Karlsruhe Institute of Technology

KIT-Campus Alpin
IMK-IFU: Atmosphärische Umweltforschung

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

RAVE
RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Offshore Wind Energy
Chances, Challenges, and Impact

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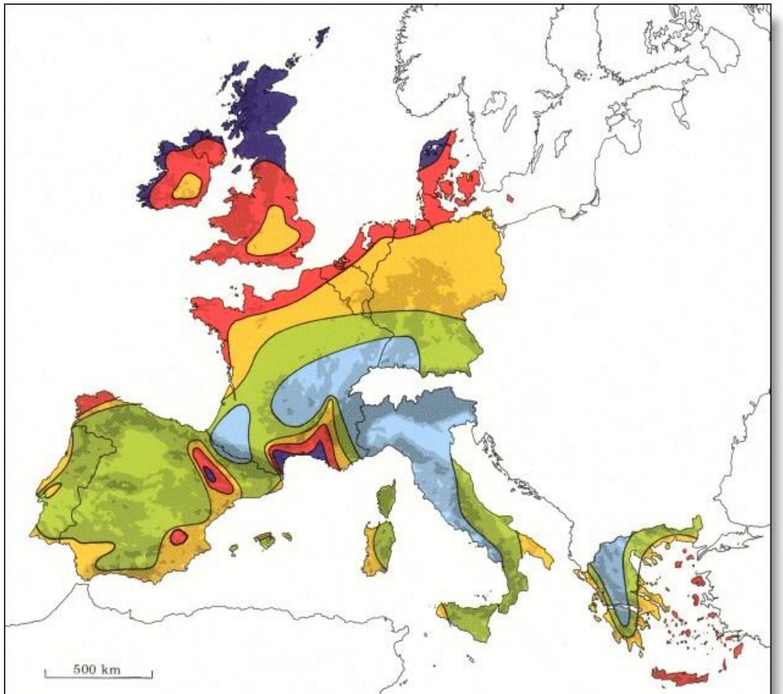
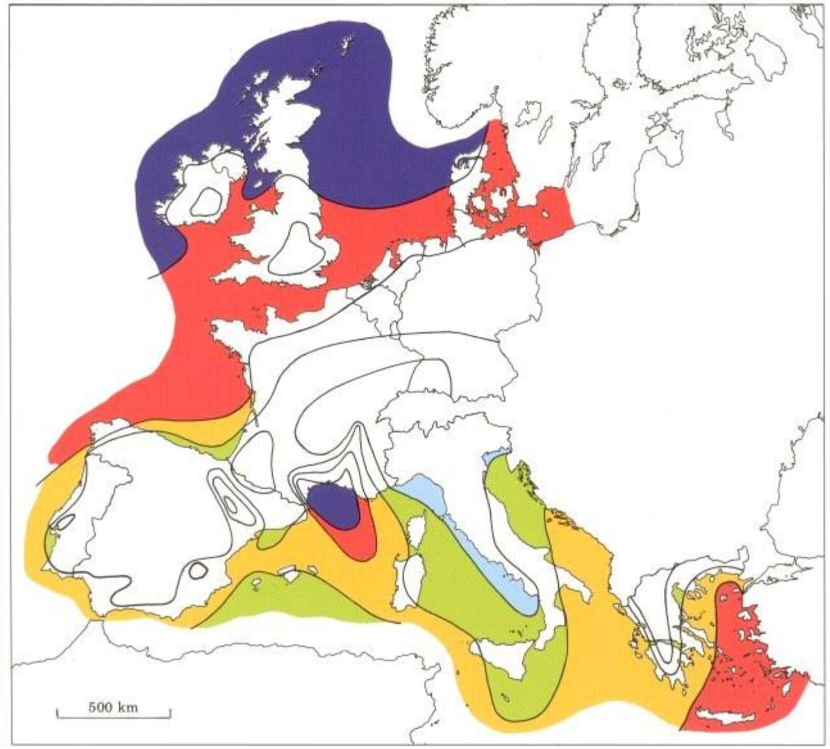
Resources map from the European Wind Atlas





Wind resources over open sea (more than 10 km offshore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

http://www.wwindea.org/technology/ch02/en/2_2_2.html

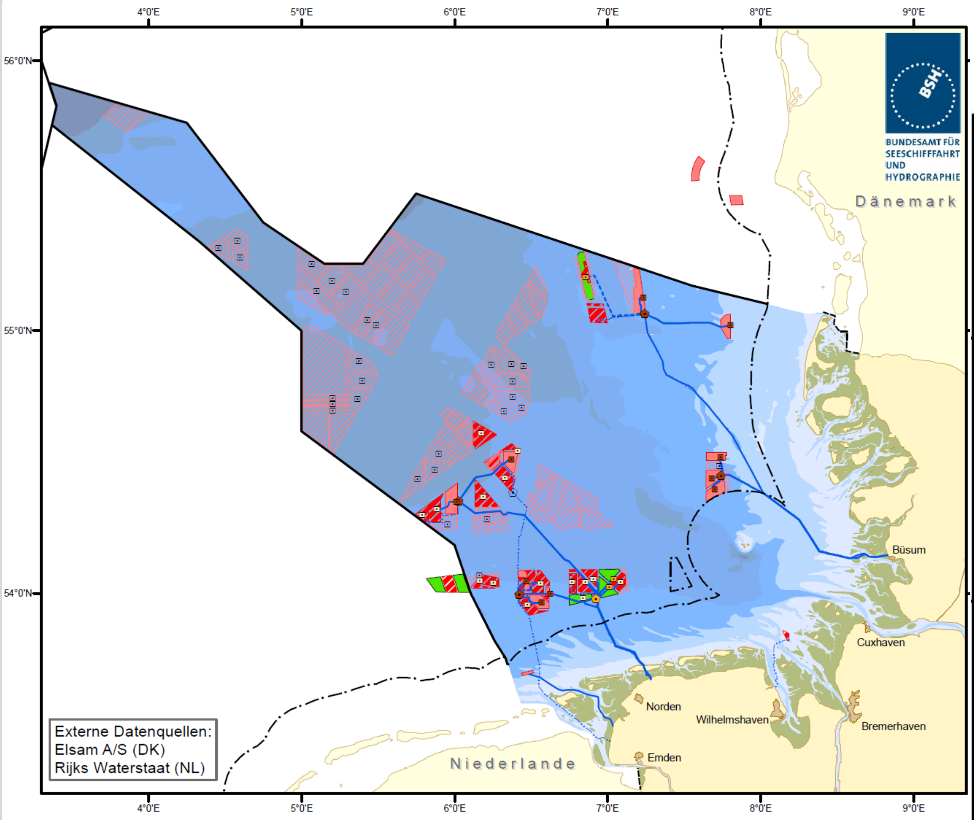
Swedish offshore farm Lillgrund
(Öresund) 110.4 MW
48 turbines (2.3 MW)

