GIFT workshop
Geosciences Information for Teachers Workshop
EGU, Vienna, Austria, 2-5 May 2010

Wind energy

Charlotte Bay Hasager

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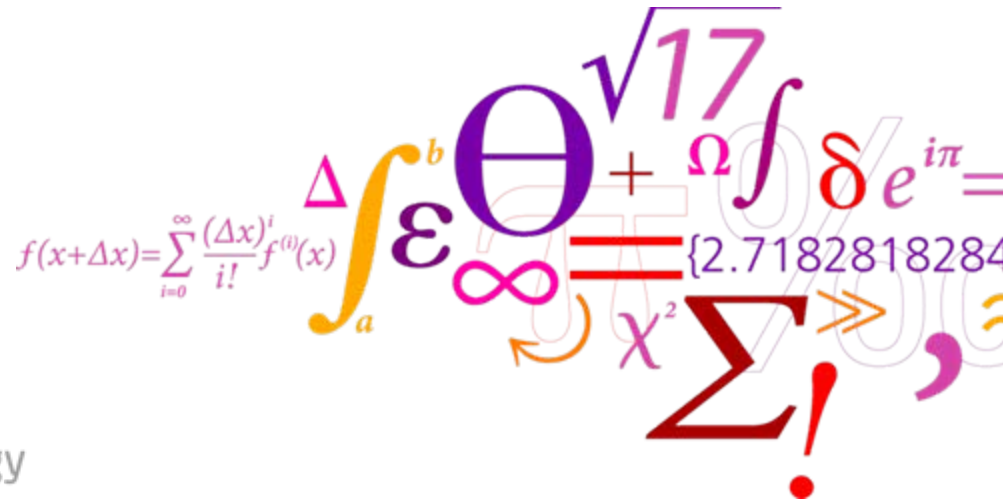
Denmark

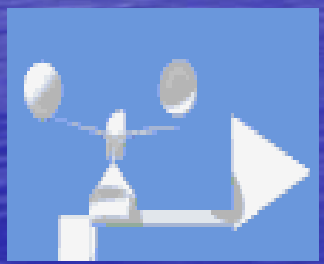


Risø DTU
National Laboratory for Sustainable Energy

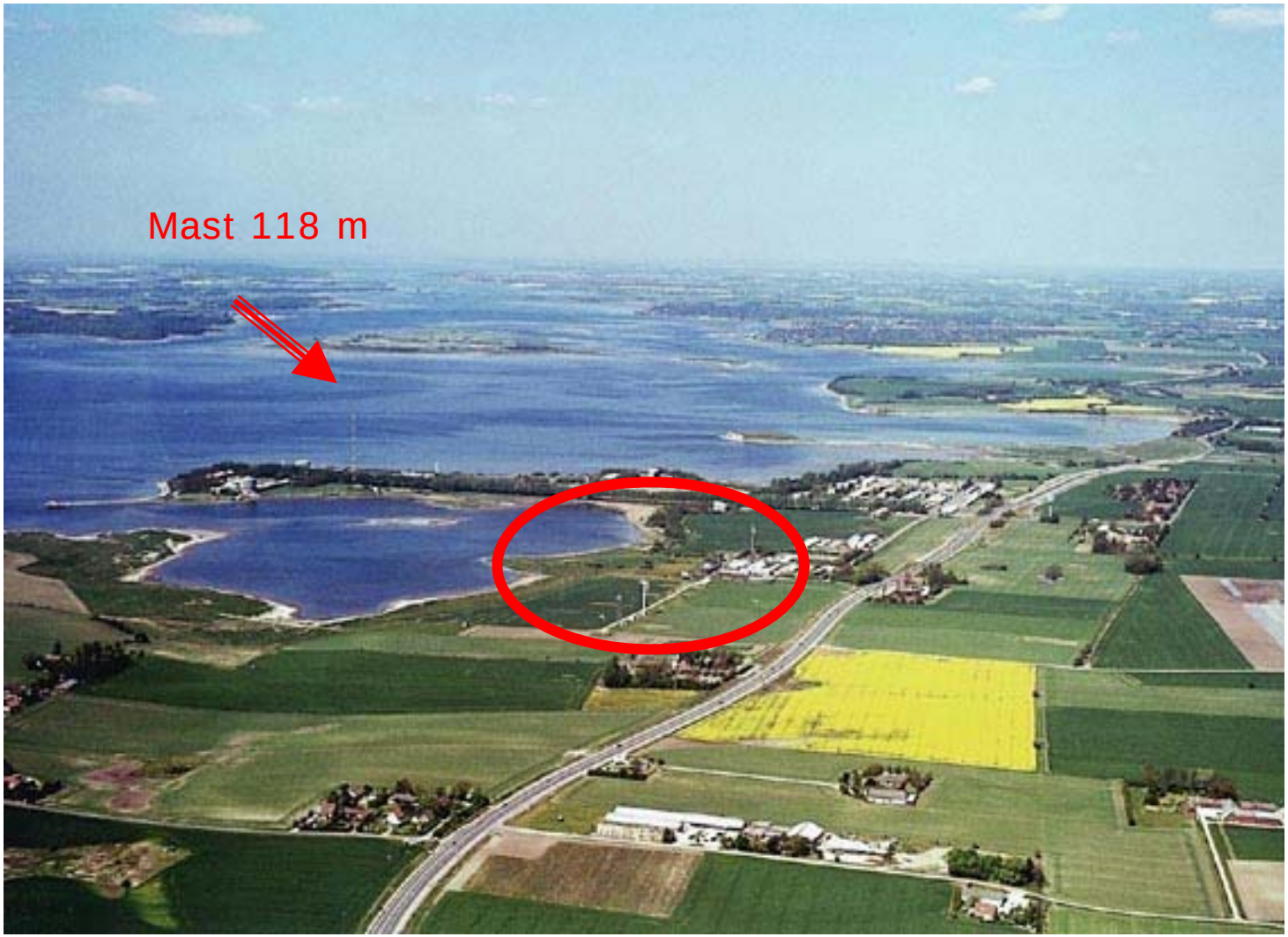
What are your first thoughts on wind energy?

Content

- Wind
- Wind farm
- Statistics



Risø DTU



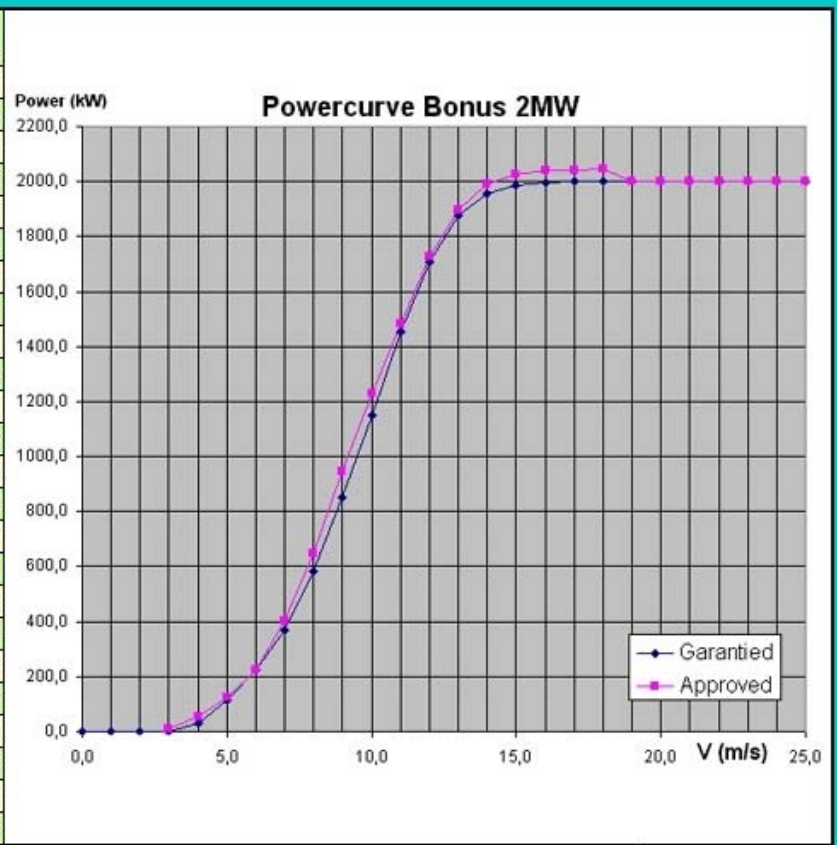

160 m tall mast
Risø DTU

testing power curves

Power Curve
The power curve shows how much the wind turbine can produce at a certain wind speed. The turbine starts the production at a wind speed of 3-4 metres per second and reaches maximum output at about 14 m/s.

Two power curves are shown. The guaranteed and the approved power curve. The guaranteed power curve is given by Bonus. The approved power curve is measured when the turbine got the A-certificate and gives a calculated production, which is 5,7% better than guaranteed.

Wind	Power, guaranteed	Power, approved
[m/s]	[kW]	[kW]
0	0.0	0.0
1	0.0	0.0
2	0.0	0.0
3	0.1	9,6
4	29.1	55,4
5	113.7	126,8
6	225.2	224,4
7	366.3	400,9
8	582.0	647,3
9	852.5	945,1
10	1151.4	1227,6
11	1451.2	1484,0
12	1707.5	1729,2
13	1875.2	1898,4
14	1956.2	1992,1
15	1986.6	2025,2
16	1996.2	2040,5
17	1999.0	2042,7
18	1999.7	2044,6
19	1999.9	2000.0
20	2000.0	2000.0
21	2000.0	2000.0
22	2000.0	2000.0
23	2000.0	2000.0
24	2000.0	2000.0
25	2000.0	2000.0



Production Guaranteed (freestanding turbine):	**5,280.0 MWh**
Production Approved (freestanding turbine):	**5,581.2 MWh**
Difference:	**5.70%**

Estimated electricity production (to top)
The annual production of the wind farm is estimated to be 99,000 MWh. The guarantied production is 89,000 MWh per year. The farm efficiency is estimated to be 93.3%.

