0
Italy	7,5	7,9	17,6
Greece	1,9	2,4	2,8
France	11,6	9,8	18,2
Germany	1,4	0,3	1,1
Belgium	0,0	0,0	0,0
Spain	7,7	18,4	16,7
Sum of UCTE	**49**	**57**	**86**
Data of NORDEL			
Norway	27,3	84,1	112,6
Finland	2,9	4,9	12,6
Sweden	16,2	33,7	63,6
Sum of NORDEL	**46**	**123**	**189**
Sum of NORDEL + UCTE	**96**	**180**	**275**

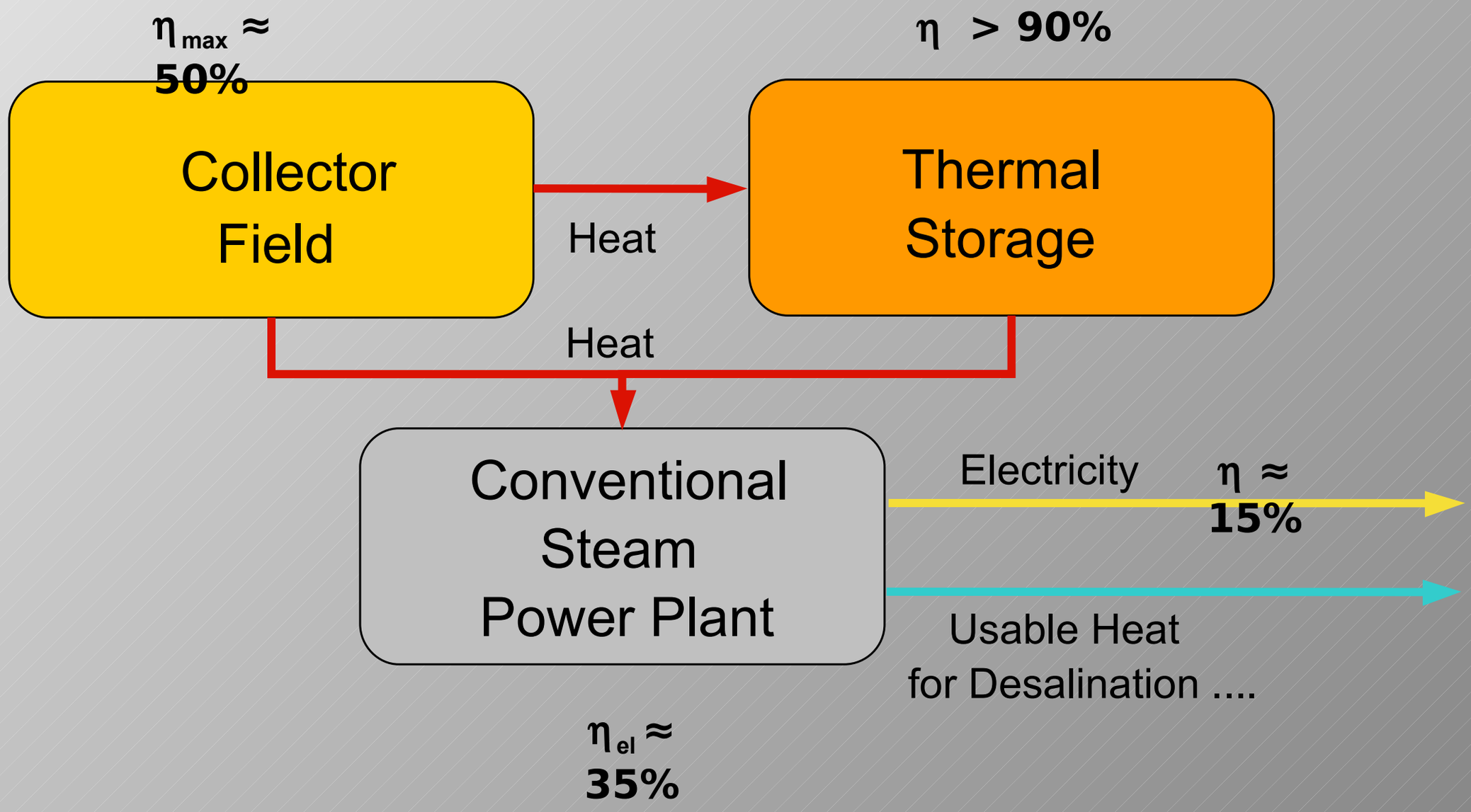
>

1 Month EU-consumption

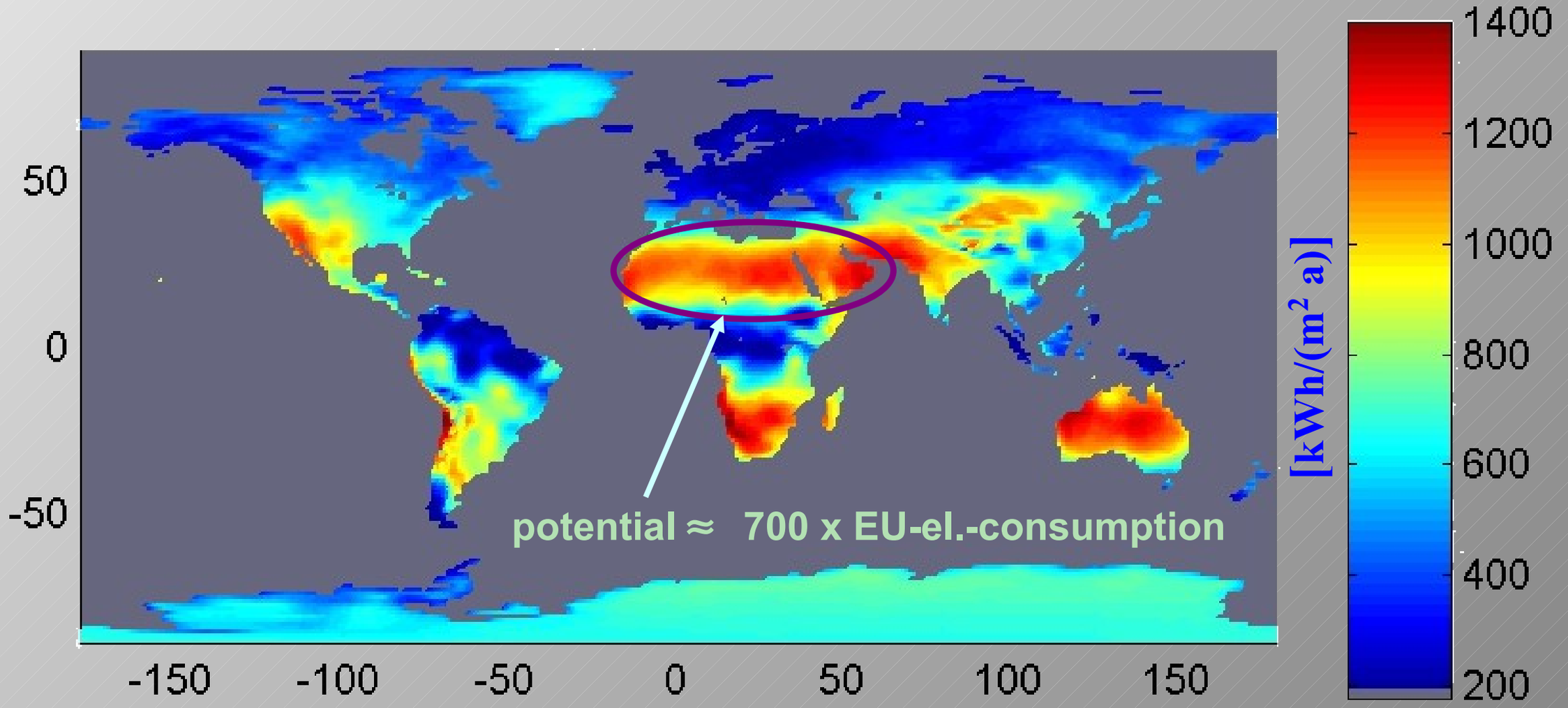
Solar Thermal Power Plant of SEGS Type

Photo source: http://www.kjcsolar.com/24bit/segs0046.jpg

Principle of a Solar Thermal Power Plant



Heat Output of Solar Fields for SEGS (Solar Thermal Power Plants)