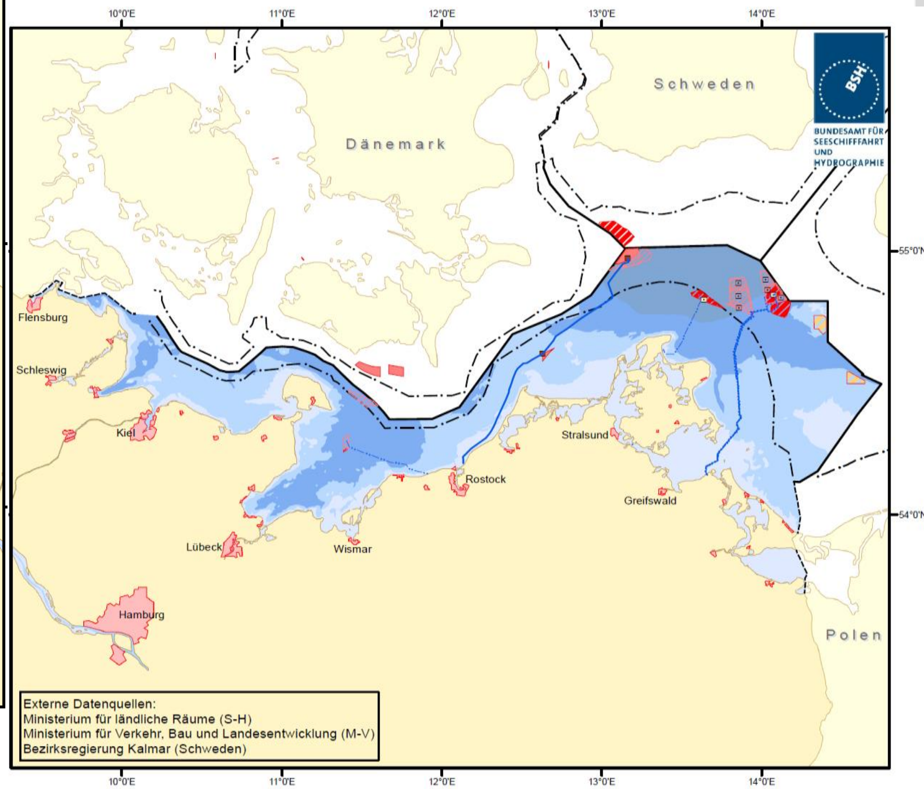
Coastal farm near Rødby
(Denmark)

Erected and planned offshore wind farms in the North Sea

Source:
http://www.4coffshore.com/offshorewind/

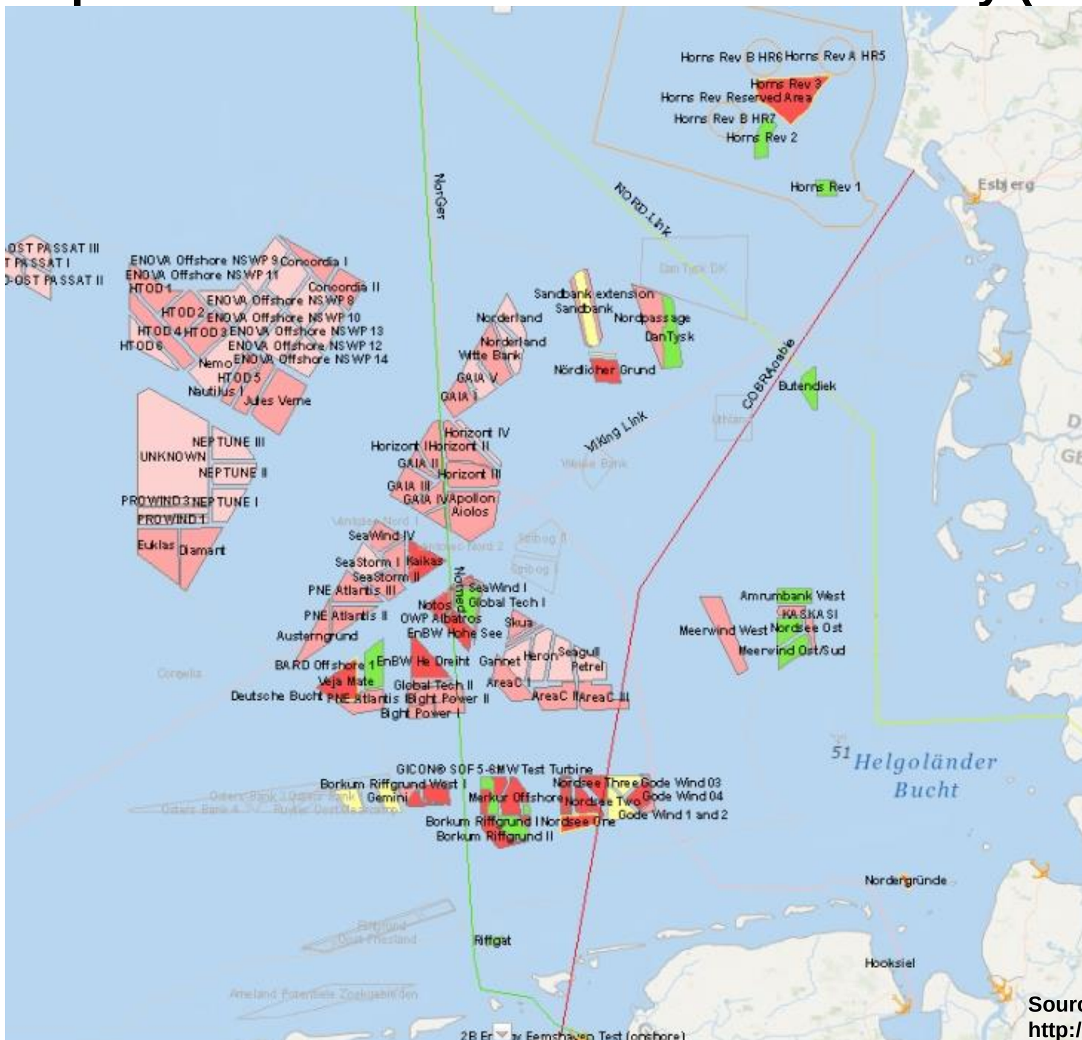
Erected and planned offshore wind farms in Germany