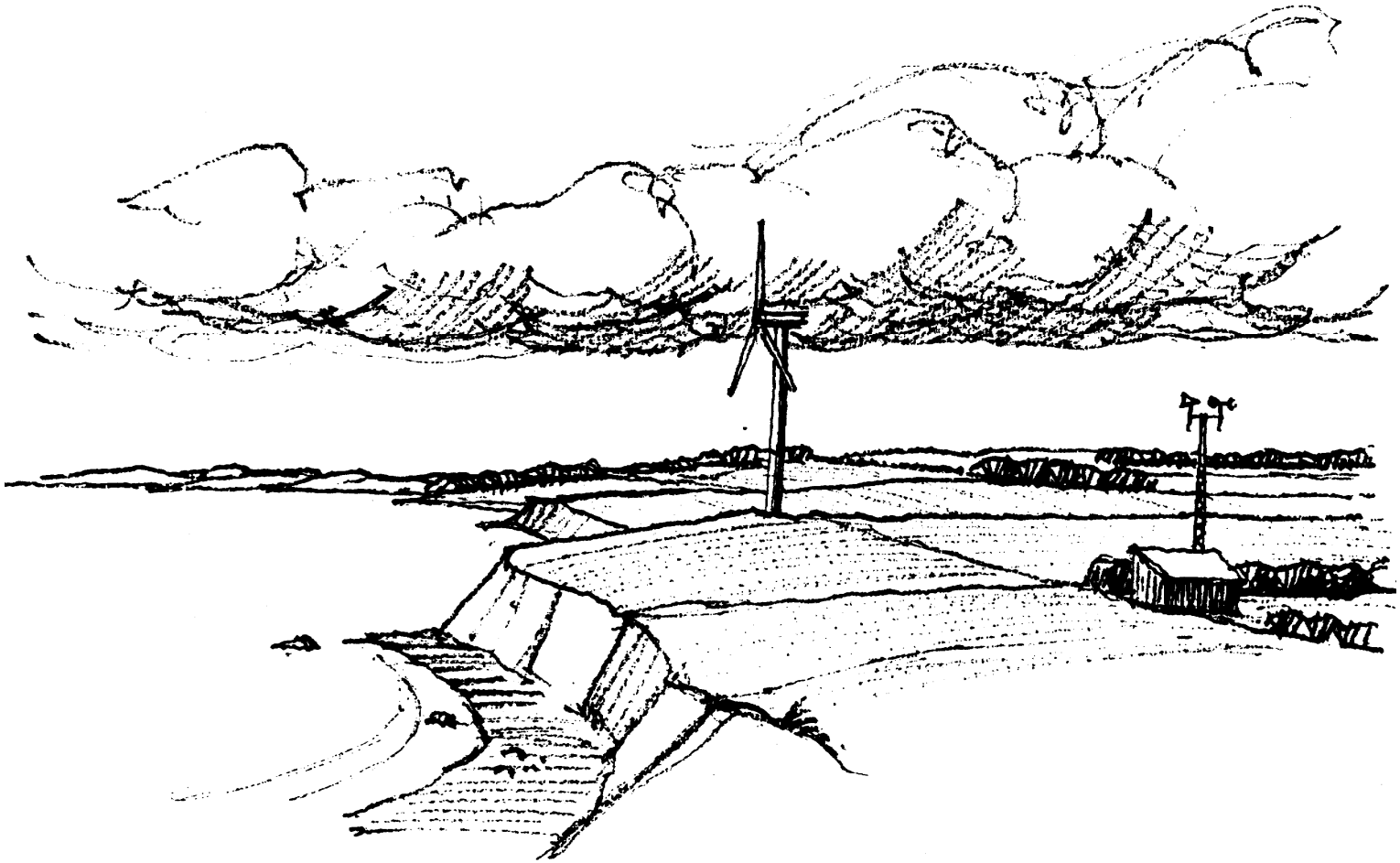
DTU

Power curve

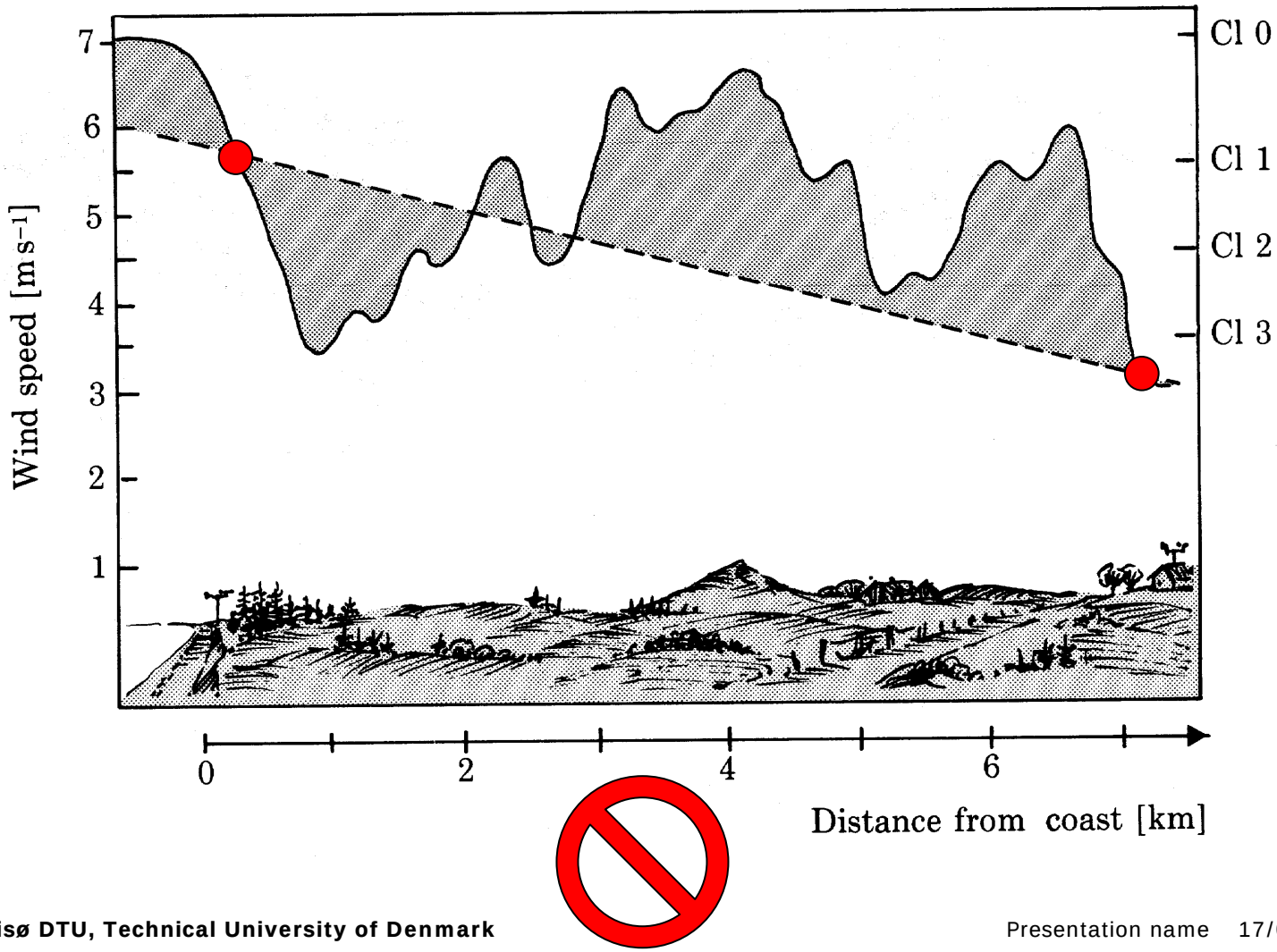
2MW wind turbine

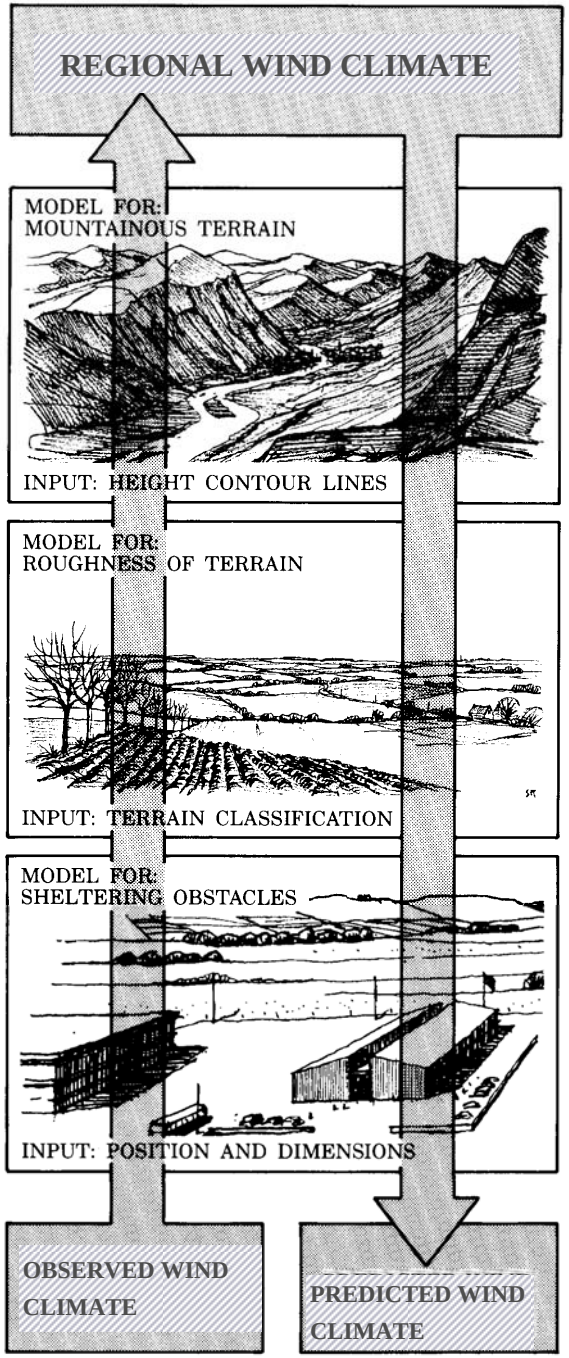
Middelgrunden

The problem

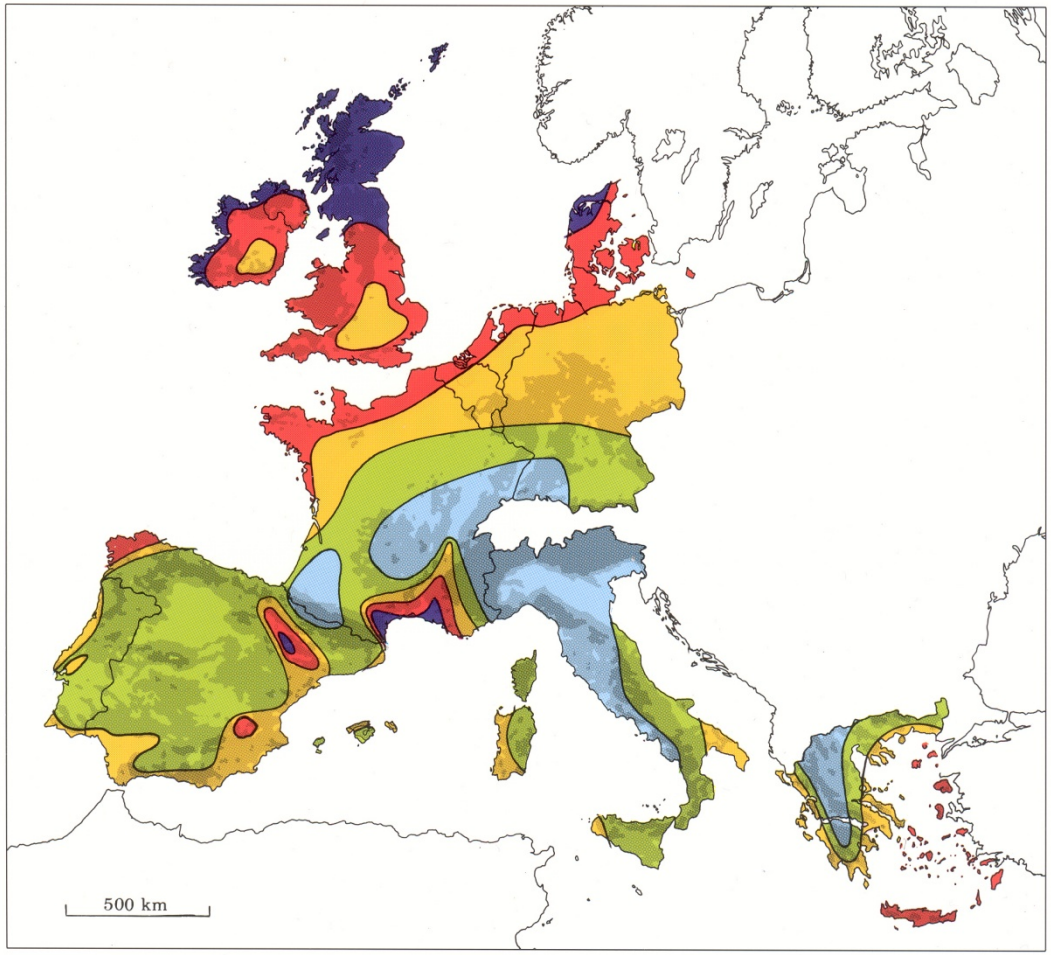


Linear interpolation

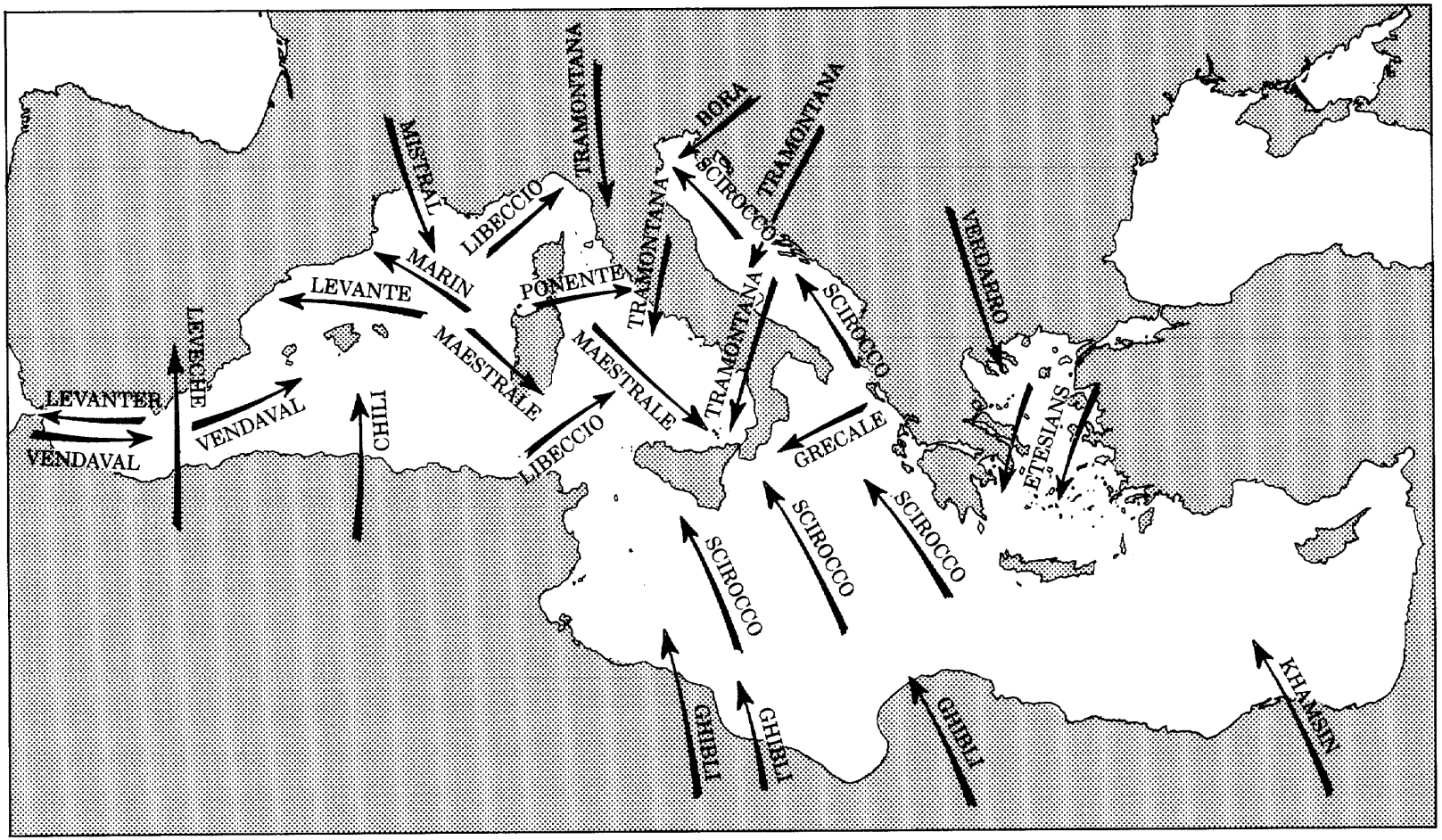


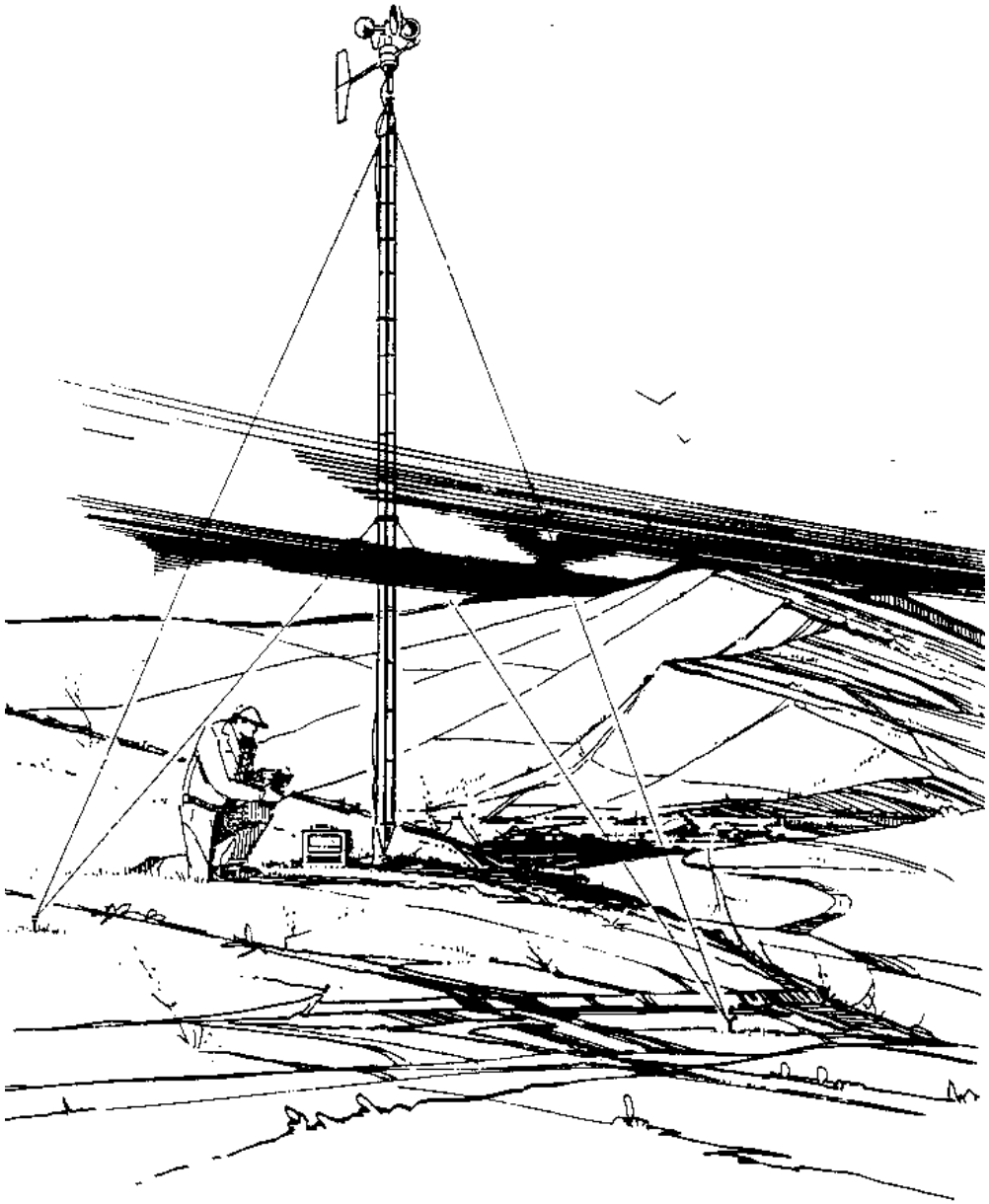

REGIONAL WIND CLIMATE
MODEL FOR:
MOUNTAINOUS TERRAIN
INPUT: HEIGHT CONTOUR LINES
MODEL FOR:
ROUGHNESS OF TERRAIN
INPUT: TERRAIN CLASSIFICATION
MODEL FOR:
SHELTERING OBSTACLES
INPUT: POSITION AND DIMENSIONS
OBSERVED WIND CLIMATE
PREDICTED WIND CLIMATE