Met.data: ECMWF and NCEP

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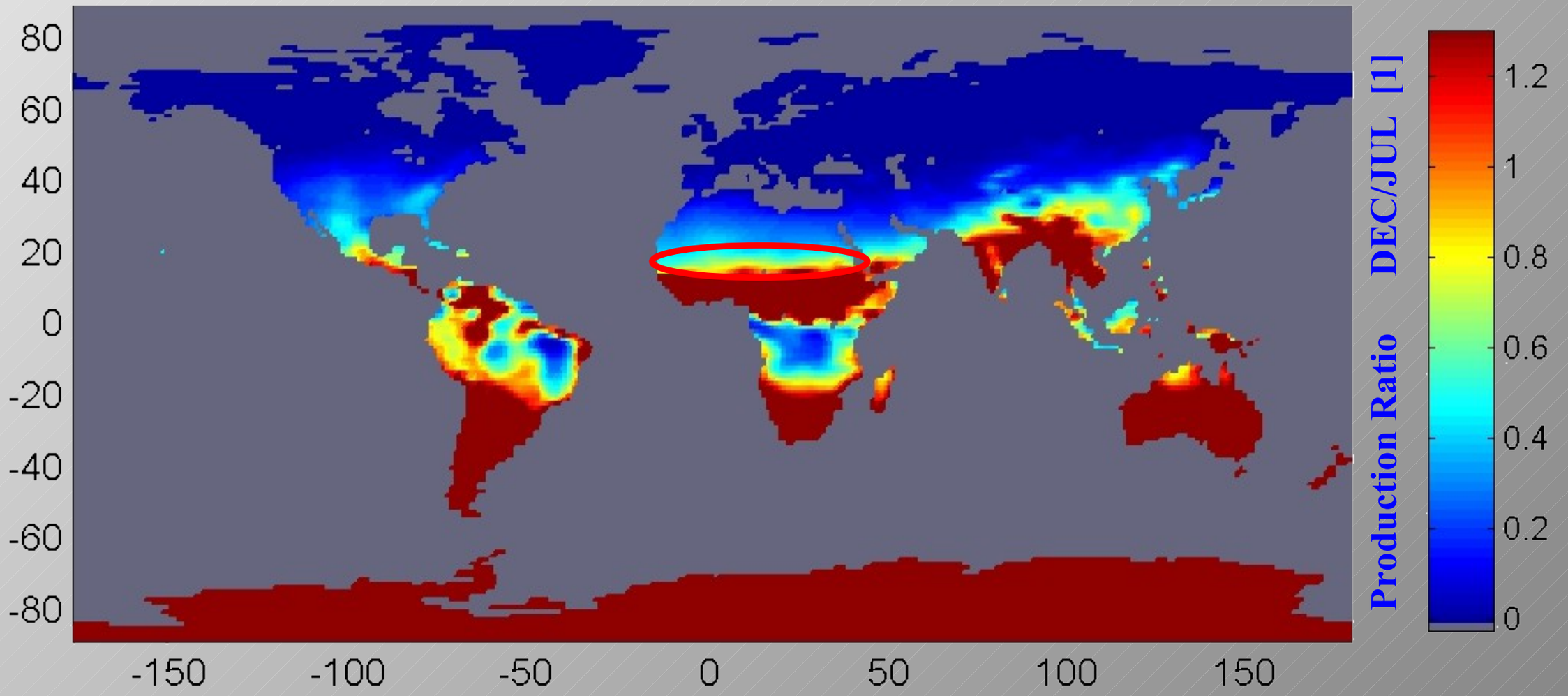
Comparison of the Average Electricity Production (DEZ ⇔ Jul) from SEGS Solar Thermal Power Plants (Monthly Mean of 10 Years)



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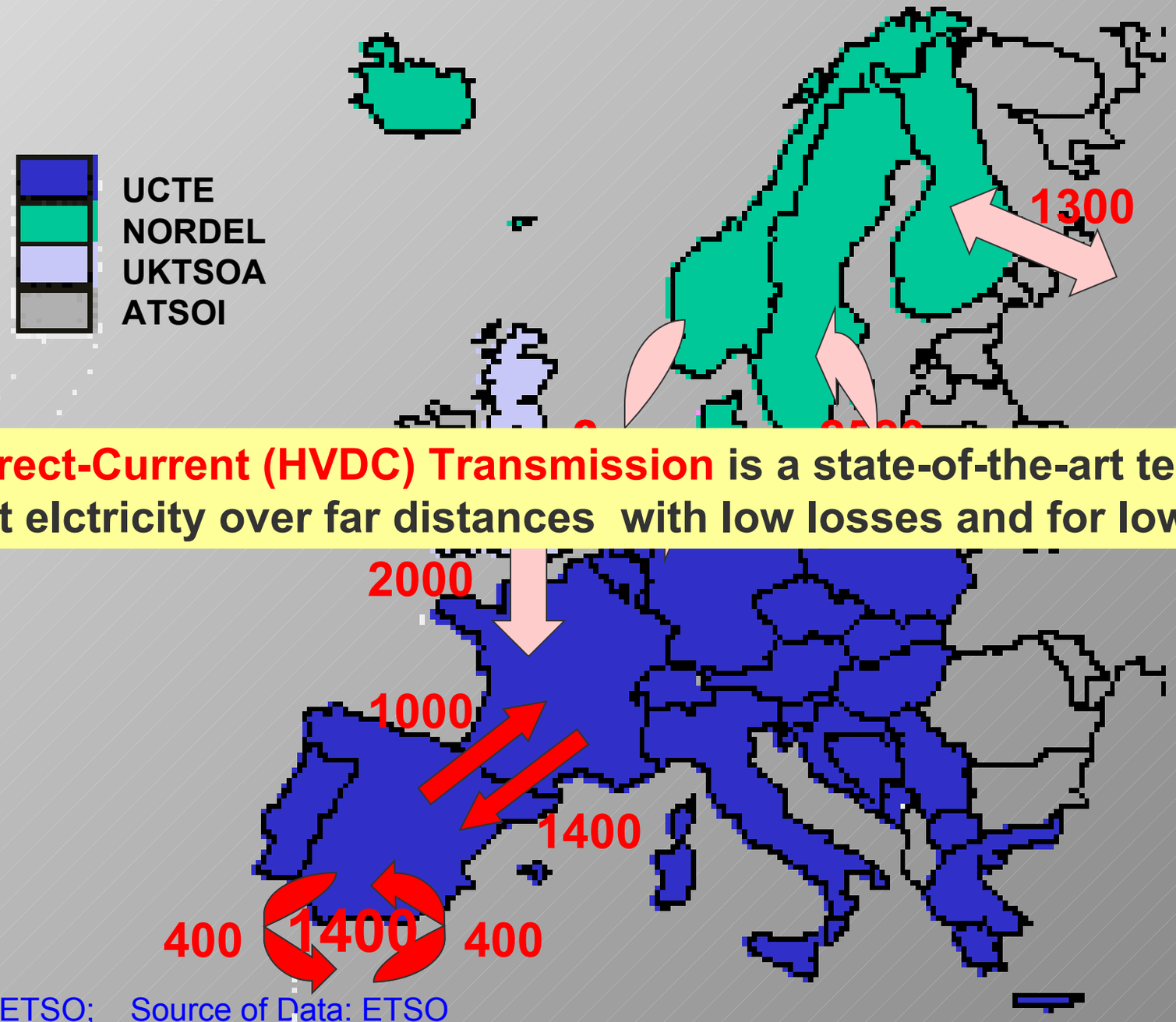
Transmission of Electricity

Photo source: http://www.nrel.gov/data/pix/searchpix.cgi

Some Estimated Maximum Net Transfer Capacities within UCTE and to its Neighbours in Winter 2004/2005 [MW]



High-Voltage-Direct-Current (HVDC) Transmission is a state-of-the-art technology able to transport elctricity over far distances with low losses and for low costs

Source of map: ETSO; Source of Data: ETSO

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Costs of Electricity Production with SEGS Solar Thermal Power Plants

Site		Iberian Peninsula	Southern Morocco	Mauritania	Brügge Belgium
Heat Production	[kWh/m^2]	610	1140	1190	300
Electrical Production (incl. 2 Weeks Revision and 97% Availability)	[FLH/a]	3000	5570	5820	1470
Cost of Electricity at each Site	[€ct/kWh]	13,9	7,5	7,2	28,4
Distance to Kassel	[km]	2500	4400	5300	500
Sea Cable Legth included	[km]	0	40	40	0
Cost of Transport	[€/(kW$_{el.}$ a)]	24	37	42	13
Losses due to Transport		6%	13%	16%	2%
Cost of Electricity in Kassel	[€ct/kWh]	15,2	9,0	9,0	29,4

SEGS Solar Power Plant	Assumptions		Costs	
Solar Mutiple	2,5			
Solar Field	185	[€/m^2]	2775	[€/kW$_{el. rated}$]
Storage Capacity	14	[FLH]		
Storage	60	[€/kWhel]	840	[€/kWel. rated]
Thermal Power Plant	525	[€/kWel]	525	[€/kWel. rated]
Total Investment (I)			4140	[€/kWel. rated]
Live Time	25	[a]		
O & M Costs	2%	[% $_{Investment}$/a]		
Insurance Costs	1%	[% $_{Investment}$/a]		
Interest	5%	[%/a]		
Annual Costs			418	[€/(kWel. rated a)]
η Power Plant	37%	[%]		
η Storage	92%	[%]		
El. Production using Stora	70%	[%]		

HVDC-System	Assumptions	
Rated Power	5	[GW]
Voltage	+-600	[kV]
Kind of HVDC Converter		Double Bipol
HVDC Converter Station [Häusler 1999]	2 * 60	[€/kWel. Nennl.]
Overhead Line [Häusler 1999]	70	[€/(kW*1000 km)]
Seekable	700	[€/(kW*1000 km)]
Live Time	25	25 a
O & M Costs	1%	[% $_{Investment}$ /a]
Interest	5%	