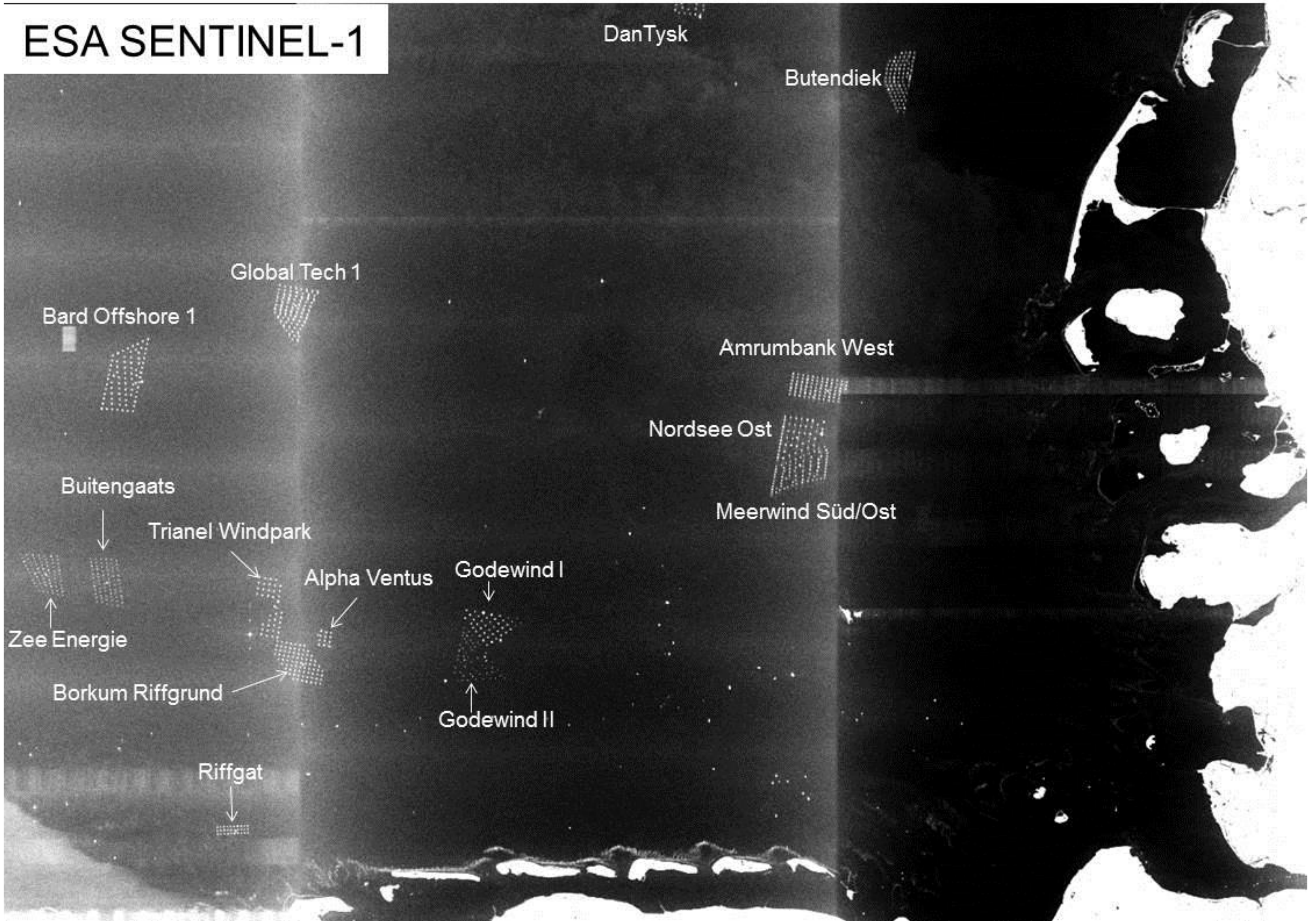
Source: http://www.bsh.de/de/Meeresnutzung/Wirtschaft/CONTIS-Informationssystem/index.jsp

Erected and planned offshore wind farms in Germany (North Sea)



Source:
http://www.4coffshore.com/offshorewind/

Present state of offshore wind farms in the North Sea (SAR satellite image)