European Wind Atlas

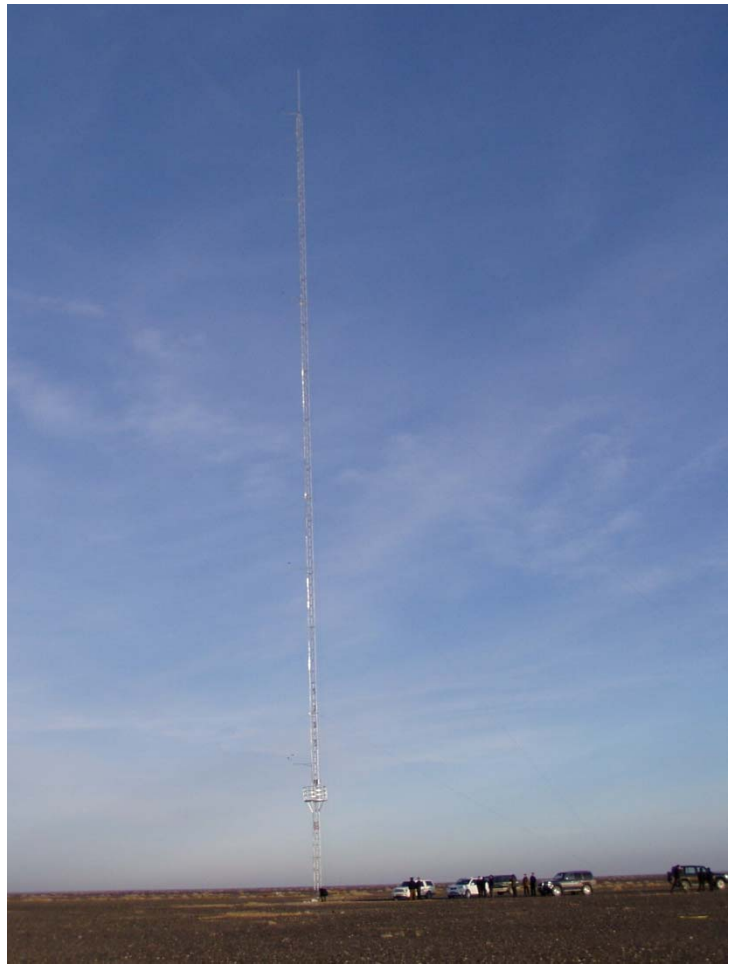


Thermal winds

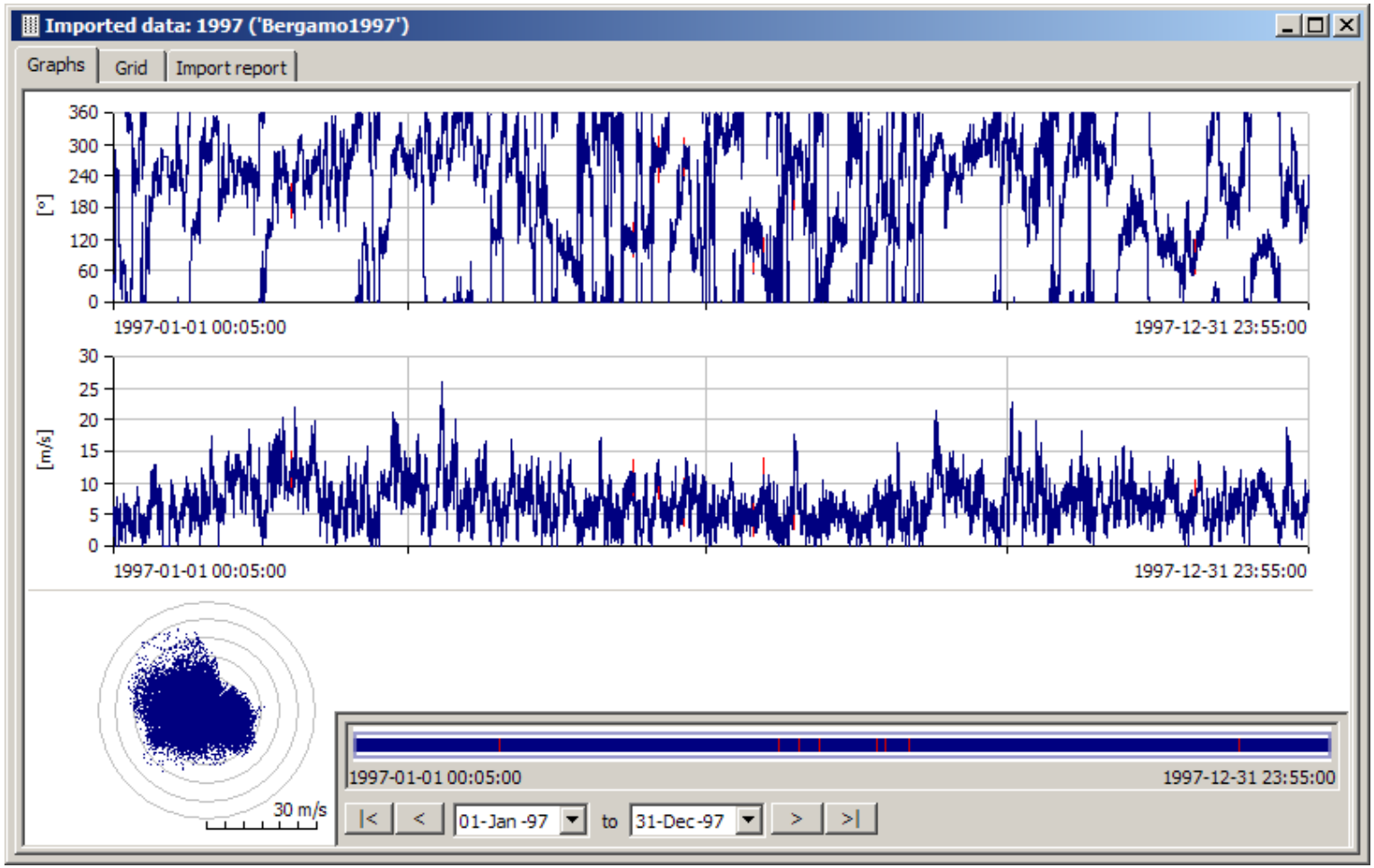




70-m mast in Gobi Desert, Gansu, China



Wind observations

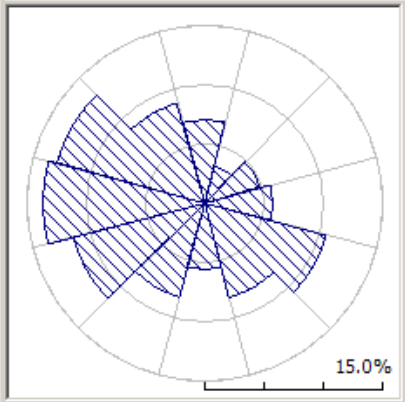


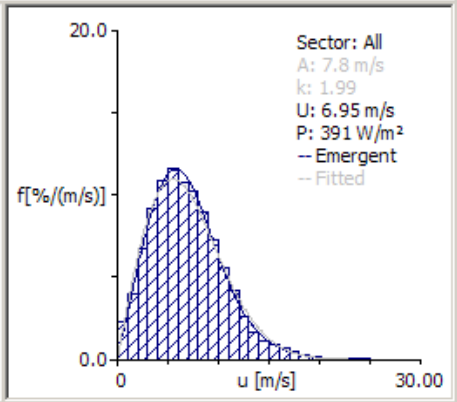
Wind distributions

'Bergamo airport at 35.0 m' Observed wind climate

Wind | Histogram bins | Location information | Generation report | Statistics

Sector		Wind climate				Power	Quality
#	angle [°]	freq. [%]	W-A [m/s]	Weibull-k	U [m/s]	power [W/m²]	delta-U [%]
1	0	7.1	6.8	1.78	6.05	294	-0.243%
2	30	3.2	4.6	2.23	4.07	71	1.133%
3	60	4.8	6.0	2.70	5.33	138	2.595%
4	90	5.8	8.1	3.19	7.27	320	2.646%
5	120	10.6	8.3	2.78	7.39	363	0.496%
6	150	8.2	7.2	2.61	6.40	246	0.134%
7	180	5.5	6.5	2.38	5.73	188	-0.026%
8	210	8.2	7.6	2.26	6.74	321	-0.683%
9	240	11.4	8.7	2.31	7.70	469	1.904%
10	270	13.7	9.2	2.11	8.15	600	1.772%
11	300	12.8	8.8	1.84	7.80	607	-0.506%
12	330	8.8	7.0	1.55	6.25	387	-1.522%
All (emergent)					6.95	391	
Source data					6.91	390	





'Bergamo airport at 35.0 m' Observed wind climate

Wind | Histogram bins | Location information | Generation report | Statistics

Description:

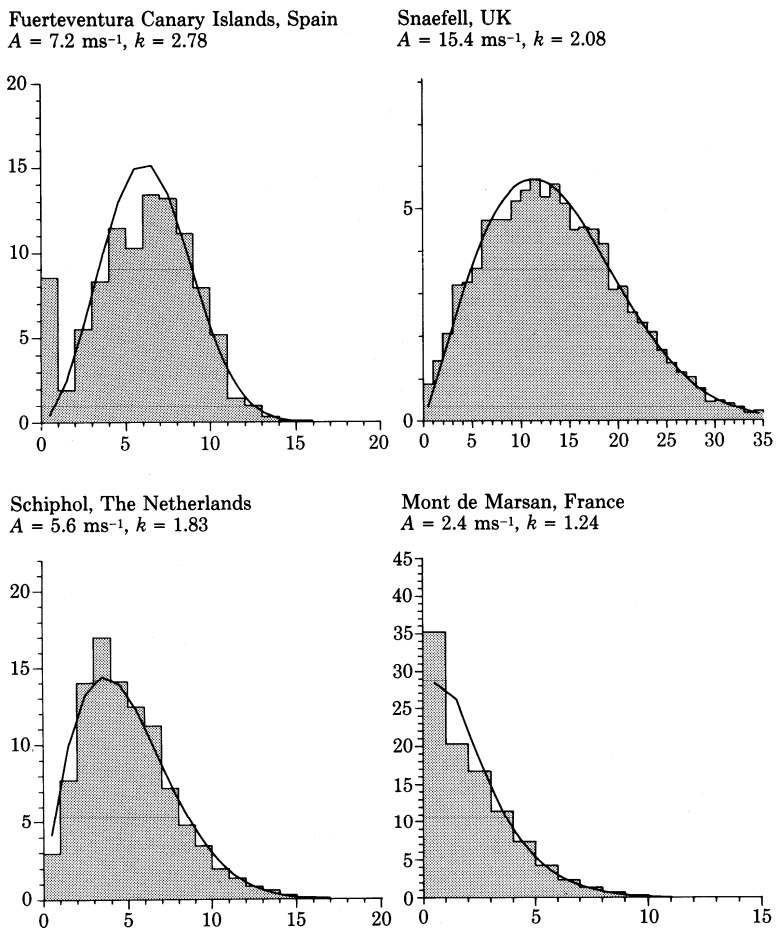
Height: 35.0 metres a.g.l.

Latitude: 45.672124° (45.6721°)

Longitude: 9.598618° (9.5986°)

Note that the location data are read from file and cannot be edited.

Weibull distributions



Weibull distribution

$$f(u) = \frac{k}{A}\left(\frac{u}{A}\right)^{k-1} \mathrm{Exp}\left(-\left(\frac{u}{A}\right)^{k}\right)$$