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Wind Energy

Photo source: http://www.nrel.gov/data/pix/searchpix.cgi

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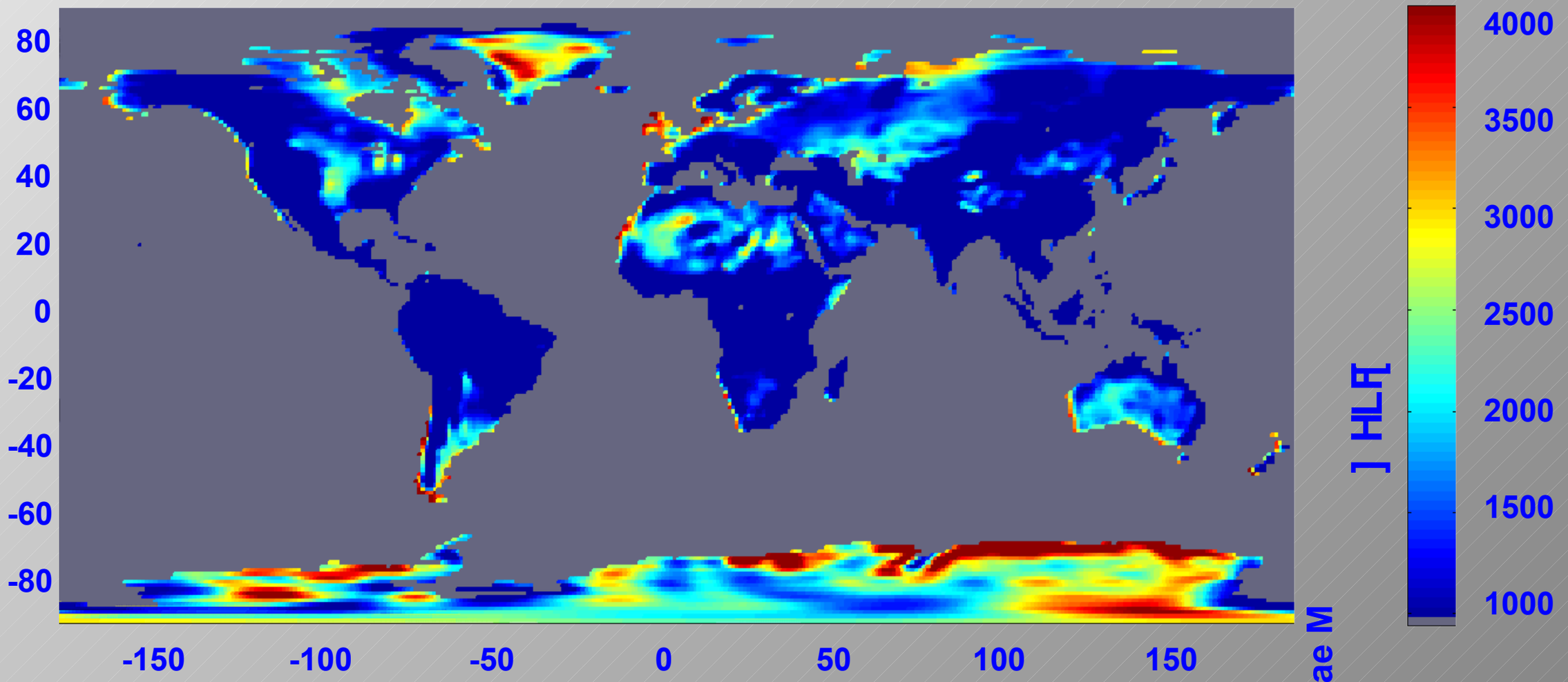
Mean Annual Production of 1.5 MW Variable Speed Wind Turbines (HH = 80 m) in Full Load Hours [FLH]



Meteorological data: ECMWF, ERA-15, 1979-1992

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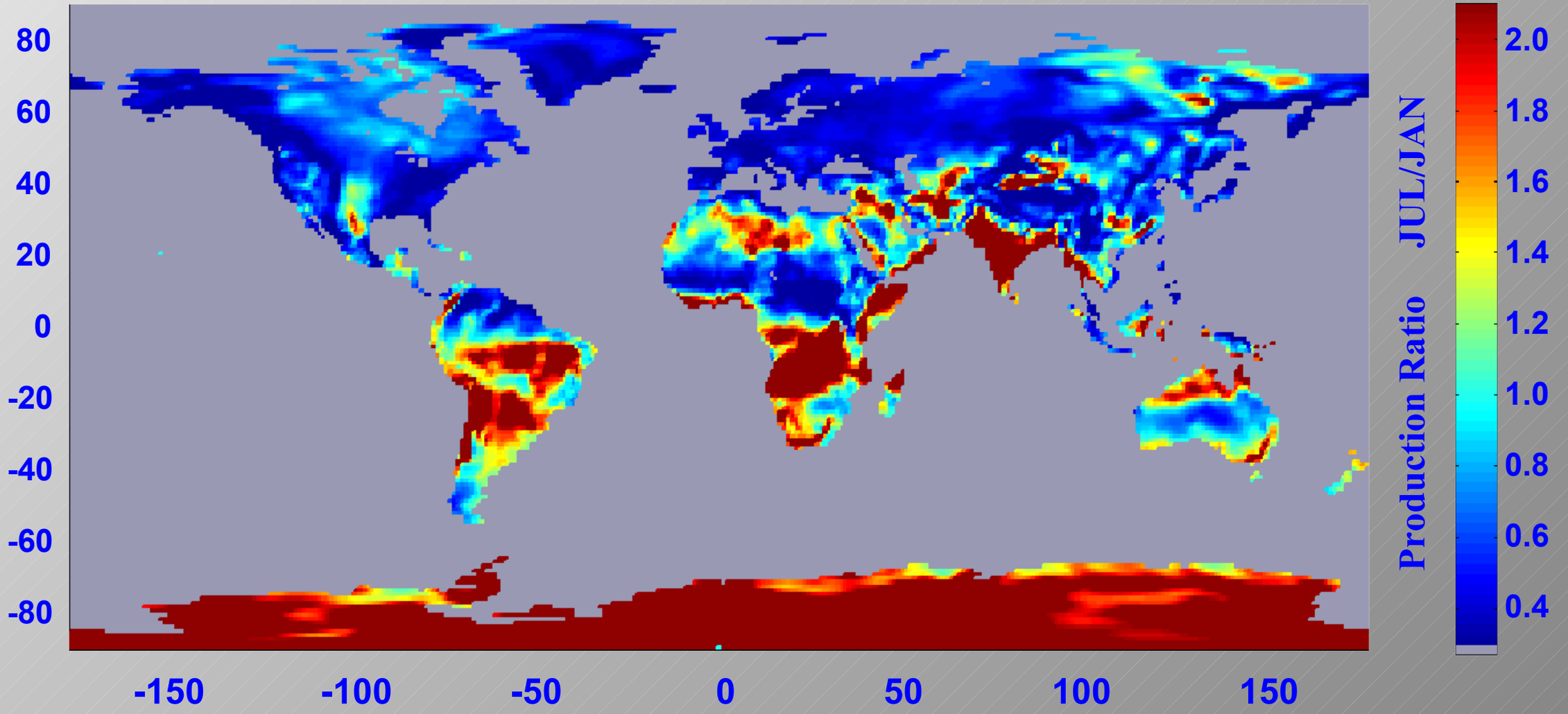
Comparison of the Average Electricity Production (Jul ⇔ Jan) from Wind Energy (Monthly Mean of 15 Years)