Dec. 2015

Pros and Cons for Offshore Wind Energy

Advantages	**Disadvantages**
<u>Physical arguments</u>	
higher capacity factors (1)	correlation between wind direction and stability (2)
higher mean wind speeds (3)	higher extreme wind speeds (gusts) (3)
less turbulence (= less loads)	longer wakes (due to less turbulence) (4)
less vertical wind shear	additional loads due to waves
no diurnal stability variations	
<u>Technical arguments</u>	
	difficult foundations
not visible to the public	bad accessibility for maintenance
lesser hub heights	difficult grid connections
enough space	aggressive environment (sea salt)

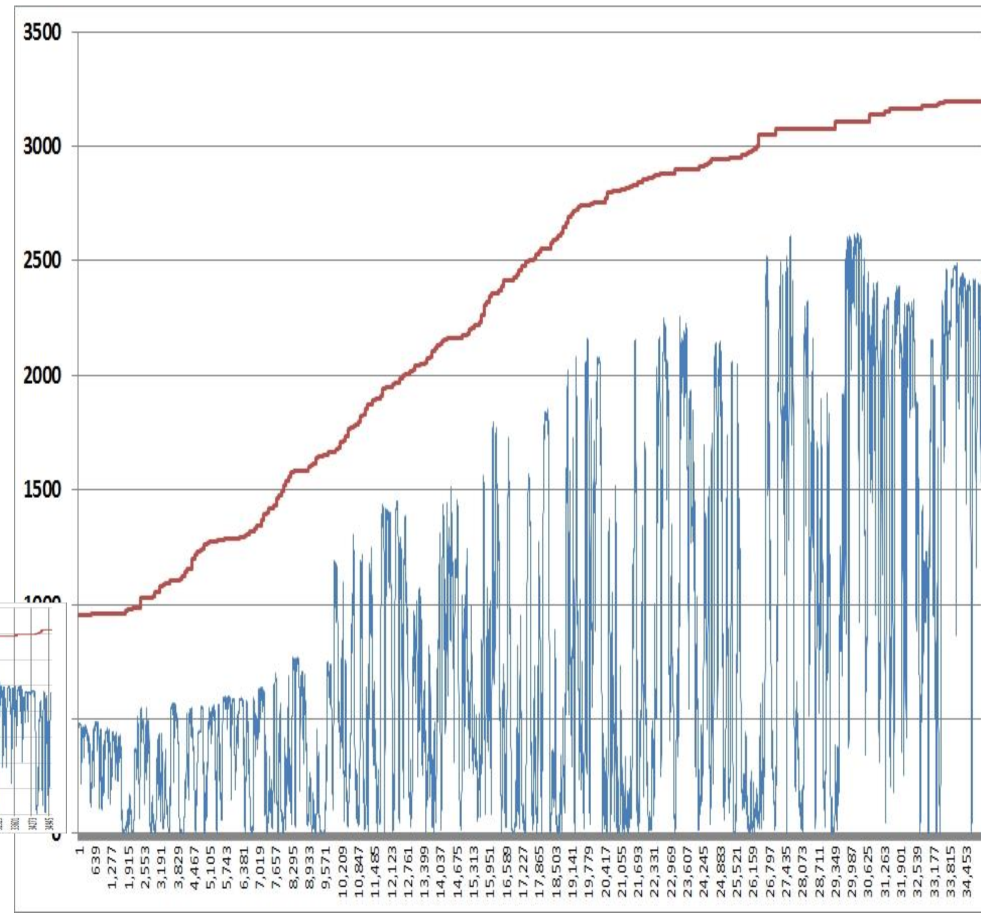
(1) higher capacity factors

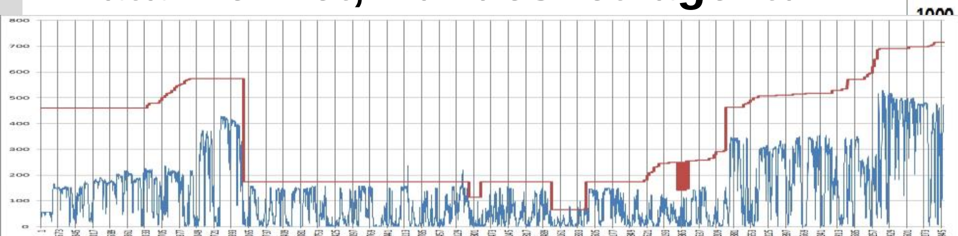
German North Sea

available power (connected to the grid, red)
harvested power (blue)