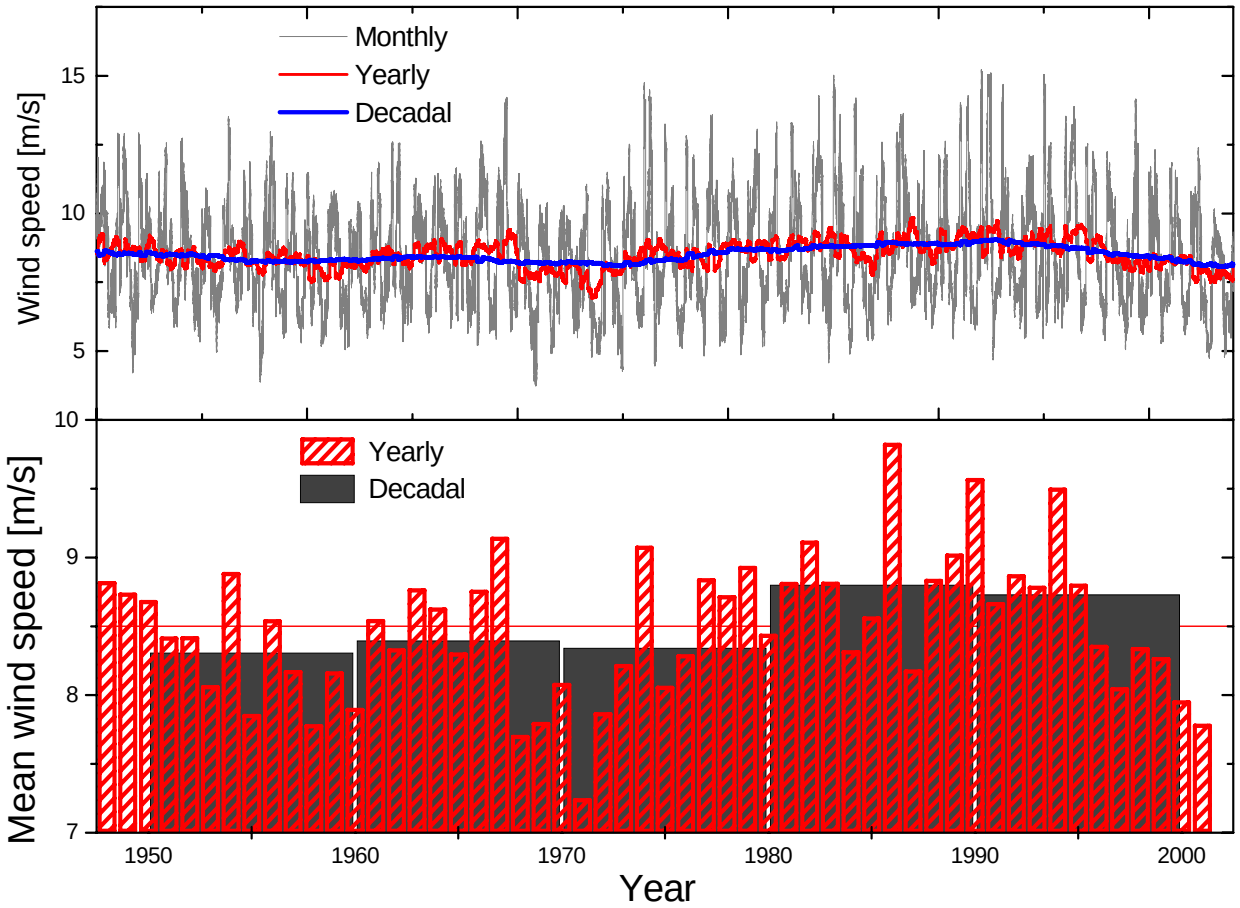
f: frequency of occurrence

u: wind speed

k: shape parameter

A: scale parameter

Annual variation

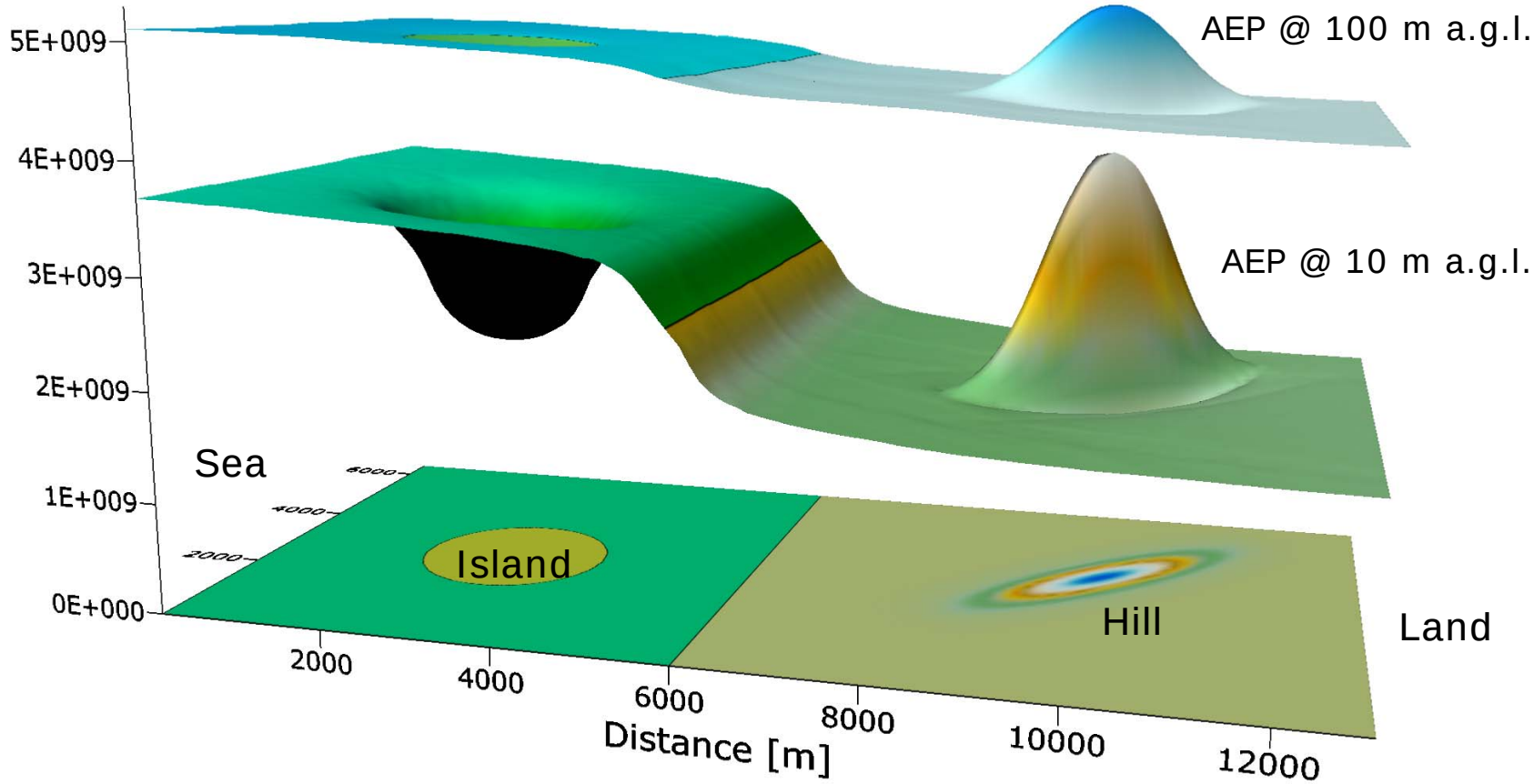


Running means

Sharp means

Data from NCEP/NCAR reanalysis for a site in Ireland

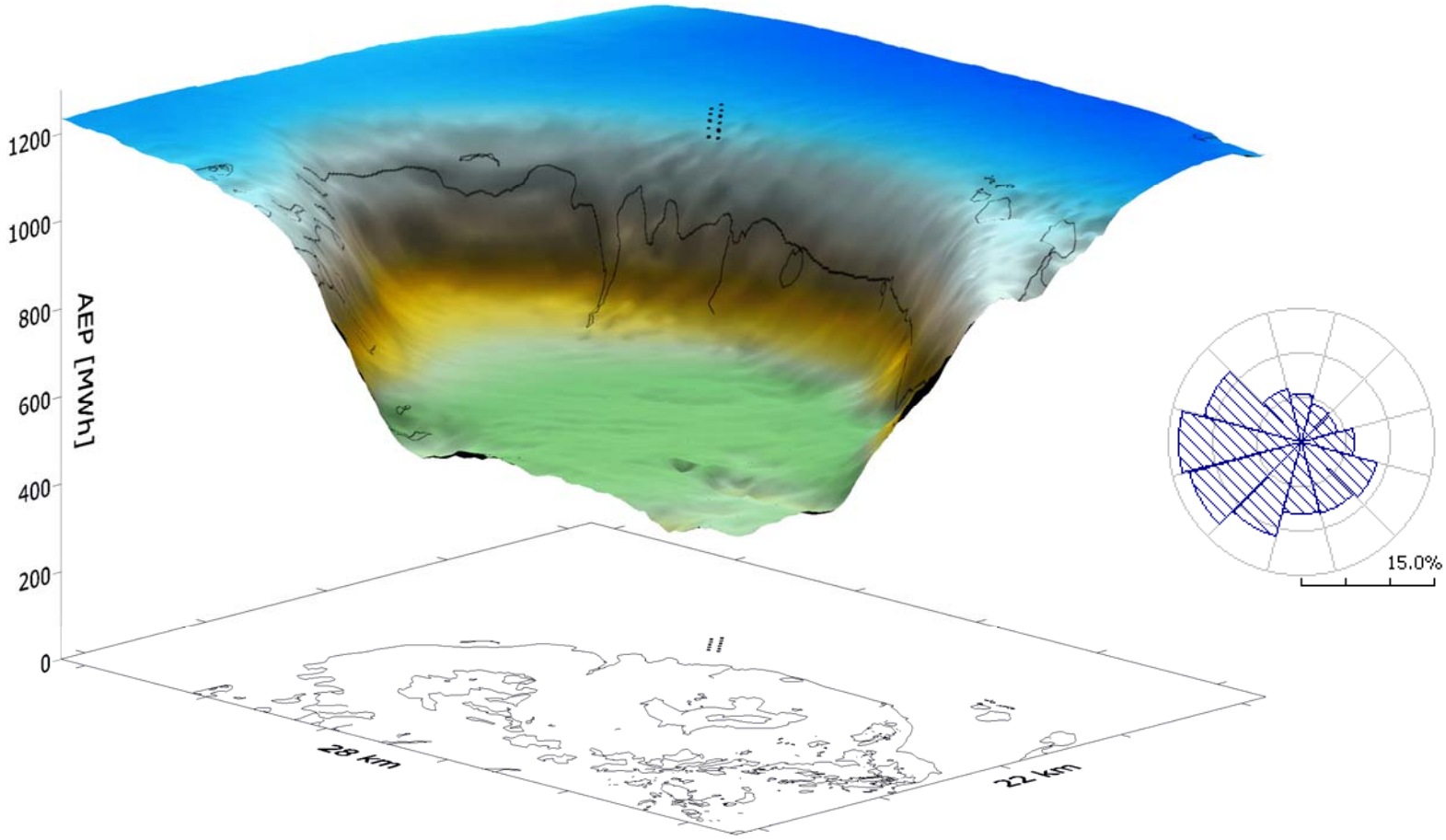
Terrain effects



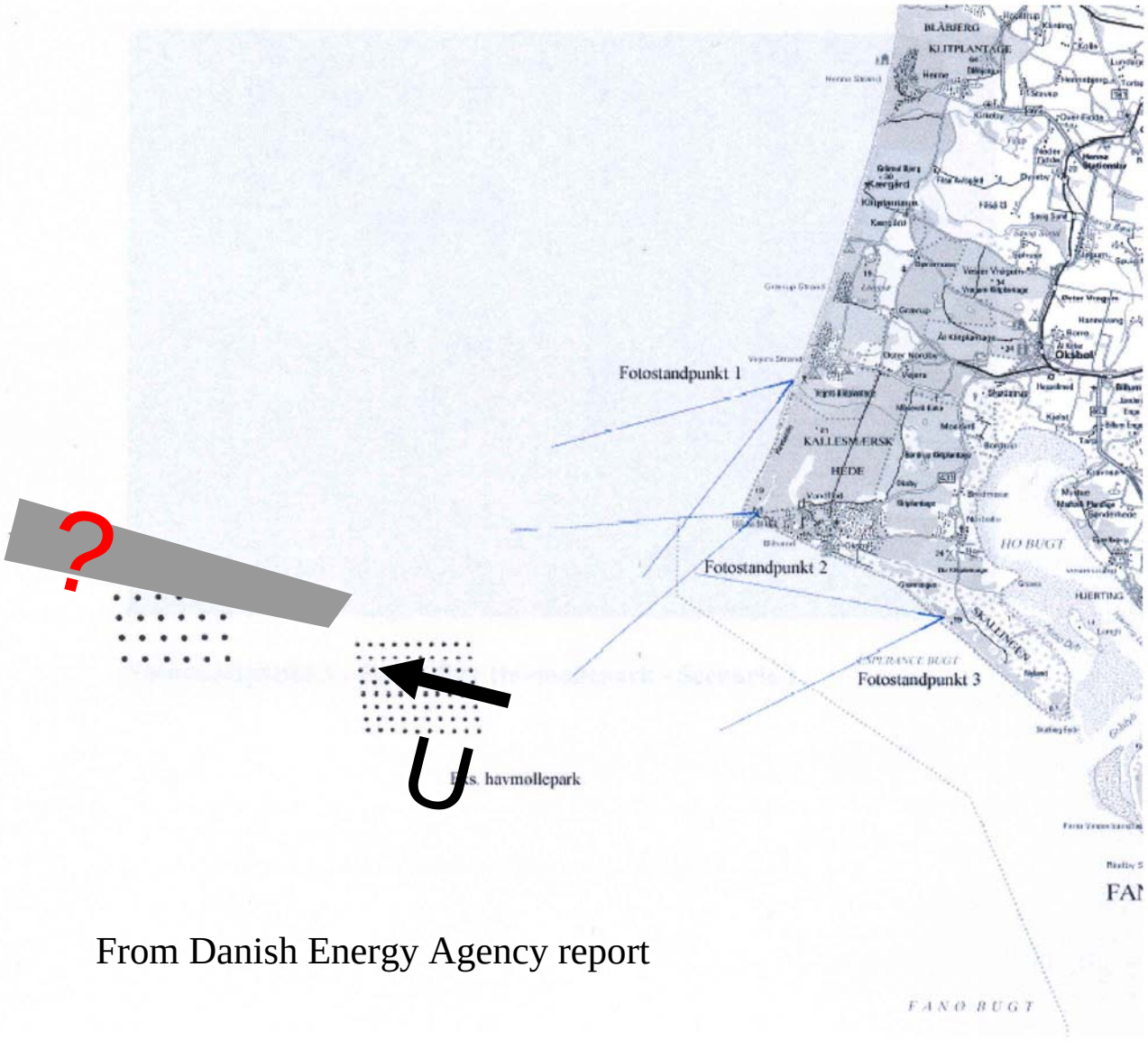
Power production at 10 & 100 m a.g.l.

Uniform wind rose, hill is 100 m high.

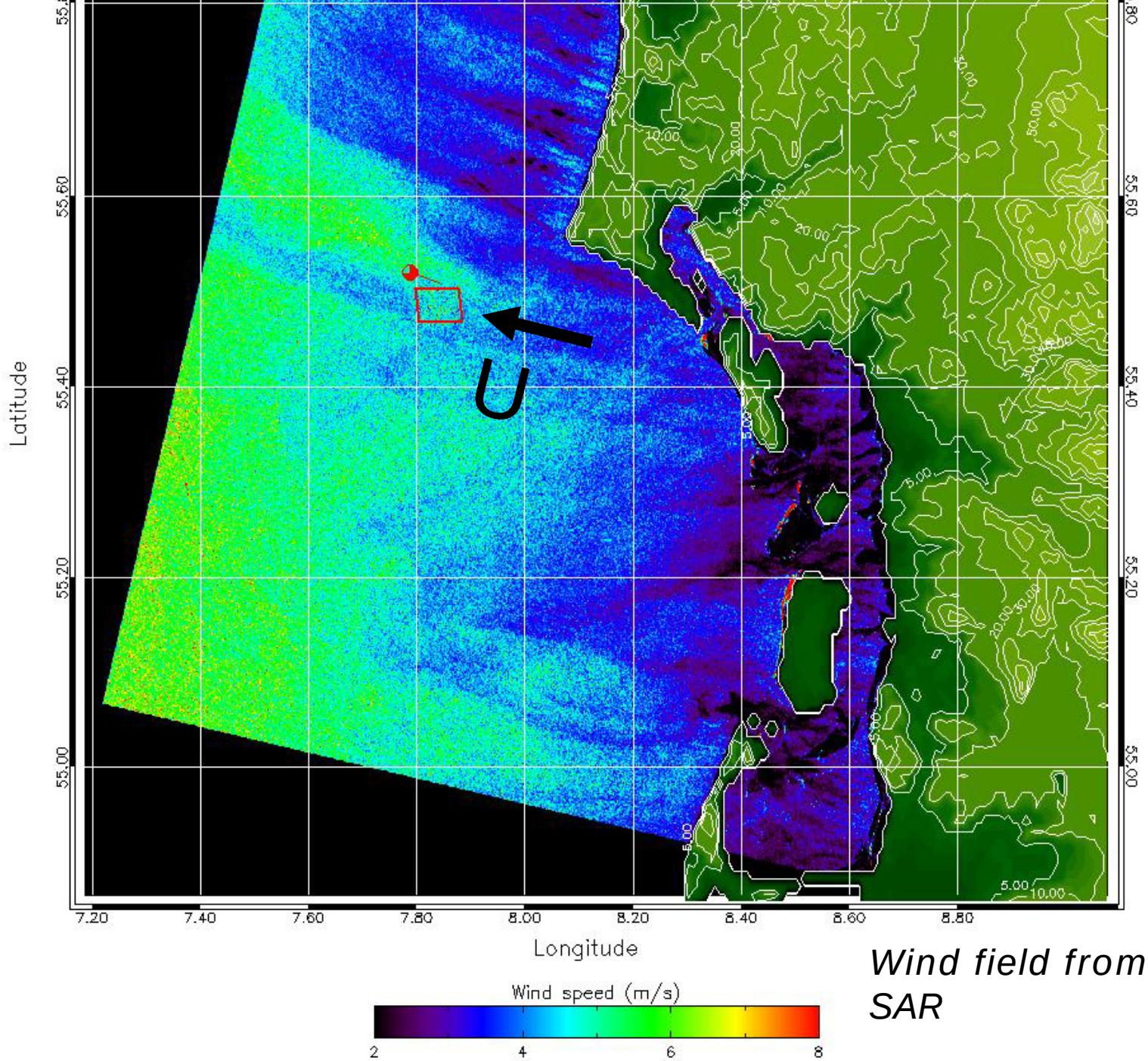
Vindeby wind farm (*h* = 37.5 m)