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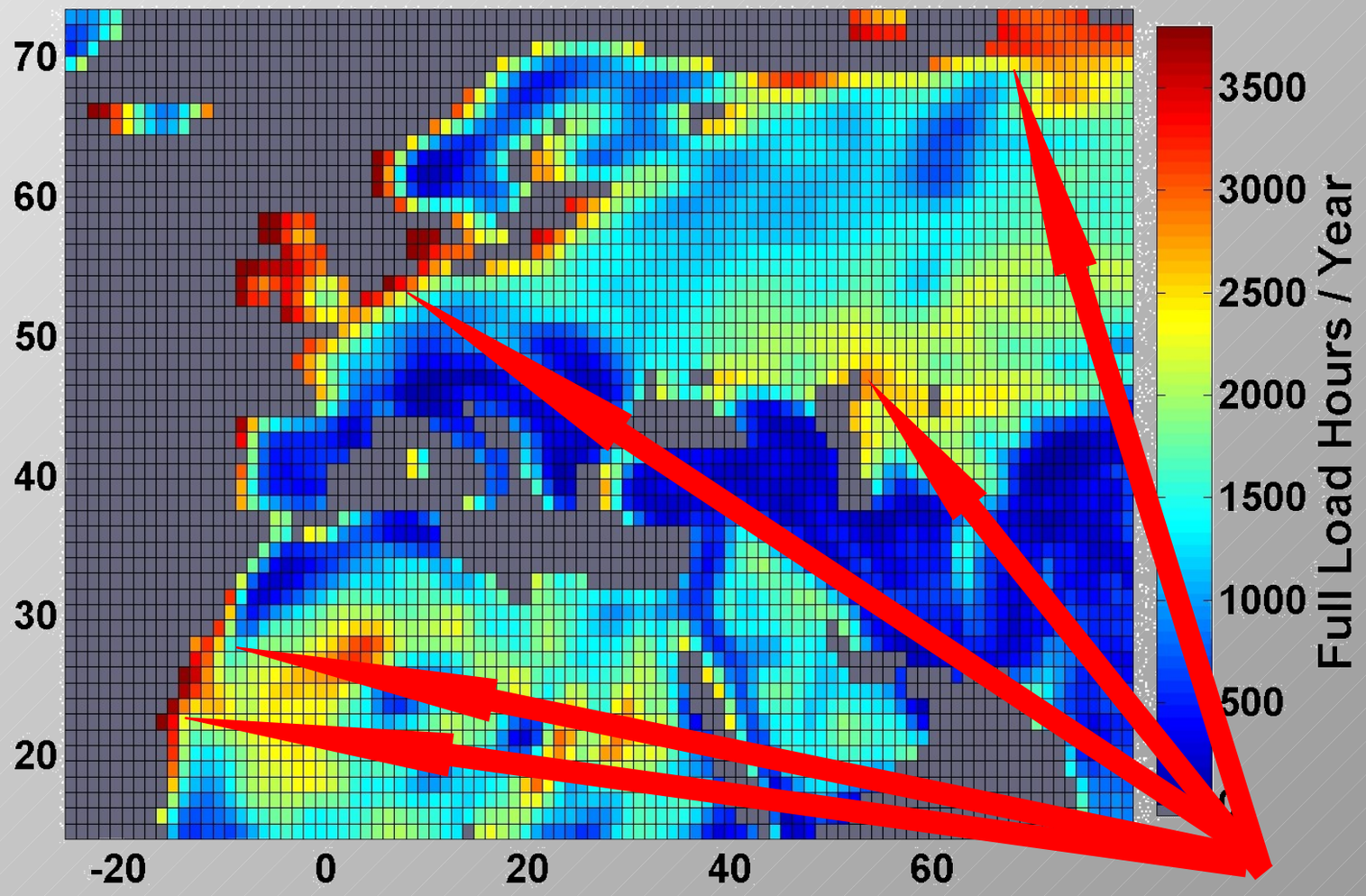
Mean Annual Production of 1.5 MW Variable Speed Wind Turbines (HH = 80 m) on Land Sites in Europe and its Neighbourhood



Electricity Demand 1998

UCTE & NODEL:

2100 TWh

Potential Wind Energy Prod. on land sites with more than 1500 FLH

at 4 – 8 MW/km²:

120 000 – 240 000 TWh

Mean Prod. at this sites: 2050 FLH

Take the best: => 0.4% of the area for 4000TWh

Iceland & Greenland & West Siberia

3500 FLH

4000 TWh

At 2.4 MW/km²

Meteorological data: ECMWF, ERA-15, 1979-1992

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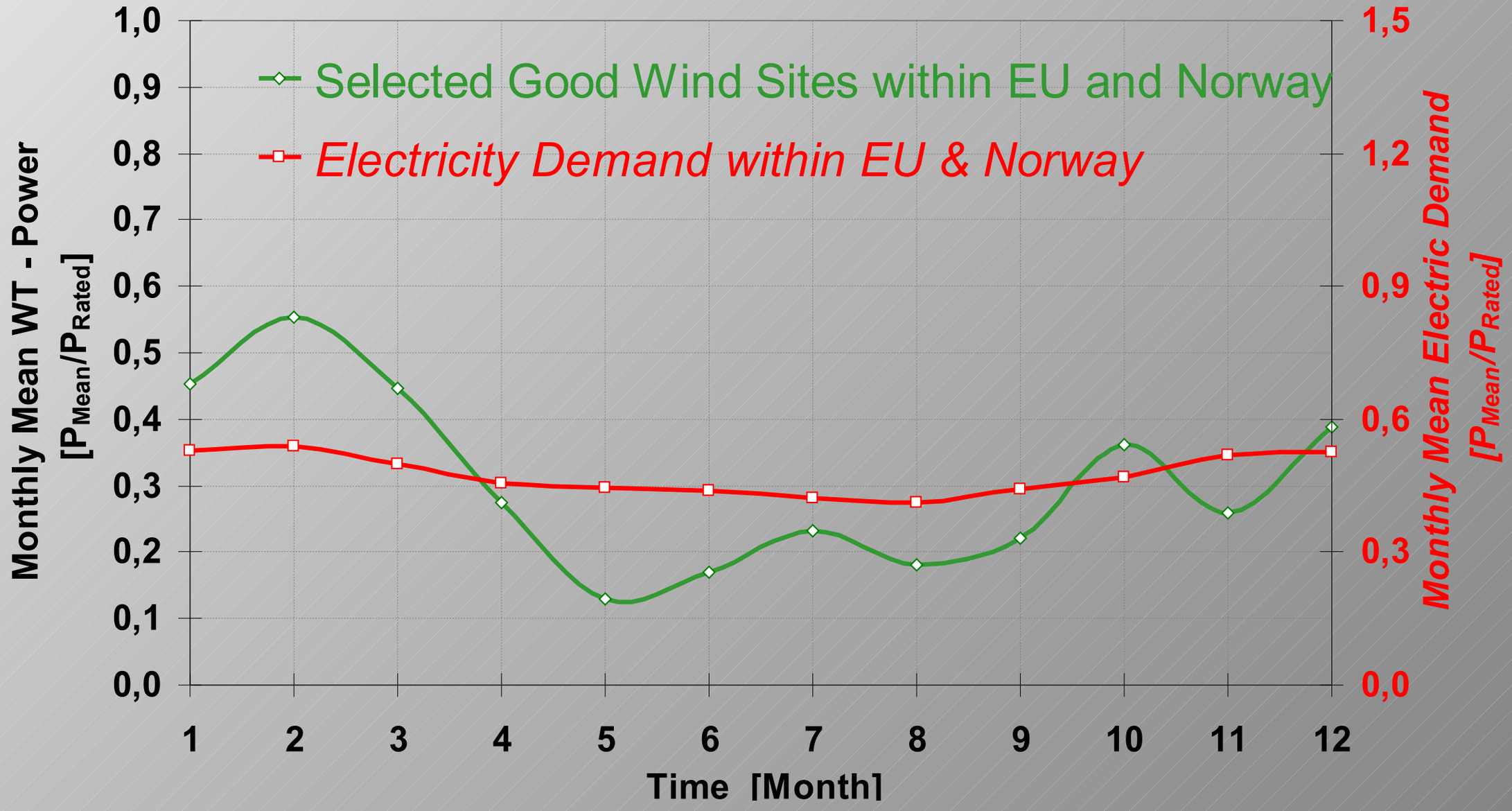
Monthly Mean Electricity Production of Wind Power within Selected Favourable Regions at Land Sites and Electricity Demand