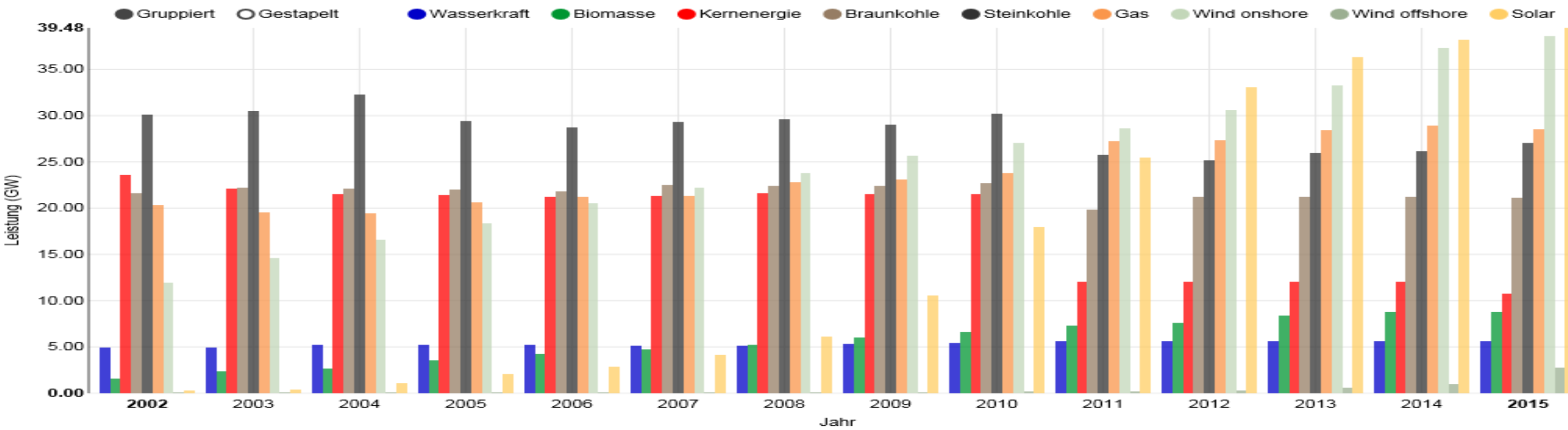
absolut values (MW)
2014 und 2015

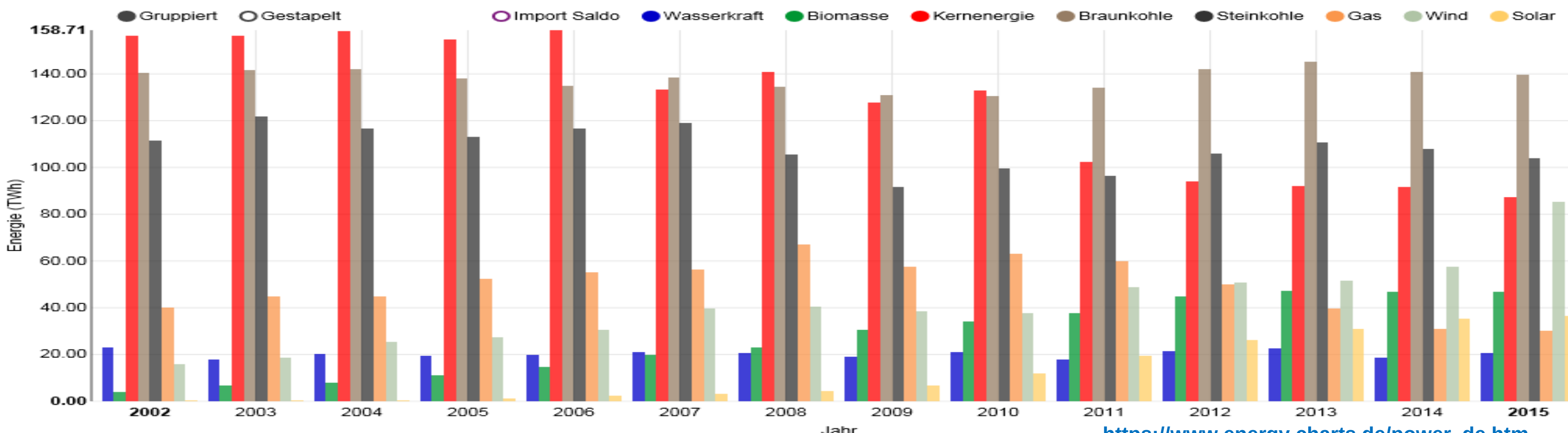
Data: Tennet, Bundesnetzagentur





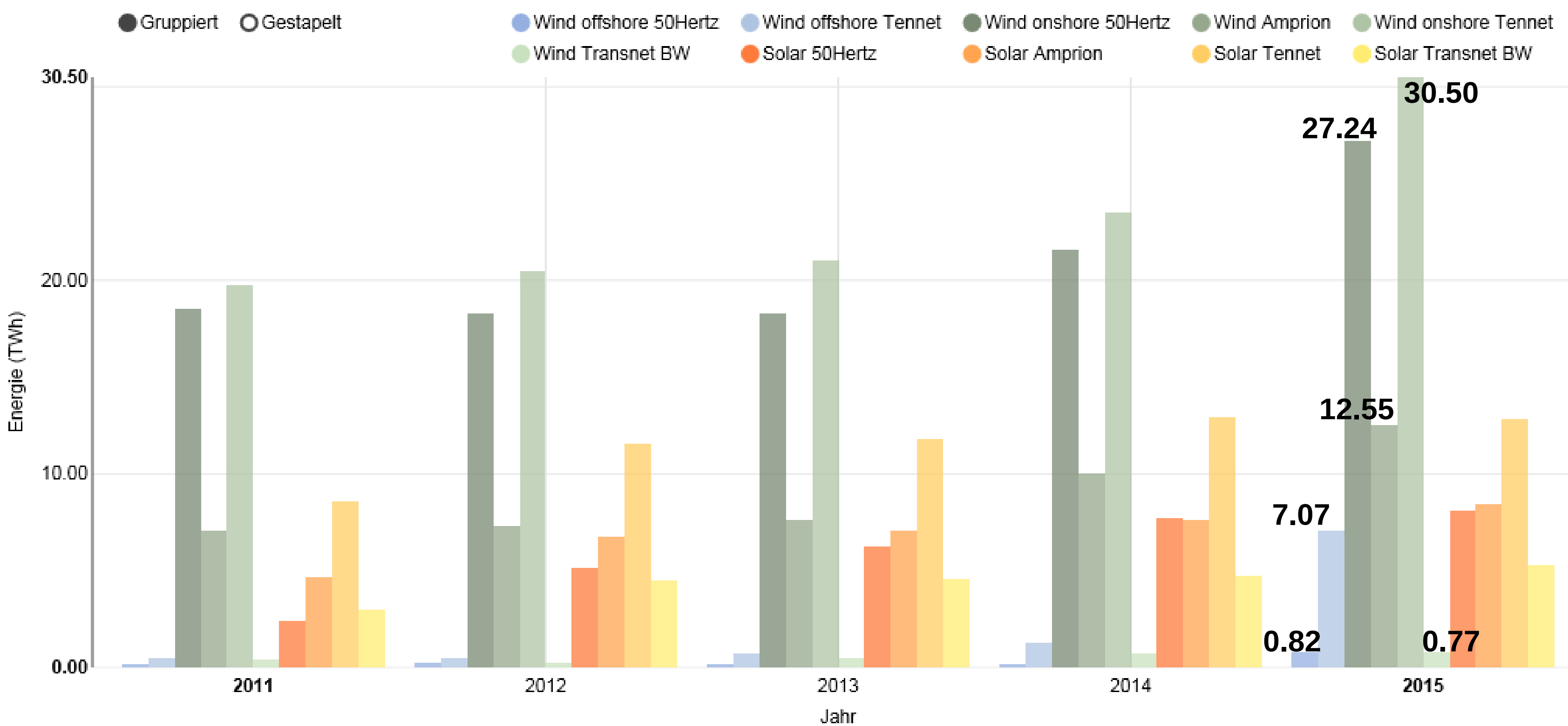
Available power (in GW, top) and harvested energy (in TWh, below) in Germany