Courtesy: DONG energy, Denmark



From Danish Energy Agency report



Wind field from ERS-2 SAR

From SJ Consult

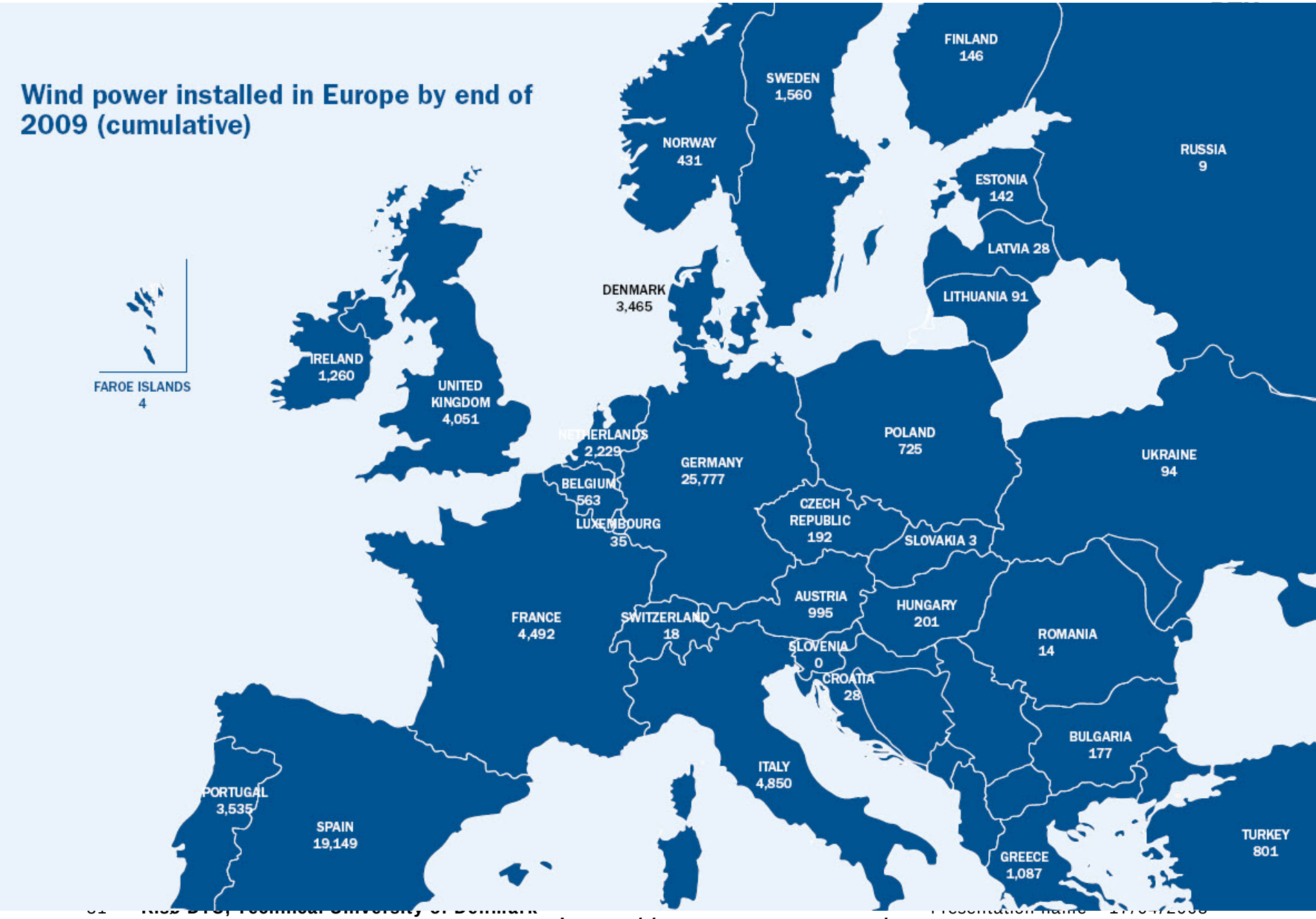
Danish wind energy

- 20% annual electricity production since year 2004
- >100% on a very wind day --→ export
- Plans from doubling the installed capacity in year 2030

Lillgrund in Baltic Sea, Sweden

48 turbines, 110MW, 60.000 households, 0.33 TWh

http://www.ewea.org/



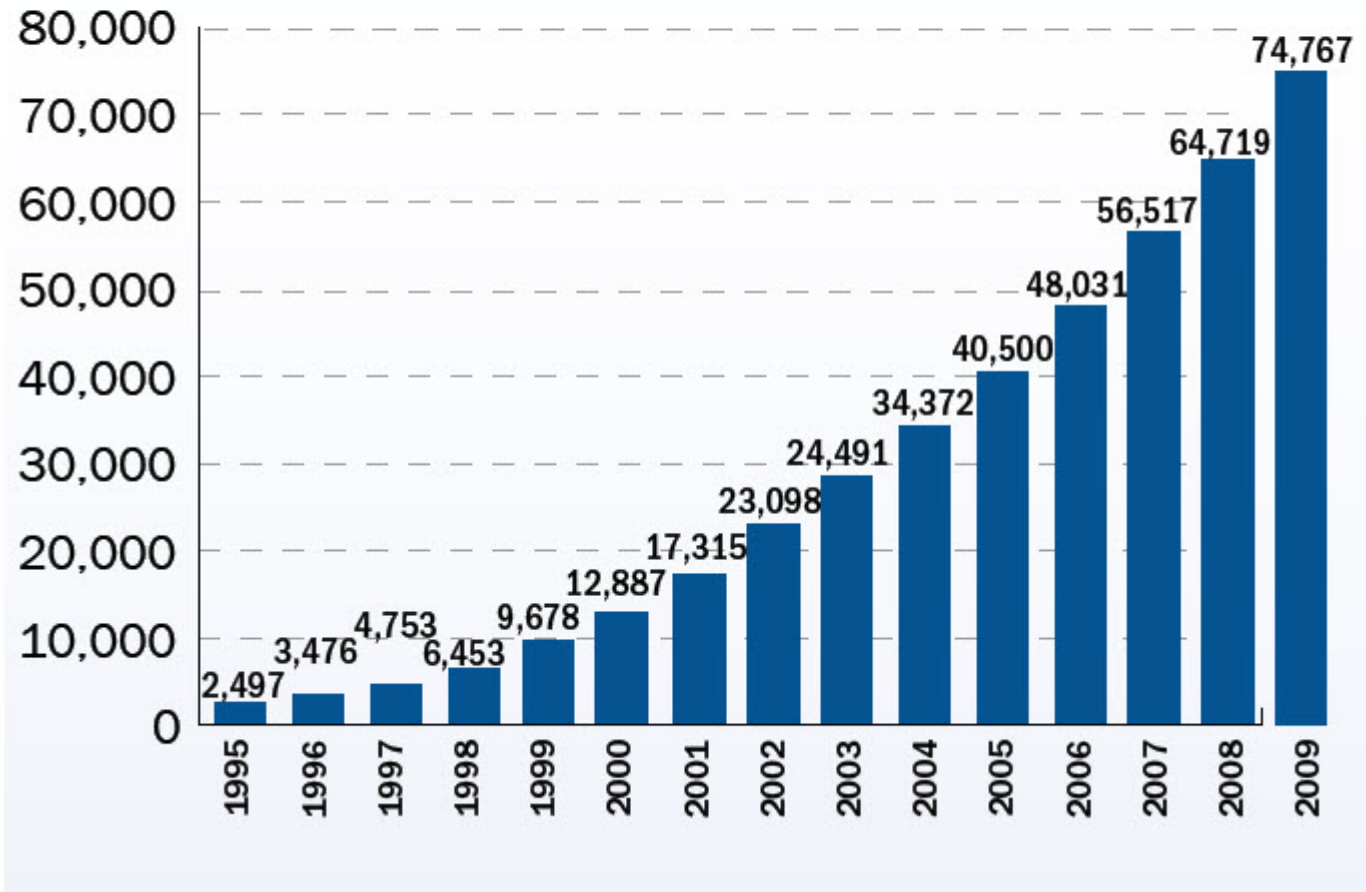
http://www.ewea.org/

	Installed 2008	End 2008	Installed 2009	End 2009
EU Capacity (MW)				
Austria	14	995	0	995
Belgium	135	415	149	563
Bulgaria	63	120	57	177
Cyprus	0	0	0	0
Czech Republic	34	150	44	192
Denmark	60	3,163	334	3,465
Estonia	19	78	64	142
Finland	33	143	4	146
France	950	3,404	1,088	4,492
Germany	1665	23,903	1,917	25,777
Greece	114	985	102	1,087
Hungary	62	127	74	201
Ireland	232	1,027	233	1,260
Italy	1010	3,736	1,114	4,850
Latvia	0	27	2	28
Lithuania	3	54	37	91
Luxembourg	0	35	0	35
Malta	0	0	0	0
Netherlands	500	2,225	39	2,229
Poland	268	544	181	725
Portugal	712	2,862	673	3,535
Romania	3	11	3	14
Slovakia	0	3	0	3
Slovenia	0	0	0	0
Spain	1558	16,689	2,459	19,149
Sweden	262	1,048	512	1,560
United Kingdom	569	2,974	1,077	4,051
Total EU-27	**8,268**	**64,719**	**10,163**	**74,767**

75 GW

http://www.ewea.org/

CUMULATIVE WIND POWER INSTALLATIONS MW FIGURE 3.3



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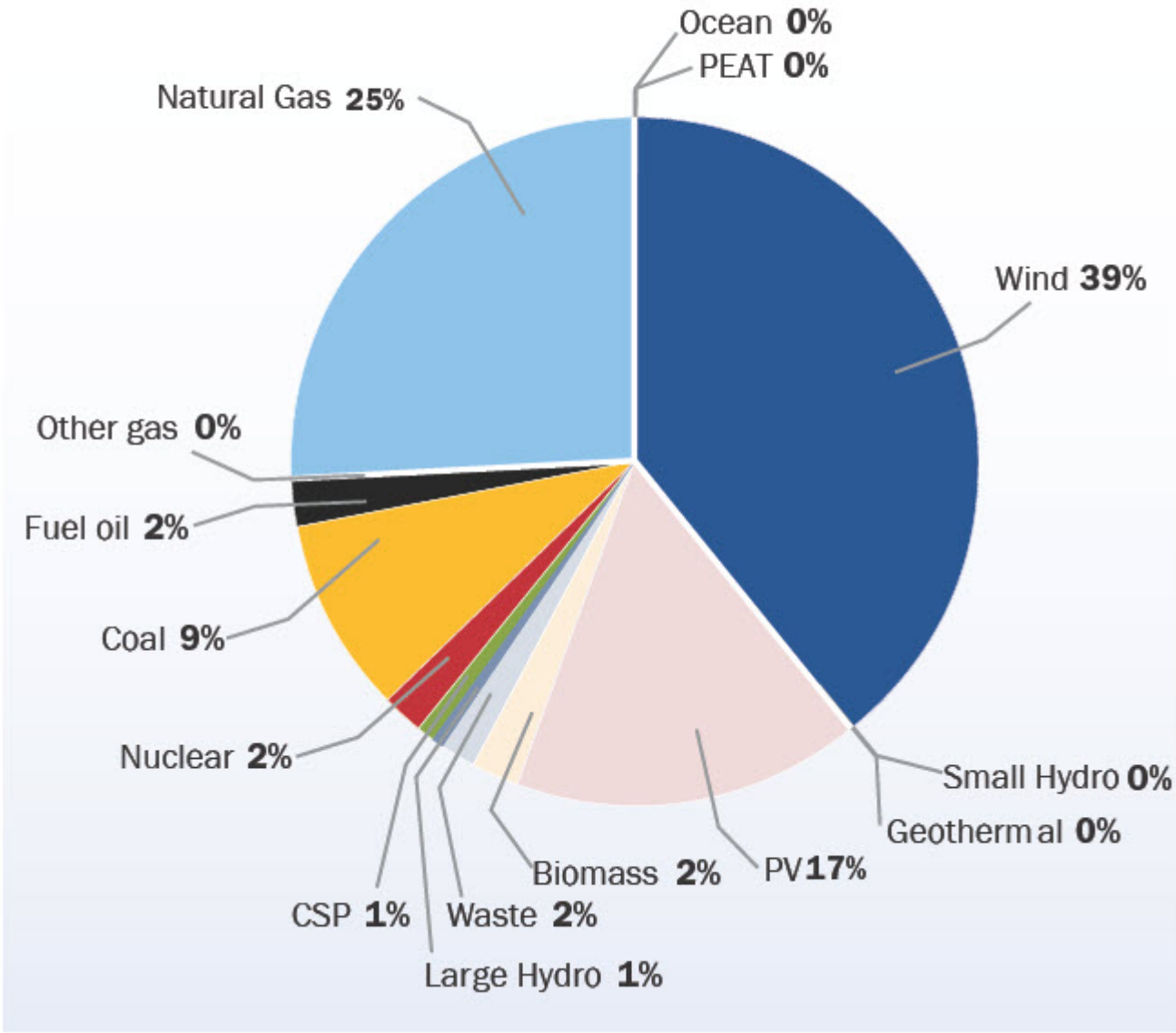
SHARE OF NEW POWER INSTALLATIONS IN EU