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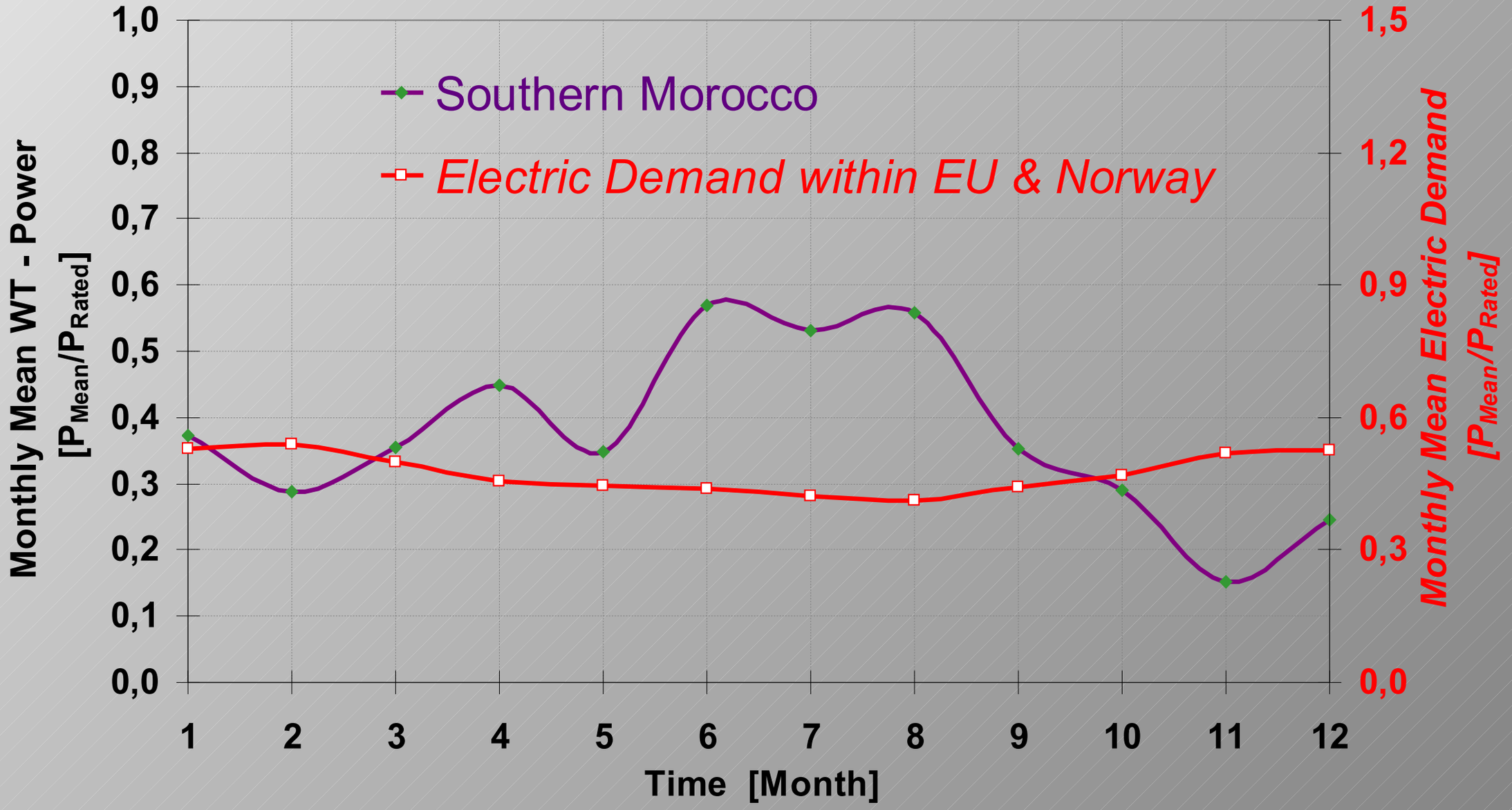

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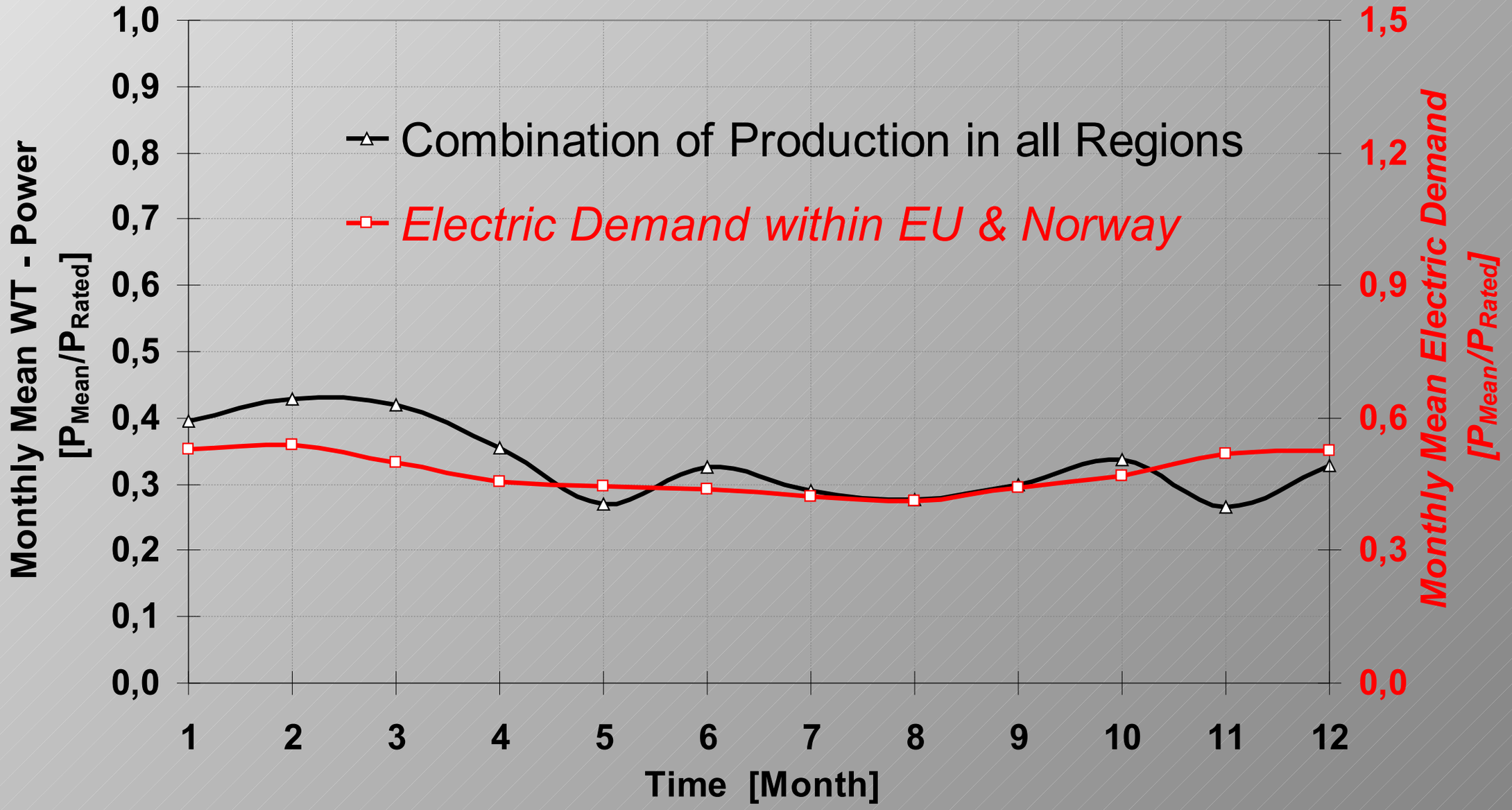

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Potential Common Electricity System

HVDC-System

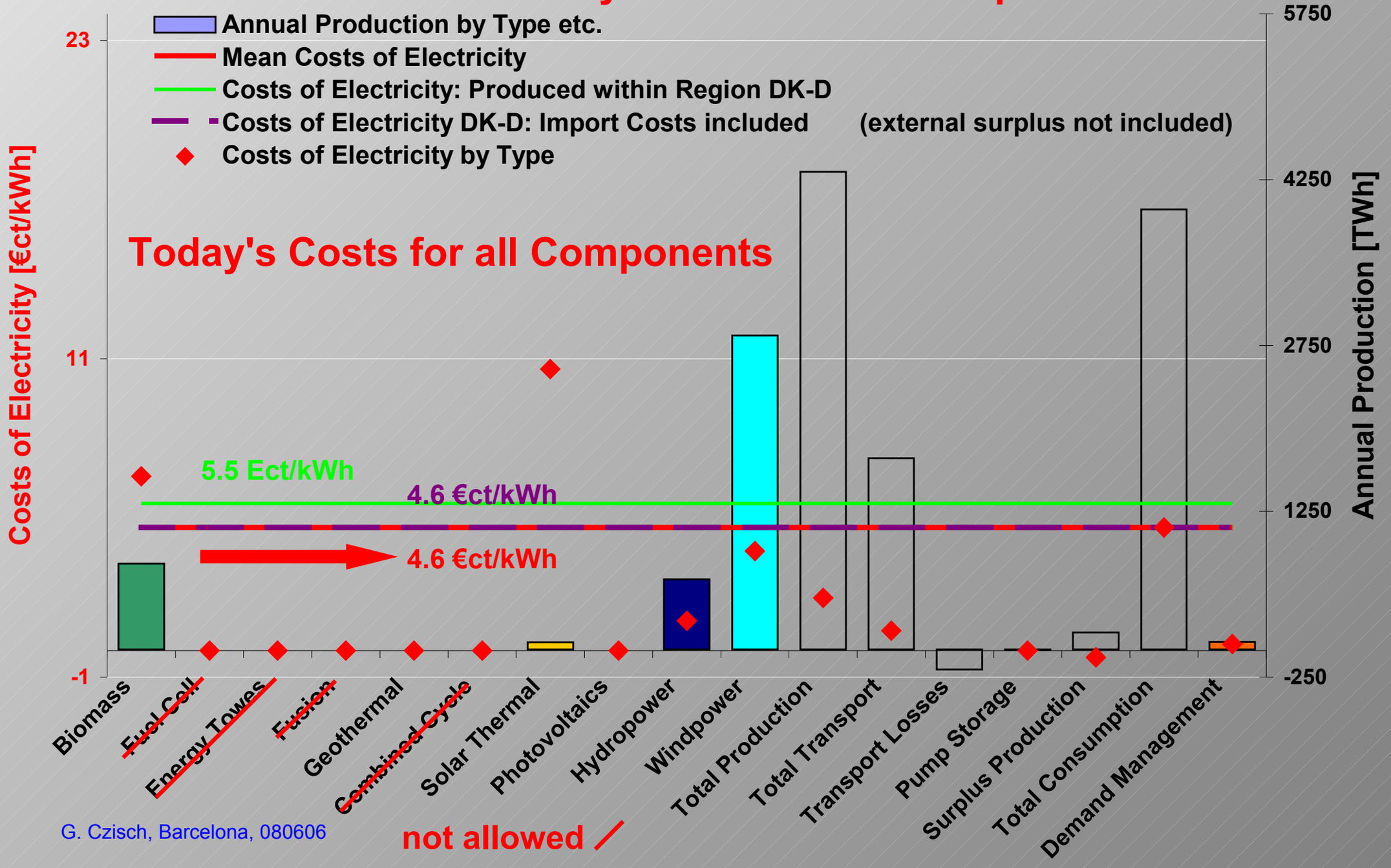
Population
1.1 billion Inhabitants

Electricity Consumption
4000 TWh/a

Largest Distance
8000 km
(Northwest-Siberia ⇔ South-Mauritania)