https://www.energy-charts.de/power_de.htm

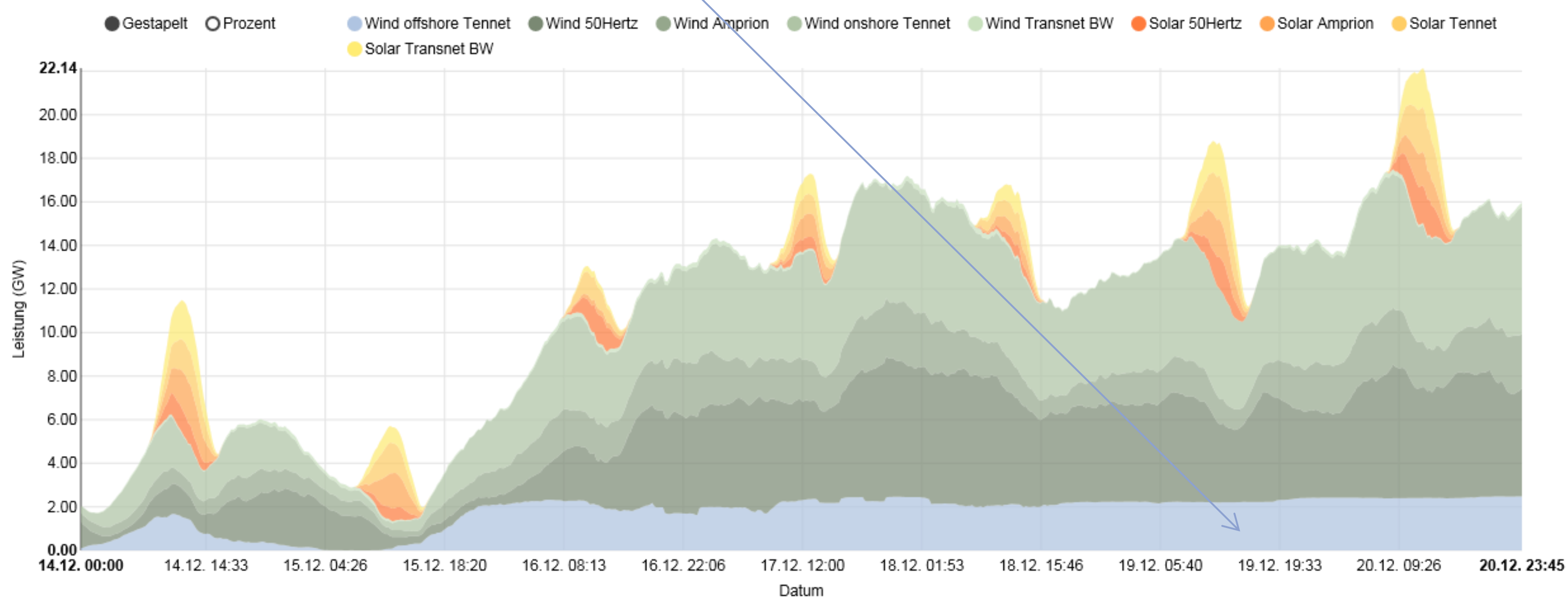
2015: yield offshore 7.89 TWh (10%), yield onshore 71.06 TWh (90%) installed offs.~2.00 GW (5%), installed onshore 38.57 GW (95%)



https://www.energy-charts.de/power_de.htm

Available wind and solar power (in GW) in Germany

offshore wind yield is much more steady



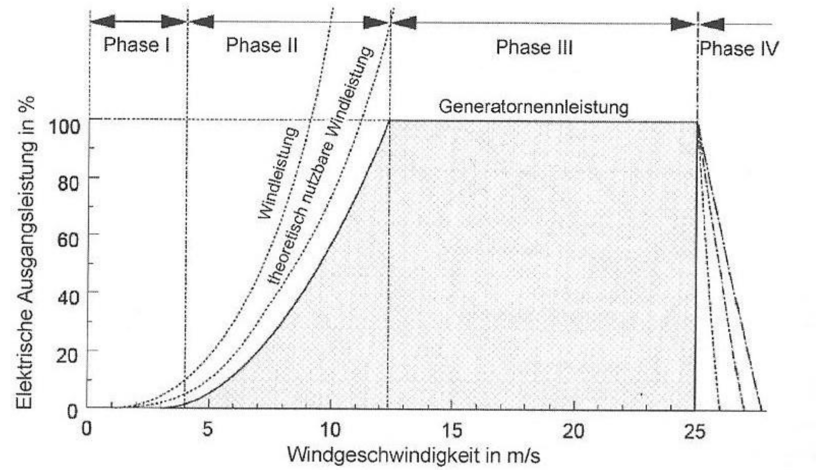
https://www.energy-charts.de/power_de.htm