FIGURE 1.3



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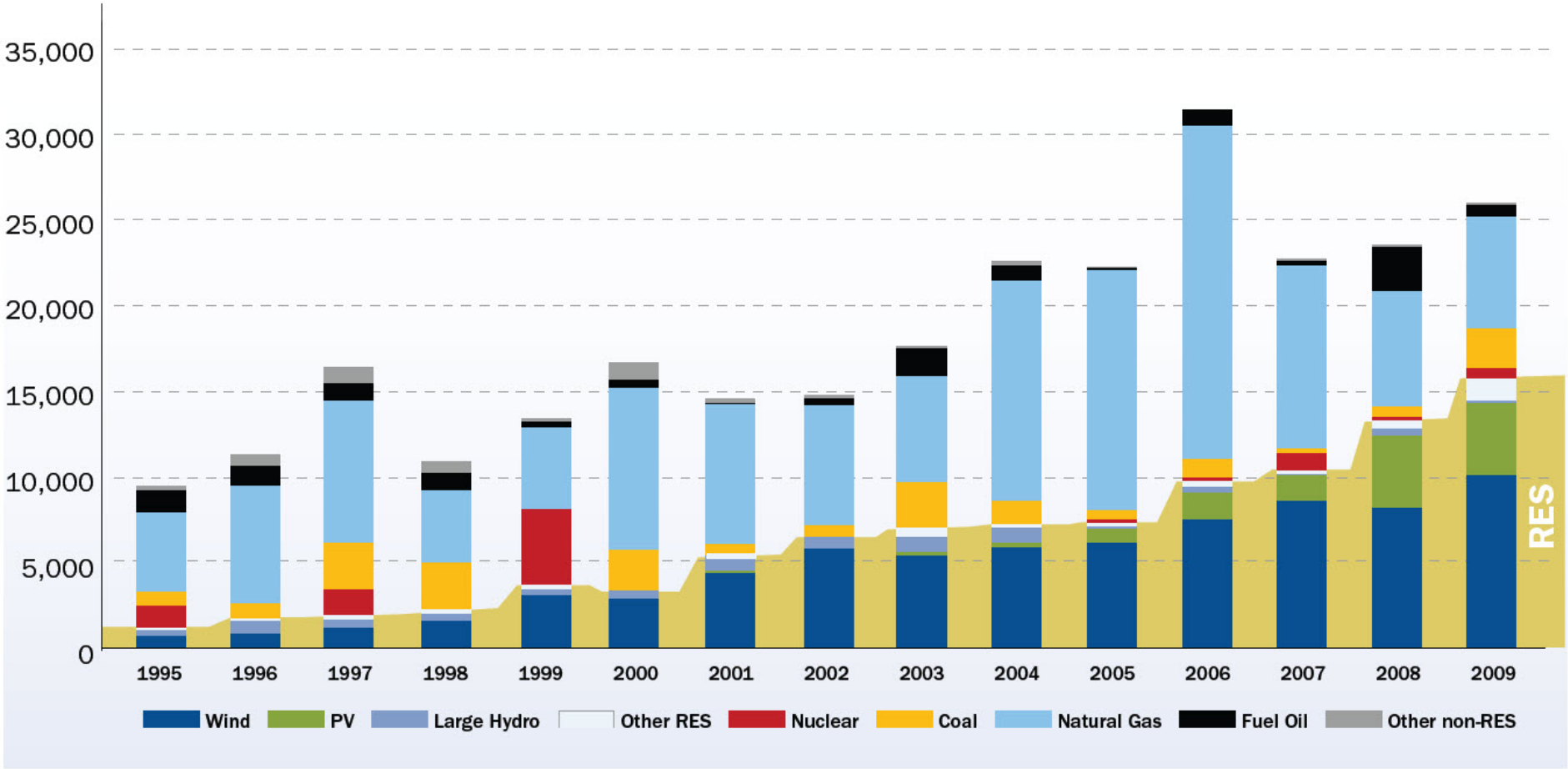
NEW INSTALLED CAPACITY PER YEAR IN MW

FIGURE 2.1



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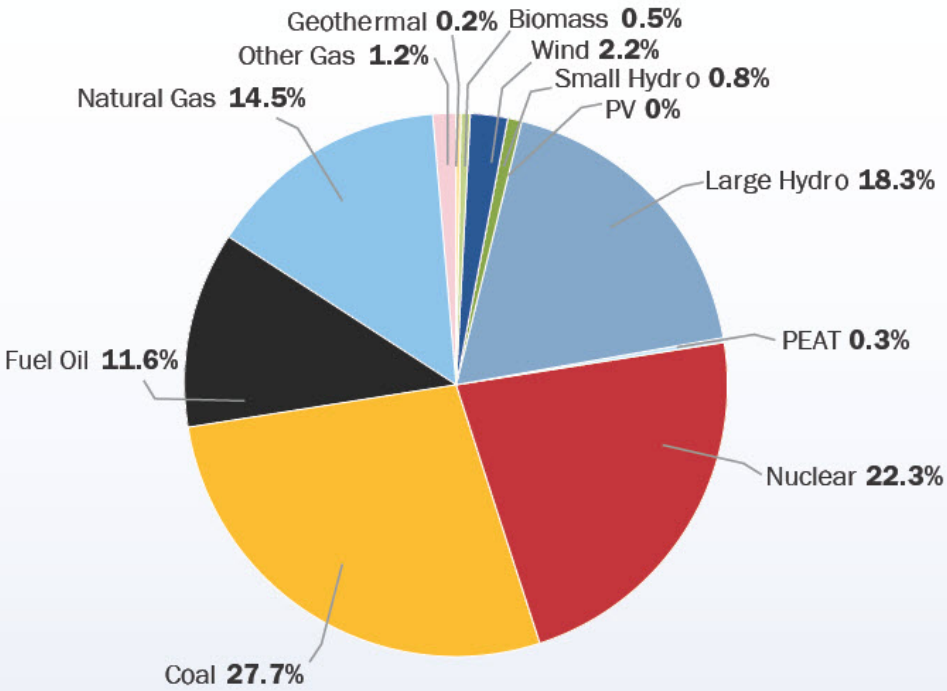
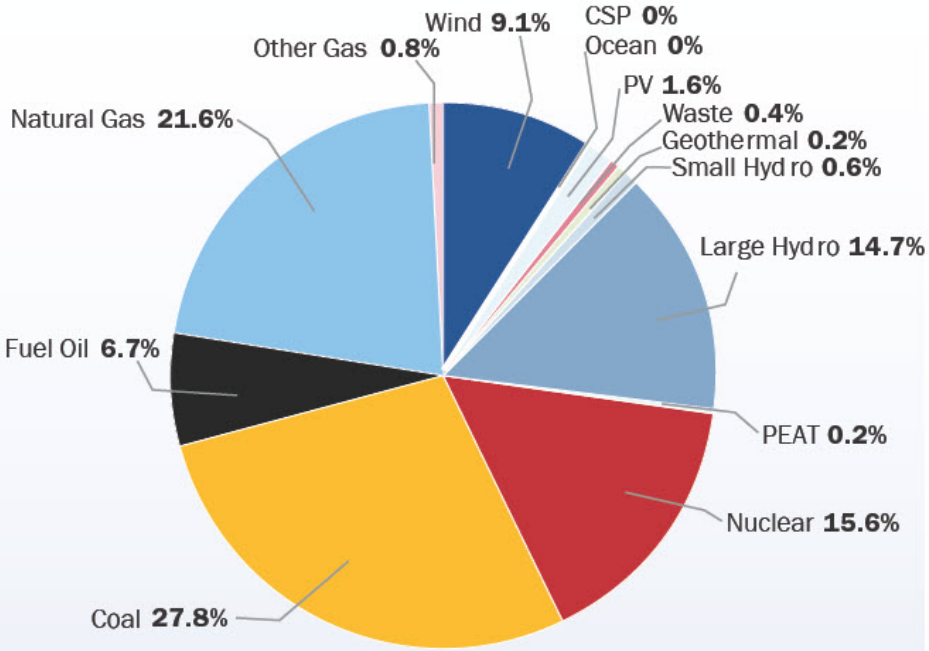
Total installed power capacity

Wind power's share of total installed capacity in the EU has increased from 2% in 2000 to 9% in 2009.

EU POWER CAPACITY MIX 2000 FIGURE 2.3



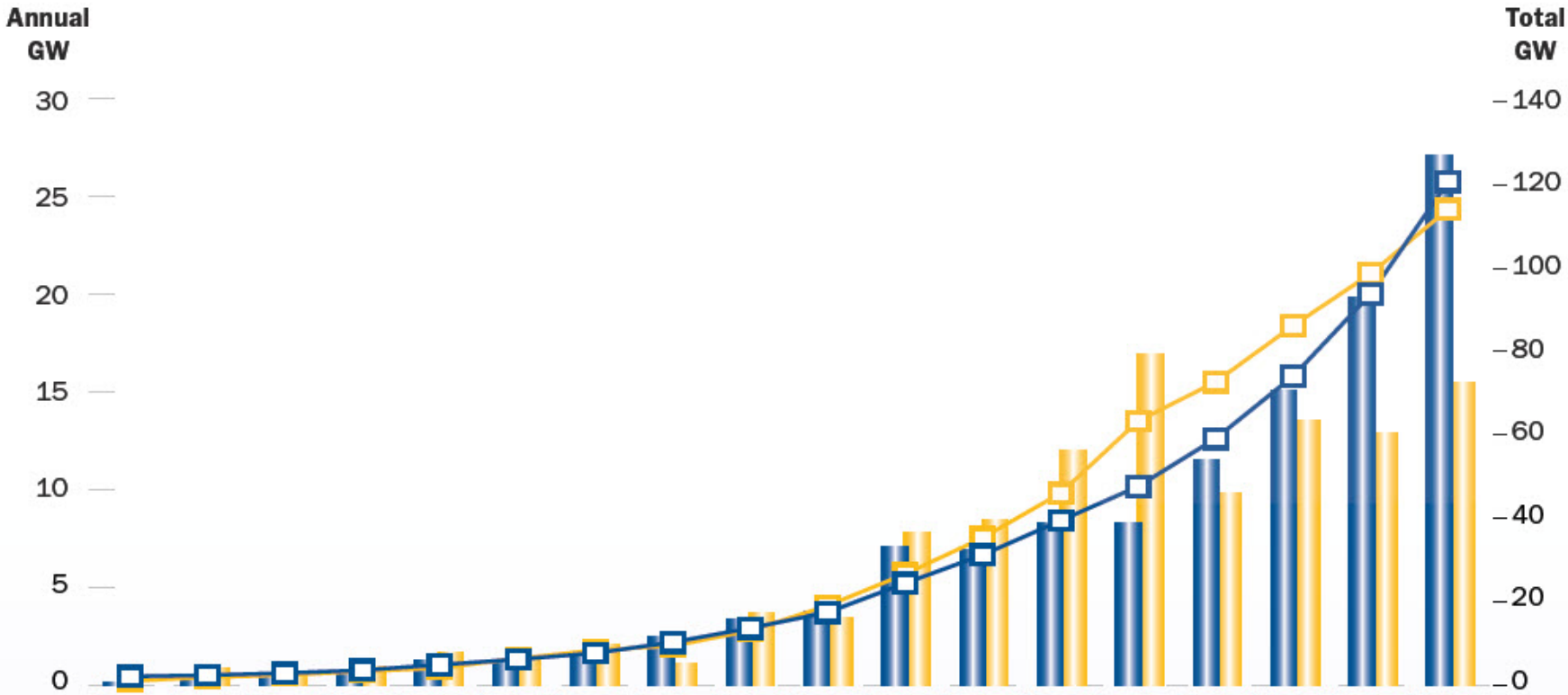
EU POWER CAPACITY MIX 2009 FIGURE 2.4



http://www.ewea.org/

GLOBAL WIND DEVELOPMENT (1991-2008) COMPARED TO NUCLEAR DEVELOPMENT (1961-1978)

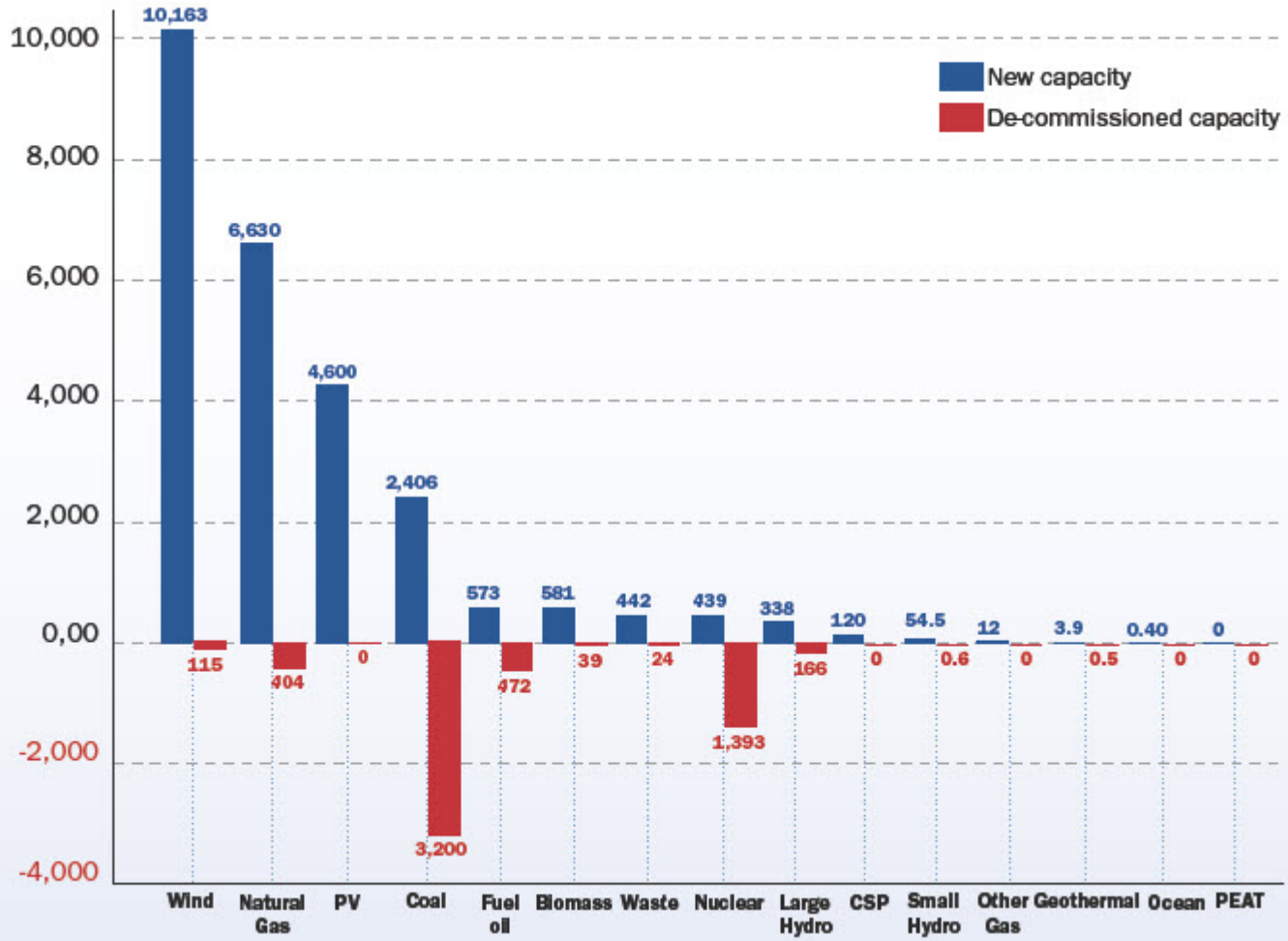
FIGURE 3.3



	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Annual Wind GW	0.2	0.3	0.5	0.7	1.3	1.3	1.5	2.5	3.4	3.8	7.1	6.9	8.3	8.3	11.5	15.1	19.8	27.1
Annual Nuclear GW	0.0	0.9	0.5	1.0	1.7	1.4	2.1	1.1	3.7	3.5	7.8	8.5	12.0	16.9	9.8	13.5	12.9	15.5
Total Wind GW	2.0	2.3	2.8	3.5	4.8	6.1	7.6	10.2	13.6	17.4	24.4	31.2	39.4	47.6	59.1	74.1	93.8	120.8
Total Nuclear GW	0.9	1.8	2.3	3.2	4.0	6.3	8.3	9.3	13.0	19.0	26.6	35.3	46.0	63.3	72.7	86.2	98.7	114.2