Annual Electricity Production by Type with Collective Demand, Transport, Surplus and Costs of Electricity

Base Scenario: Today's Costs for all Components



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Cost of Electricity (CoE) for Base Scenario (BS) and National Economies

- **Cost of Electricity Production in Base Scenario**
  (including: Production, HVDC Transmission and Storage)
  CoE ≅ 4.6 €ct/kWh

- **Relation of Costs to National Income of EU-15 & Norway**
  Σ CoE ≅ 1.1 % of GDP

- **Today's Expenses for Electricity ≅ 2.2 % of GDP (Germany today > 3%)**

- **Thereof for Production ≅ 0.8 % of GDP**

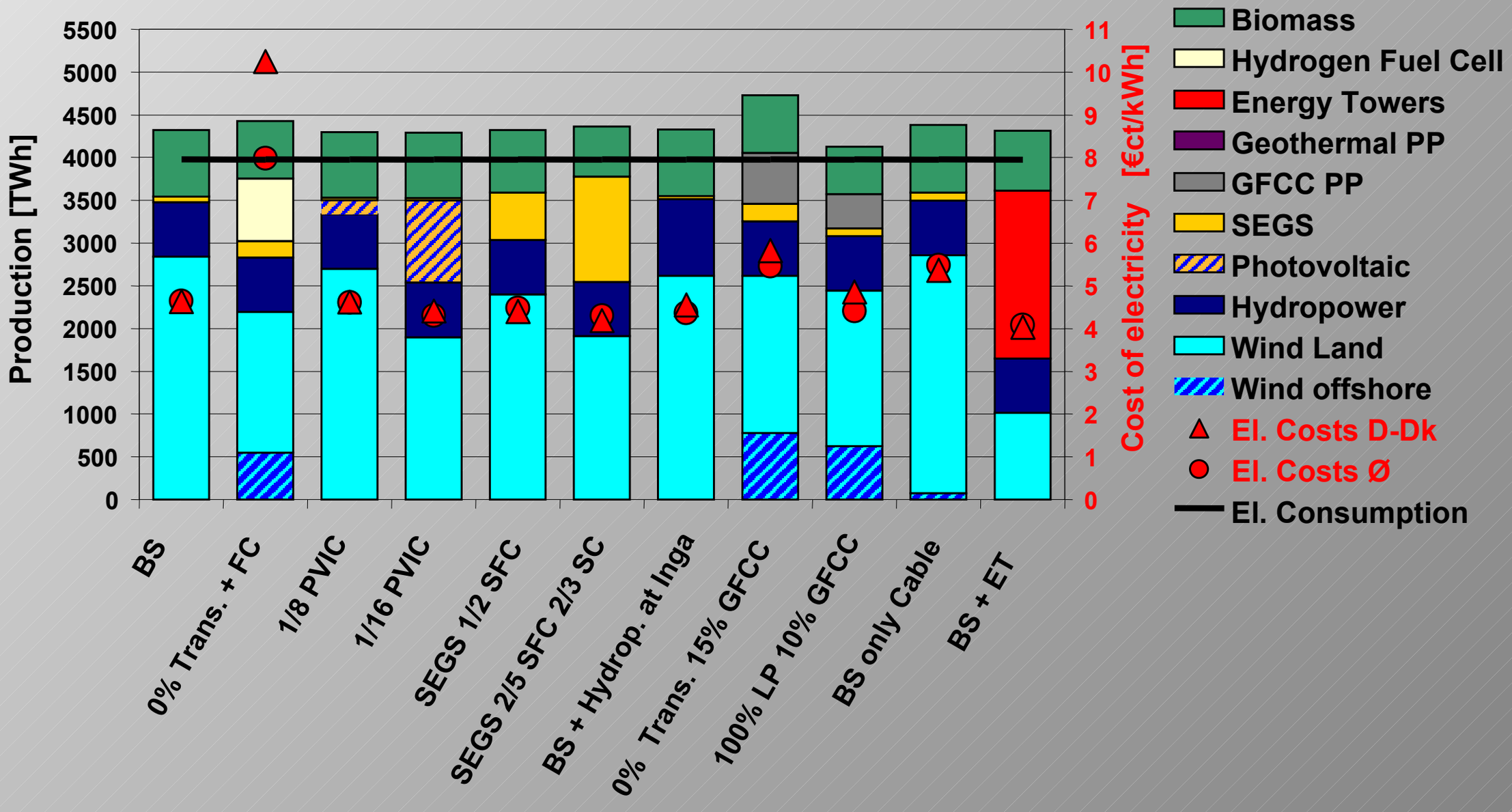
- **Costs difference BS ⇔ Today ≅ 0.3 % of GDP**

- **Further Progress in Renewable Technology => Cost Reduction > 30%**

- **=> A future renewable electricity supply could produce cheaper electricity than our current conventional system.**

- **Prices at EEX: German-Baseload-Cal-07 already exceeded 6 €ct/kWh**

Annual Electricity Production by Type, und Costs of Electricity
different Scenarios



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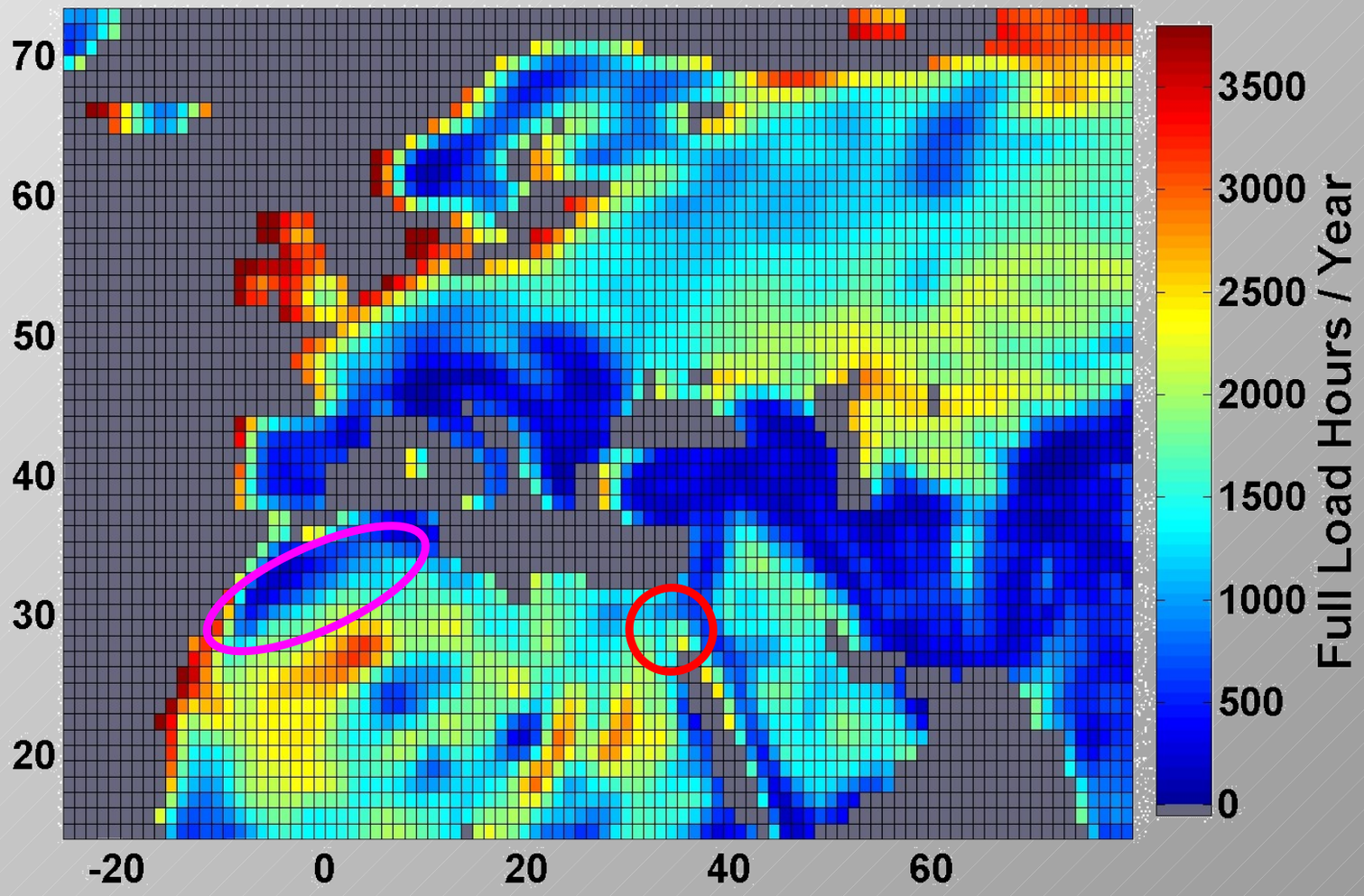