Power Curves

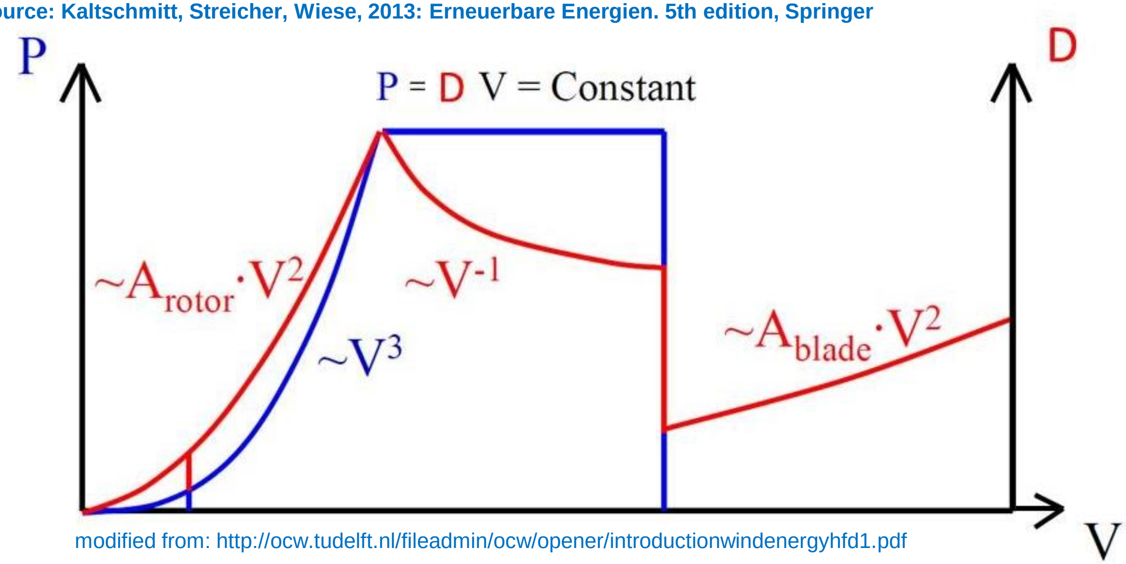
essential parameters

1 cut in speed
2 rated speed
3 cut out speed

P	Power
D	Drag
V	Wind speed



Source: Kaltschmitt, Streicher, Wiese, 2013: Erneuerbare Energien. 5th edition, Springer