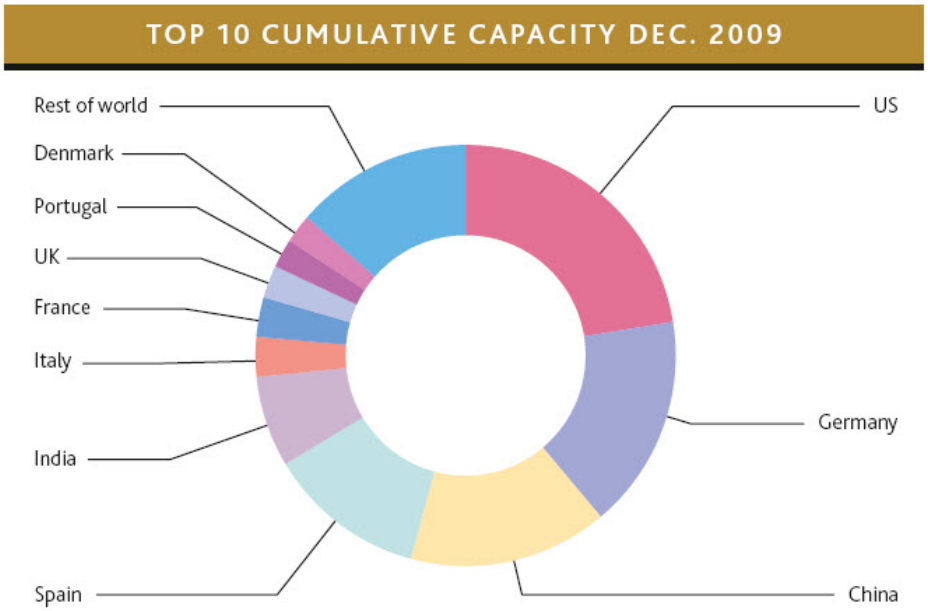
Source: EWEA and International Atomic Energy Agency (IAEA)

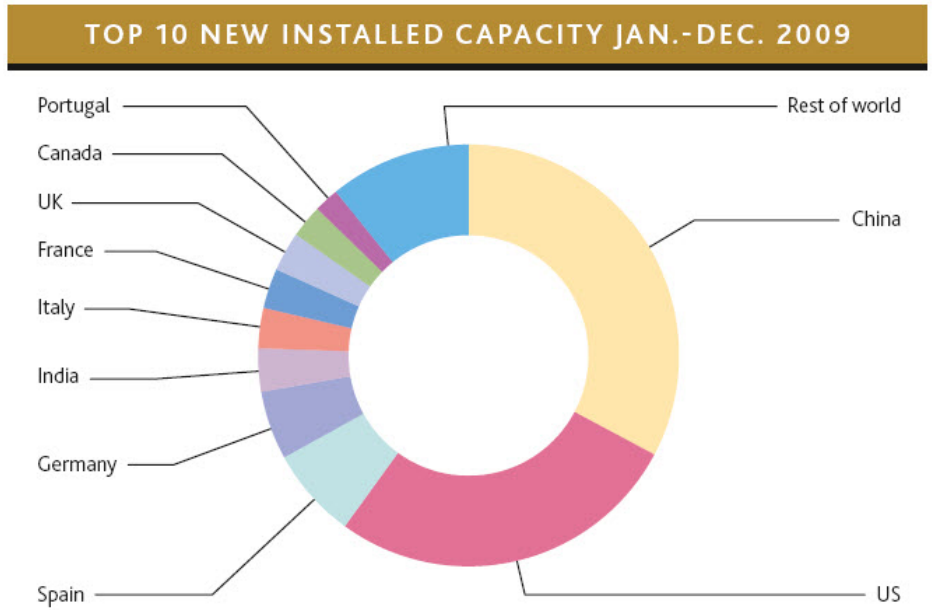
NEW INSTALLED CAPACITY AND DE-COMMISSIONED CAPACITY IN EU 2009 IN MW. TOTAL 25,963 MW FIGURE 1.2



http://www.ewea.org/

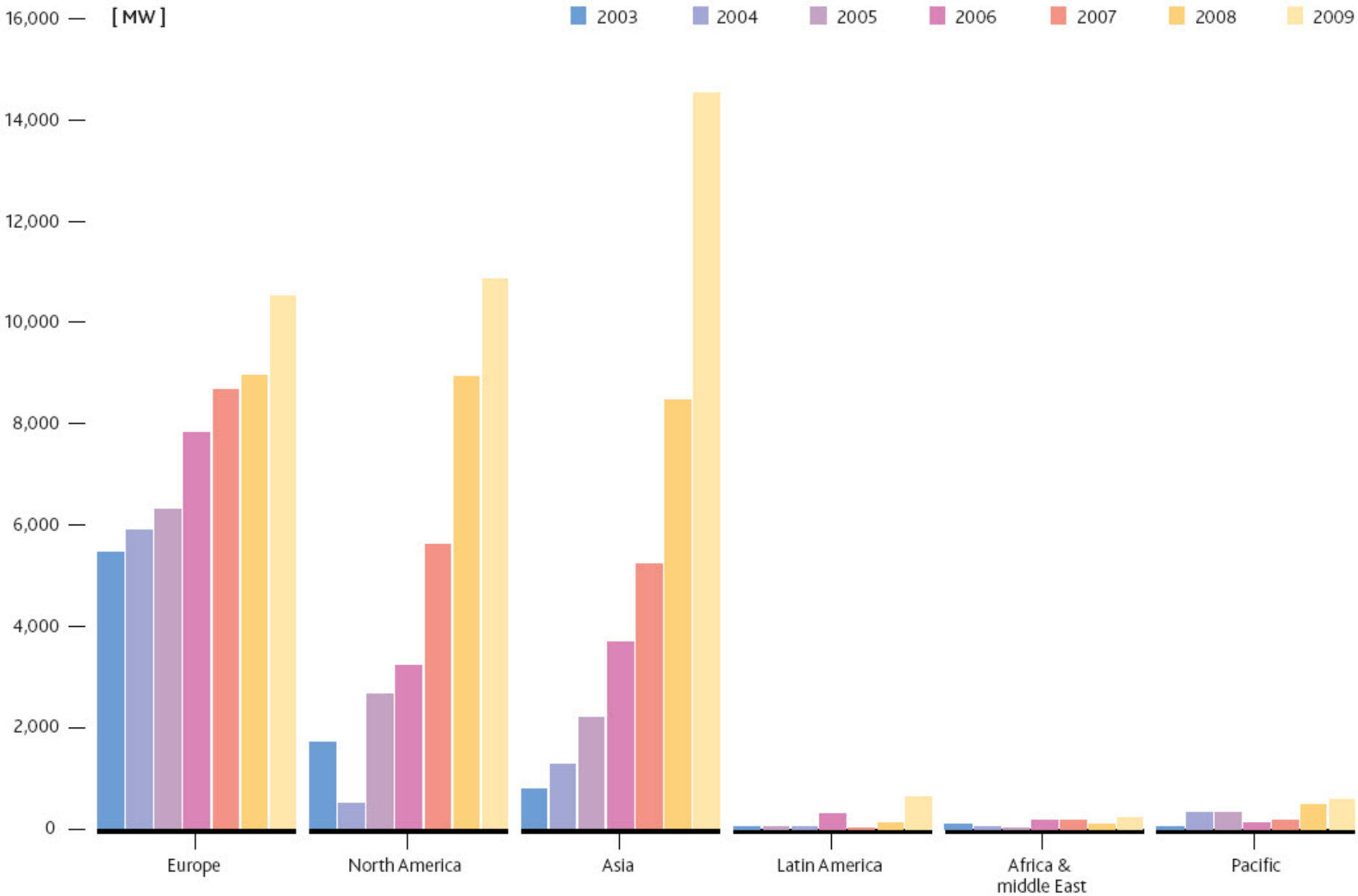
From Global Wind Energy Council (GWEC)





ANNUAL INSTALLED CAPACITY BY REGION 2003-2009

From Global Wind Energy Council (GWEC)



Wind power race

US and China in race to the top of global wind industry

- The United States passed Germany to become world #1 in wind power installations.

- China was the world's largest market in 2009.

Global wind power boom continues despite economic woes

- The world's wind power capacity 157.9 GW.

158 GW

http://www.ewea.org/

EWEA
THE EUROPEAN WIND ENERGY ASSOCIATION

The competitors

Oil: Not really…

Gas: Increasingly expensive and depleting
Risk: Lower oil and gas prices; lower demand

Coal: Environmentally damaging and increasingly costly as carbon market materialise
Risk: Environmental ignorance and CCS-frenzy

Nuclear: Requires state intervention
Risks: State intervention, justified by environmental and supply concerns; life extension of existing plants

Future: Pure Power

The European Commission

- EU oil production decline 73% between 2000 and 2030.
- Gas production will fall by 59% and coal by 41%.

By 2030, the EU will be importing 94% of its oil, 84% of its gas and 59% of its coal.

Wind power target of EWEA for EU-27:

230 GW in 2020

400 GW in 2030

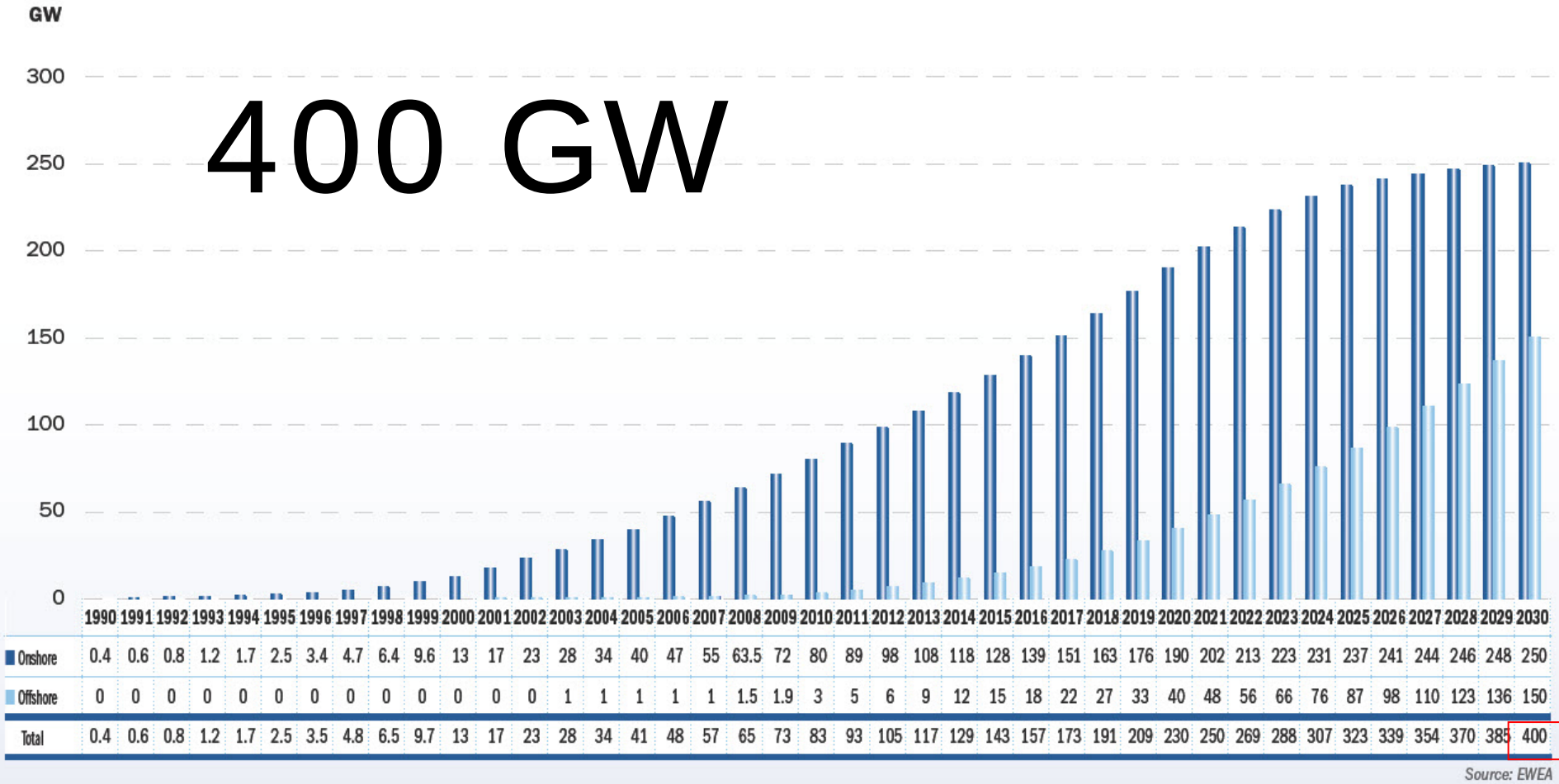
TWO SCENARIOS UP TO 2020* TABLE 1.1

	MW installed end 2008			MW installed 2020 low			MW installed 2020 high			Avg annual MW low (2009-2020)	Avg annual MW high (2009-2020)
Country	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total		
Austria	995	0	995	3,500	0	3,500	4,000	0	4,000	209	250
Belgium	354	30	384	2,100	1,800	3,900	2,500	2,000	4,500	293	343
Bulgaria	158	0	158	3,000	0	3,000	3,500	0	3,500	237	279
Cyprus	0	0	0	300	0	300	500	0	500	25	42
Czech Republic	150	0	150	1,600	0	1,600	1,800	0	1,800	121	138
Denmark	2,771	409	3,180	3,700	2,300	6,000	4,000	2,500	6,500	235	277
Estonia	78	0	78	500	0	500	500	100	600	35	44
Finland	119	24	143	1,500	400	1,900	2,000	1,000	3,000	146	238
France	3,404	0	3,404	19,000	4,000	23,000	20,000	6,000	26,000	1,633	1,883
Germany	23,891	12	23,903	41,000	8,000	49,000	42,000	10,000	52,000	2,091	2,341
Greece	985	0	985	6,500	0	6,500	8,300	200	8,500	460	626
Hungary	127	0	127	900	0	900	1,200	0	1,200	64	89
Ireland	977	25	1,002	5,000	1,000	6,000	6,000	1,000	7,000	417	500
Italy	3,736	0	3,736	15,000	500	15,500	17,000	1,000	18,000	980	1,189
Latvia	27	0	27	200	0	200	200	100	300	14	23
Lithuania	54	0	54	1,000	0	1,000	1,000	100	1,100	79	87
Luxembourg	35	0	35	300	0	300	700	0	700	22	55
Malta	0	0	0	100	0	100	200	0	200	8	17
Netherlands	1,978	247	2,225	5,000	4,500	9,500	5,400	6,000	11,400	606	765
Poland	472	0	472	10,000	500	10,500	12,000	500	12,500	836	1,002
Portugal	2,862	0	2,862	7,500	0	7,500	9,000	0	9,000	387	512
Romania	10	0	10	3,000	0	3,000	3,500	0	3,500	249	291
Slovakia	3	0	3	800	0	800	1,000	0	1,000	66	83
Slovenia	0	0	0	500	0	500	700	0	700	42	58
Spain	16,740	0	16,740	39,000	1,000	40,000	41,000	1,500	42,500	1,938	2,147
Sweden	888	133	1,021	6,000	3,000	9,000	8,000	3,000	11,000	665	832
UK	2,650	591	3,241	13,000	13,000	26,000	14,000	20,000	34,000	1,897	2,563
EU-27	**63,464**	**1,471**	**64,935**	**190,000**	**40,000**	**230,000**	**210,000**	**55,000**	**265,000**	**13,755**	**16,672**