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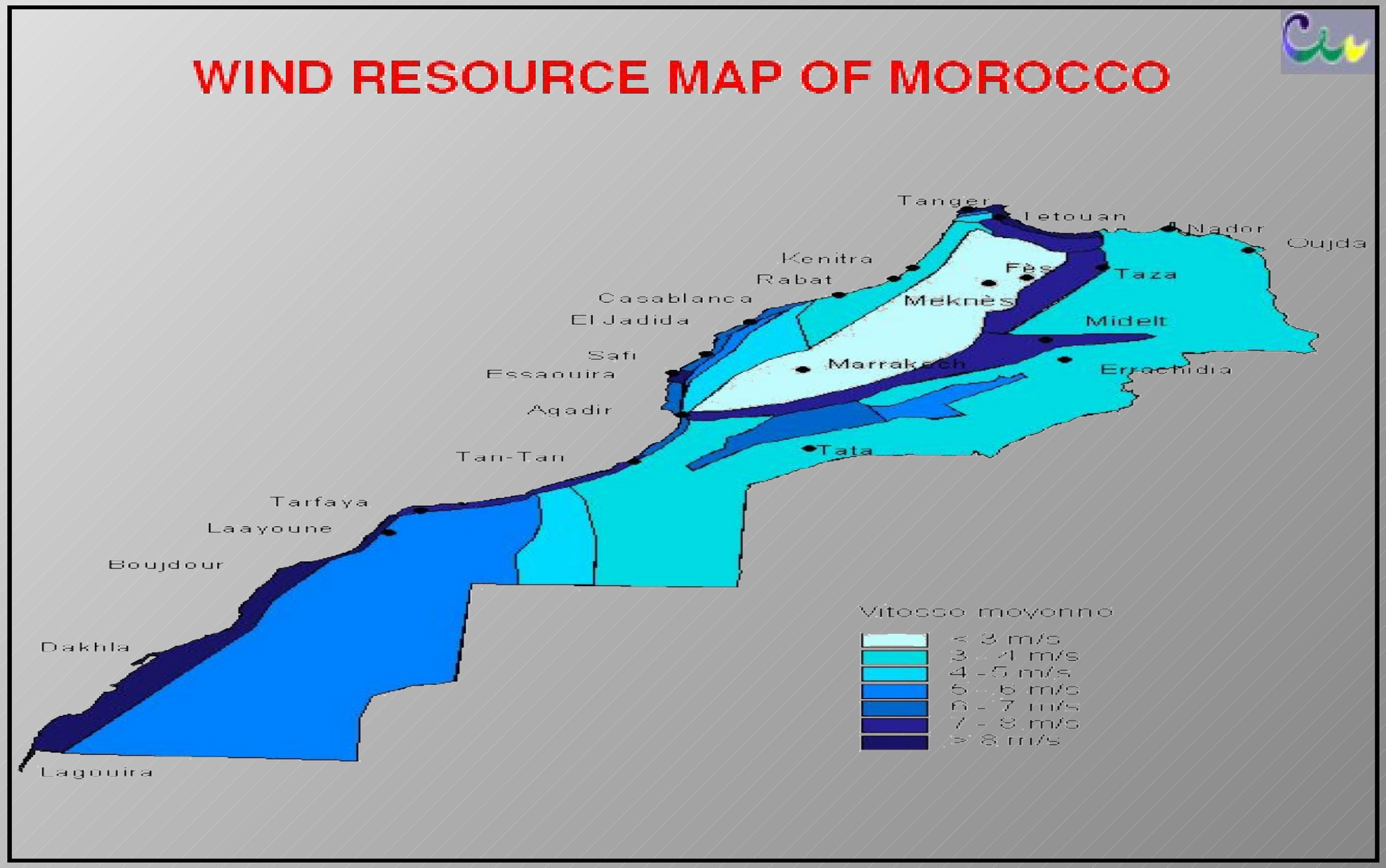
Moroccan Wind Potentials (wind speed [m/s] 10 m above ground?)



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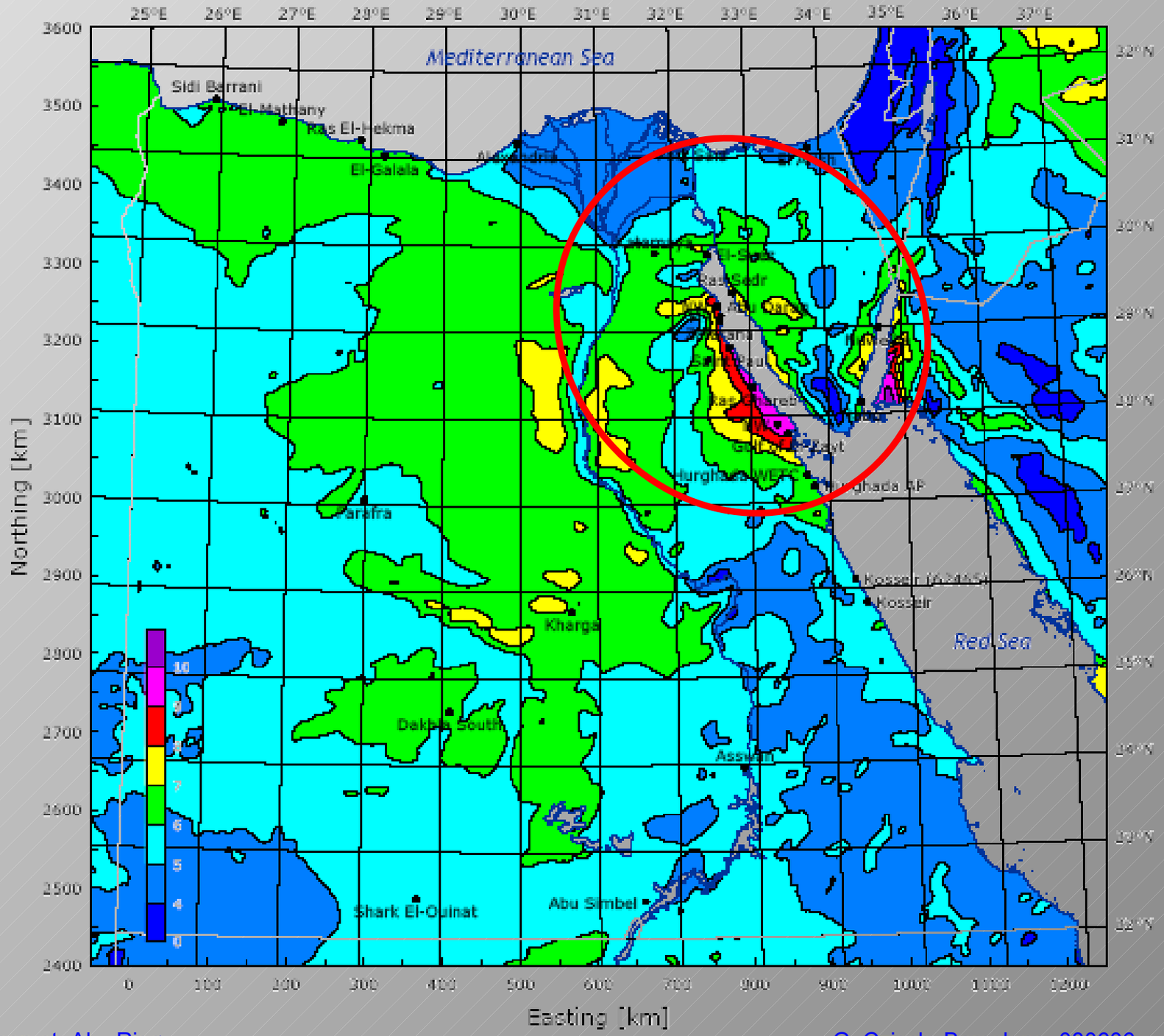
Wind Atlas for Egypt (wind speed 50m above ground [m/s])



Source: Mortensen et. Al. , Risø

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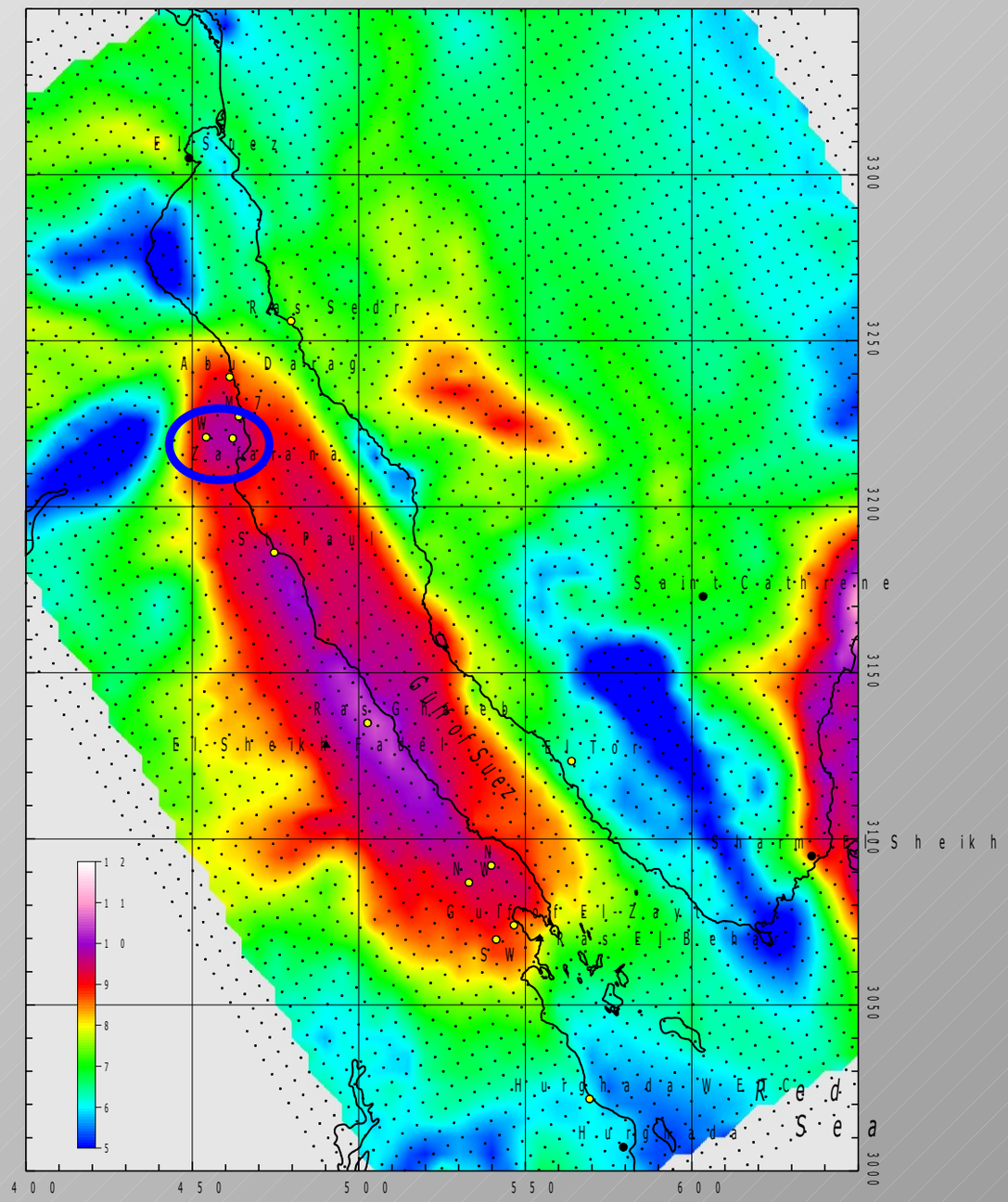
Gulf of Suez – Wind resource (calculated by Risø National Laboratory)



- KAMM/WAsP Mesoscale modelling
  - domain rotated 30°
  - 60 x 81 grid points
  - 5 km grid point spacing
  - 28 vertical levels from 0 to 6000 m a.s.l.
- Climatological data
  - NCEP/NCAR reanalysis data from 1965-98
- Current wind farm: Zafarana

Map and Explanation: Niels Gylling Mortensen and Gregor Giebel, Risø

Current Zafarana wind farm

Wind farm built 2002

Danida/KfW support (soft loans 3% over 15 years)

60 MW of Nordex turbines (picture from Nordex-online)

4570 Full Load Hours

Still more than 1000€/kW investment cost

Tariff paid = 2.9 USc/kWh leads to IRR = 5.36%

This is without CO_2 value

10$/t$CO_2$ leads to IRR = 9.5%

Numbers from UNEP Collaborating Centre at Risø
(download from uccee.org/WindCDM)

Return on equity 19% with CDM at 2 – 10 US$/tCO2 => 21 – 29%

Cost Calculation for Electricity Production and HVDC Transmission

Example **Morocco Germany**

Financing

return on equity	19%
equity ratio	0%
debt interest rate	5,0%

2,9 €ct/kWh **at production site**

4,5 €ct/kWh **with transport**

Examples	Offshore for Switzerland	Morocco Germany	Egypt Germany
Production [FLh/a]	**3500**	**3400**	**5000**
Investment Wind Park [€/kW]	**2000**	**1000**	**1000**
Distance [1000km]	**1,0**	**4,4**	**4,8**
Transmission Losses	**3,0%**	**10,4%**	**16,3%**

Wind Park		HVDC		Wind Park + HVDC	
Production [FLh/a]	**3400**				
		Investment HVDC			
Investment [€/kW]	**1000**	Converter [€/(2*1kW)]	120		
		Distance [km]	**4,4**		
		Investment overhead			
		line [€/kW]	308		
		Losses	**10,4%**		
Capital Return	5,0%	Capital Return	5,0%		
Calcul. Lifespan [a]	20	Calcul. Lifespan [a]	25		
Annuity	8,0%	Annuity	7,1%		
O&M [% of IV/a]	2,0%	O&M [% of IV/a]	1,5%		
O&M costs [€/kW/a]	20	O&M costs [€/kW/a]	6,4		
Annual Costs		Annual Costs		Annual Costs	
[€/(kW a)]	100	[€/(kW a)]	36,79	[€/(kW a)]	137
		without losses		**without losses**	
Production Costs		Costs of Transmission		Costs of Electricity	
[€ct/kWh]	2,95	System [€ct/kWh]	1,08	[€ct/kWh]	4,03
		with losses		**with losses**	
		Total Transmission		**Total Costs of**	
		costs [€ct/kWh]	1,55	**Electricity [€ct/kWh]**	4,499
				Total Costs of Losses	
				[€ct/kWh]	0,47

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Expected impact and development prospects of a wind energy cooperation between Morocco and the EU

Assumption: In Morocco, 10% of EU electricity consumption are produced from wind energy for export to Europe.

- **This electricity production for the EU corresponds to roughly 16 times the of today's Moroccan electricity consumption.**
- **This would demand for roughly 5% of the Moroccan wind potential.**
- **The total investment in WTC would only be about 0.8% of the EU GDP.**
- **The total investment in WTC is roughly equivalent to 200% of the Moroccan GDP.**
- **This option would open up completely new development prospects.**
- **In Morocco it could be generated an economic growth in the high single digit percentage range over many years.**
- **Since the production of large parts of the wind turbines are relatively easy it can be expected that the vertical range of manufacture in Morocco soon would receive a high level and thereby the dramatic unemployment could quickly be reduced.**

Summary and Conclusion

- There are enough renewables for all needs.
- The bigger the catchment area the better temporal behaviour.
- Backup and storage are existent.
- The grid must be reinforced.
- Costs for backup and HVDC – lines would not dominate.
- Also the cost of electricity of a fully renewable electricity supply would be quite reasonable.
- Now politics and economy are responsible, now they must act!

- For Europe the investment in renewable energies offers an interesting combination of climate protection and development strategy.

EU Feed in Law with Special Tariffs for Renewable Electricity from Neighbour Countries

Possible Strategy for a Large Scale Implementation

Example: Production of Wind Power in S-Morocco (conservative 3400VLh)

Phase 1 up to 1 GW (limiting factor capacity of Moroccan electricity system)

- **cost of electricity from wind power (economic assumption) < 3€ct/kWh**
  IR=5%/a, life time=20a, O&M=2% of Invest./a
- **cost of electricity from wind power (business assumption = BA)**
  20% return on equity 30% equity **< 4 €ct/kWh**
- **value of CDM (20 €/tCO2, 0,6 kgCO2/kWhel) ca. - 1.2 €ct/kWh**
- **market price of electricity from wind power - 2.0 €ct/kWh**
- **remainder covered by feed in tariff 0.8 €ct/kWh**

Phase 2 up to 5 GW (feed in via HVDC in existing net of South Spain)

- **costs for HVDC-line inclusive losses for BA <1,2 €ct/kWh**
- **remainder covered by feed in tariff 2.0 €ct/kWh**

Phase 3 more than 100GW technically possible
(feed in via different HVDC systems to many different points within the UCTE-Network)

- **costs for HVDC-lines inclusive losses for BA <1,8 €ct/kWh**
- **remainder covered by feed in tariff 2.6 €ct/kWh**

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