	TWh end 2008			Twh 2020 low			TWh 2020 high			Final Electricity Consumption (2007)	Final Electricity Consumption (2020)	Wind share 2008	Wind Share 2020 low	Wind share 2020 high
Country	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total					
Austria	2.0	0.0	2.0	7.5	0.0	7.5	8.6	0.0	8.6	70.0	78.5	2.9%	9.5%	10.9%
Belgium	0.7	0.1	0.8	4.7	6.6	11.3	5.6	7.4	13.0	95.6	109.5	0.9%	10.4%	11.9%
Bulgaria	0.3	0.0	0.3	7.1	0.0	7.1	8.3	0.0	8.3	38.8	56.1	0.9%	12.6%	14.7%
Cyprus	0.0	0.0	0.0	0.6	0.0	0.6	1.0	0.0	1.0	4.9	6.5	0.0%	8.9%	14.8%
Czech Republic	0.3	0.0	0.3	3.5	0.0	3.5	3.9	0.0	3.9	72.0	103.3	0.4%	3.4%	3.8%
Denmark	6.3	1.4	7.7	8.6	8.4	17.0	9.3	9.1	18.5	38.2	40.0	20.3%	42.5%	46.2%
Estonia	0.2	0.0	0.2	1.2	0.0	1.2	1.2	0.4	1.6	9.8	14.5	1.8%	8.4%	10.9%
Finland	0.3	0.0	0.4	3.7	1.5	5.1	4.9	3.7	8.6	93.8	101.6	0.4%	5.0%	8.4%
France	8.1	0.0	8.1	47.7	14.7	62.4	50.2	22.1	72.3	513.0	633.0	1.6%	9.9%	11.4%
Germany	42.9	0.0	42.9	77.4	29.4	106.8	79.4	36.8	116.2	620.5	674.1	6.9%	15.8%	17.2%
Greece	2.5	0.0	2.5	17.5	0.0	17.5	22.4	0.7	23.1	67.9	80.2	3.7%	21.8%	28.8%
Hungary	0.3	0.0	0.3	2.1	0.0	2.1	2.8	0.0	2.8	43.9	53.0	0.6%	4.0%	5.3%
Ireland	2.7	0.0	2.7	13.9	3.7	17.6	16.7	3.7	20.4	29.6	36.8	9.3%	47.8%	55.4%
Italy	7.9	0.0	7.9	33.5	0.0	33.5	38.1	0.0	38.1	360.2	441.6	2.2%	7.6%	8.6%
Latvia	0.1	0.0	0.1	0.5	0.0	0.5	0.5	0.4	0.8	7.8	9.5	0.8%	5.0%	8.9%
Lithuania	0.1	0.0	0.1	2.4	0.0	2.4	2.4	0.4	2.7	12.6	21.3	1.0%	11.1%	12.8%
Luxembourg	0.1	0.0	0.1	0.6	0.0	0.6	1.5	0.0	1.5	8.0	4.4	0.9%	14.1%	33.1%
Malta	0.0	0.0	0.0	0.2	0.0	0.2	0.4	0.0	0.4	2.3	1.7	0.0%	11.2%	22.4%
Netherlands	4.2	0.9	5.0	11.0	16.5	27.6	12.0	22.0	34.0	120.8	152.1	4.2%	18.1%	22.3%
Poland	1.0	0.0	1.0	23.6	1.8	25.4	28.3	1.8	30.1	154.0	203.7	0.7%	12.5%	14.8%
Portugal	6.3	0.0	6.3	16.8	0.0	16.8	20.2	0.0	20.2	54.7	77.4	11.4%	21.8%	26.2%
Romania	0.0	0.0	0.0	7.1	0.0	7.1	8.3	0.0	8.3	59.6	92.6	0.0%	7.7%	8.9%
Slovakia	0.0	0.0	0.0	1.8	0.0	1.8	2.3	0.0	2.3	29.8	43.0	0.0%	4.2%	5.3%
Slovenia	0.0	0.0	0.0	1.1	0.0	1.1	1.6	0.0	1.6	15.3	18.2	0.0%	6.3%	8.8%
Spain	36.7	0.0	36.7	91.3	3.7	94.9	96.2	5.5	101.7	297.5	387.0	12.3%	24.5%	26.3%
Sweden	1.9	0.5	2.3	13.5	11.0	24.5	18.1	11.0	29.1	150.2	187.3	1.6%	13.1%	15.5%
UK	7.2	2.1	9.3	36.2	47.7	83.9	39.0	73.5	112.5	401.4	452.3	2.3%	18.6%	24.9%
EU-27	**131.9**	**5.2**	**137.0**	**435.0**	**145.1**	**580.1**	**482.9**	**198.4**	**681.4**	**3,372.2**	**4,079.3**	**4.1%**	**14.2%**	**16.7%**

CUMULATIVE ONSHORE AND OFFSHORE WIND IN THE EU (1990-2030)

FIGURE 7.1

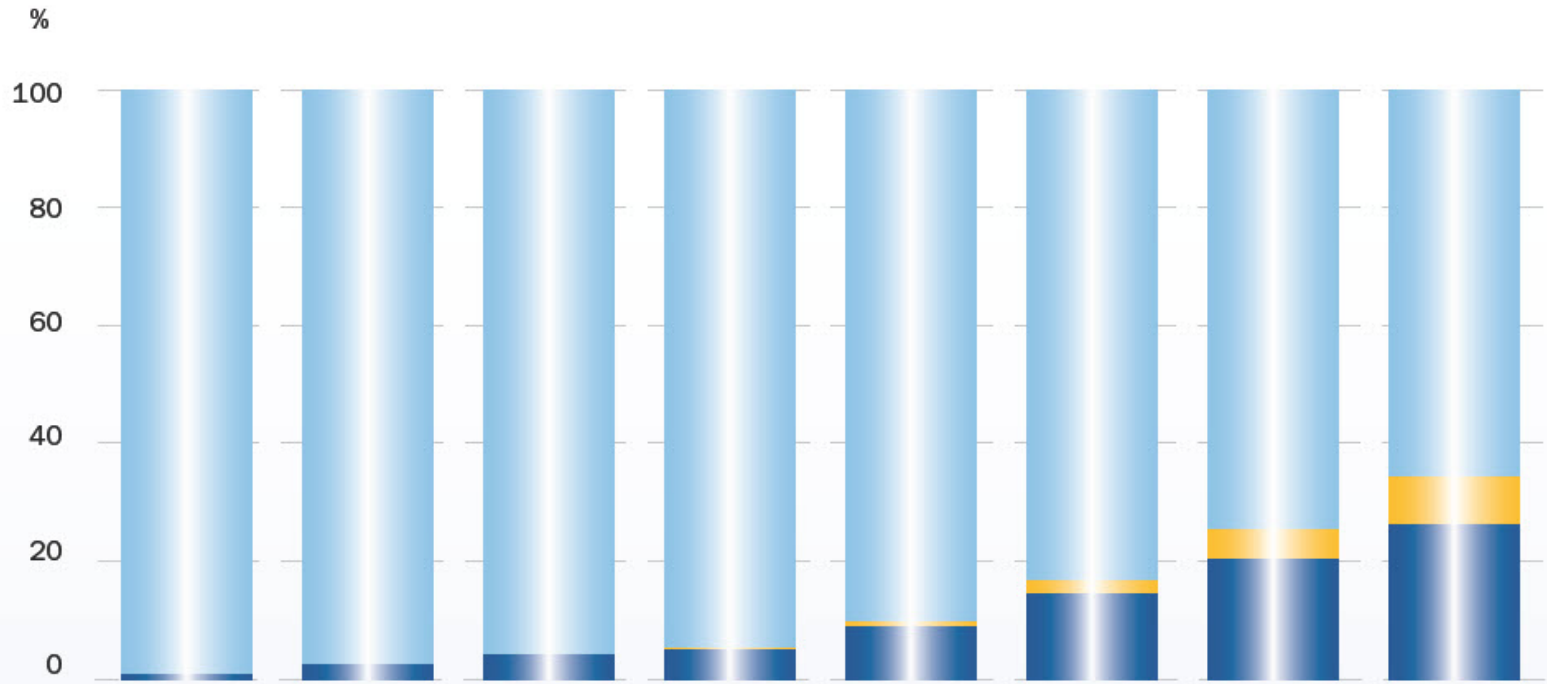


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Onshore	0.4	0.6	0.8	1.2	1.7	2.5	3.4	4.7	6.4	9.6	13	17	23	28	34	40	47	55	63.5	72	80	89	98	108	118	128	139	151	163	176	190	202	213	223	231	237	241	244	246	248	250
Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1.5	1.9	3	5	6	9	12	15	18	22	27	33	40	48	56	66	76	87	98	110	123	136	150
Total	0.4	0.6	0.8	1.2	1.7	2.5	3.5	4.8	6.5	9.7	13	17	23	28	34	41	48	57	65	73	83	93	105	117	129	143	157	173	191	209	230	250	269	288	307	323	339	354	370	385	400

Source: EWEA

WIND POWER'S SHARE OF EU ELECTRICITY DEMAND (1995-2030)

FIGURE 8.1



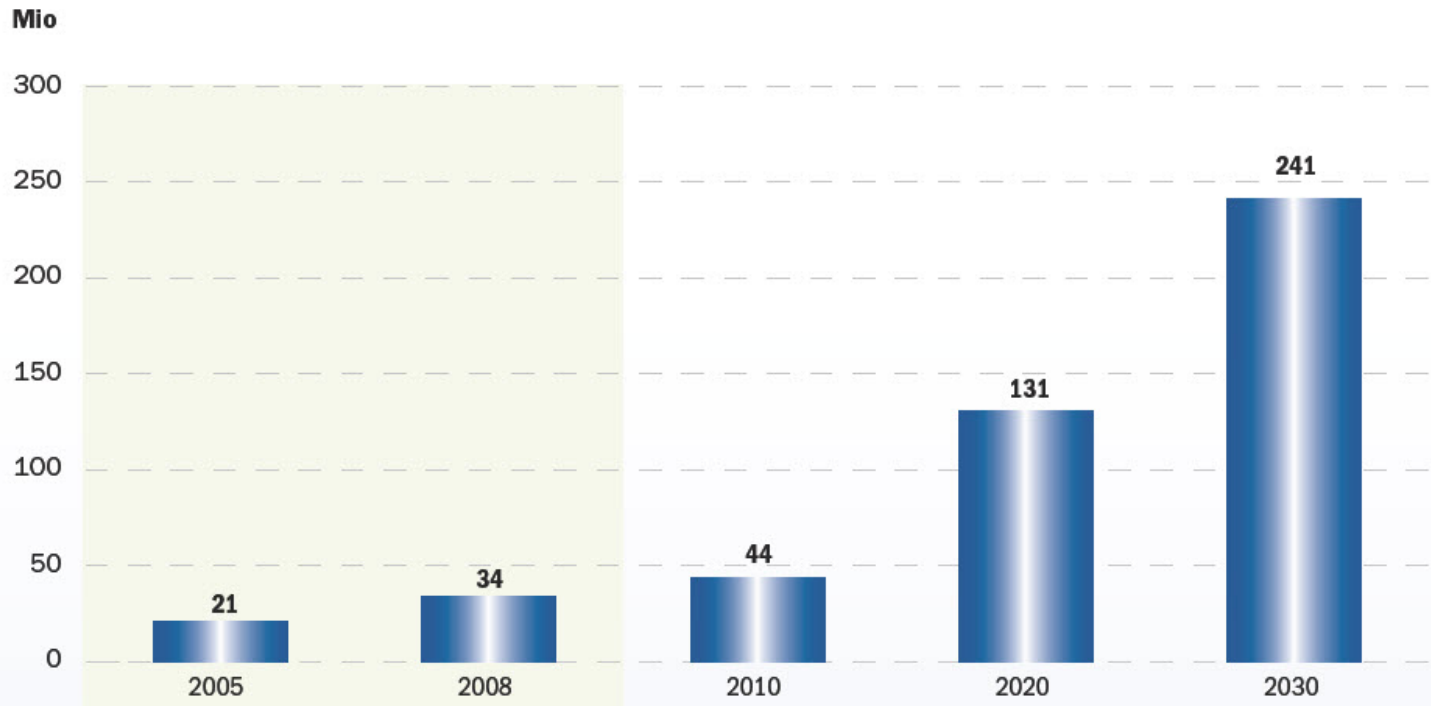
	2000	2005	2008	2010	2015	2020	2025	2030
Wind energy production (TWh)	22.6	82.9	136.9	178.7	335.2	581.6	873.4	1,154.6
EU Baseline (TWh)	2,993.7	3,320.3	3,386.6	3,569.8	3,840.9	4,066.0	4,273.9	4,408.9
Wind energy share - Baseline scenario	0.8%	2.5%	4.0%	5.0%	8.7%	14.3%	20.4%	26.2%
New Energy Policy (TWh)	2,993.7	3,320.3	3,386.6	3,404.5	3,449.2	3,494.0	3,431.1	3,368.1
Wind energy share - New Energy Policy	0.8%	2.5%	4.0%	5.2%	9.7%	16.6%	25.5%	34.3%

Wind energy share - Baseline scenario Wind energy share - New Energy Policy Other energy sources

Source: EWEA; European Commission

WIND POWER'S SHARE OF EU HOUSEHOLD DEMAND

FIGURE 8.2



	2005	2008	2010	2020	2030
Average household consumption (kWh)	3,973	4,037	4,079	4,441	4,787
Number of households (Mio)	196	201	205	221	233
Wind power production (TWh)	83	137	179	582	1,155
Equivalent electricity demand met by wind power (million households)	21	34	44	131	241
Equivalent electricity demand met by wind power (% of households)	**11%**	**17%**	**21%**	**59%**	**104%**

Source: EWEA

[21] Source: Eurelectric and European Commission, 2005.