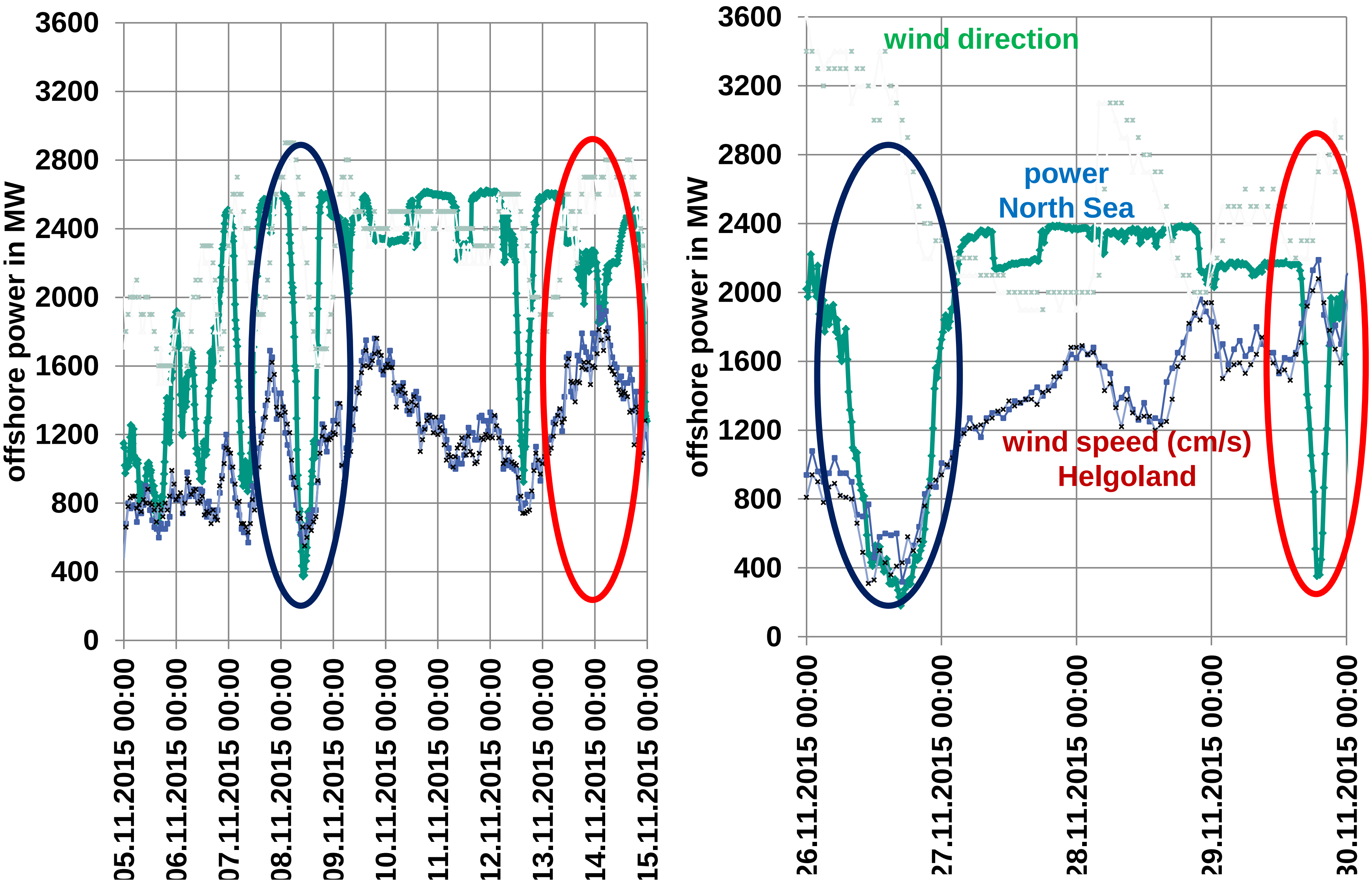


modified from: http://ocw.tudelft.nl/fileadmin/ocw/opener/introductionwindenergyhfd1.pdf

1 2 3

impact of cut-in (blue) and cut-off (red) wind speed

(Data sources: Tennet, DWD)



(2) correlation between wind direction and stability

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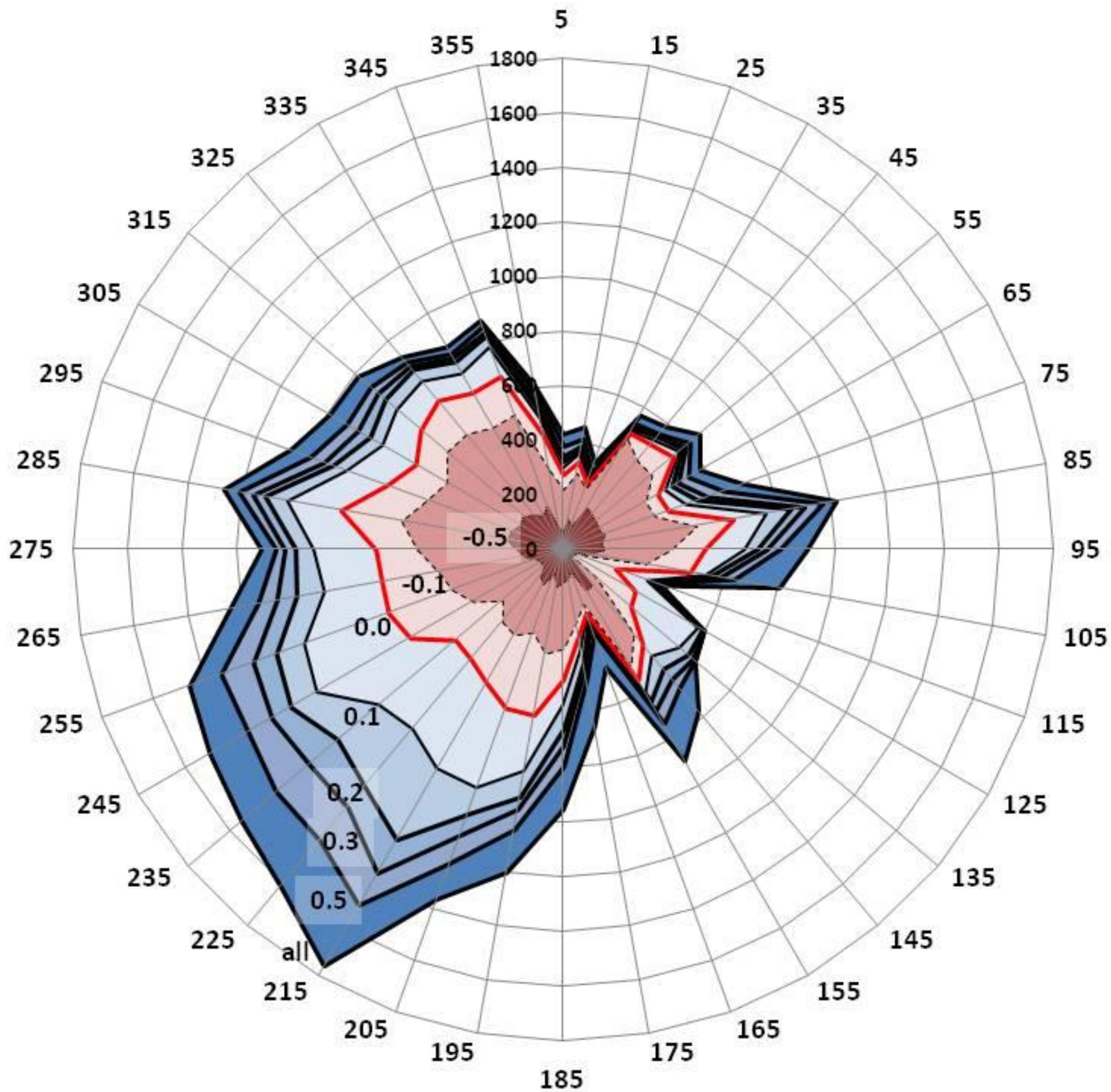
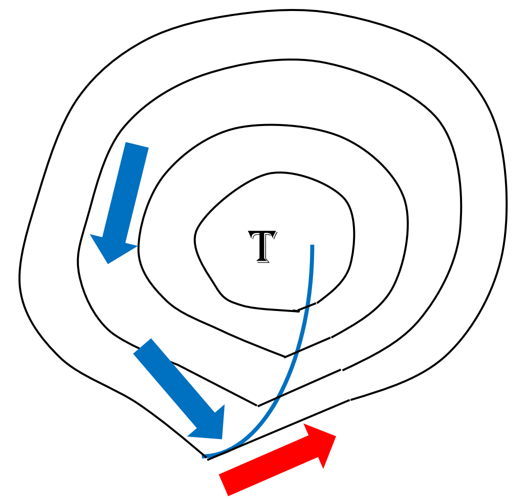


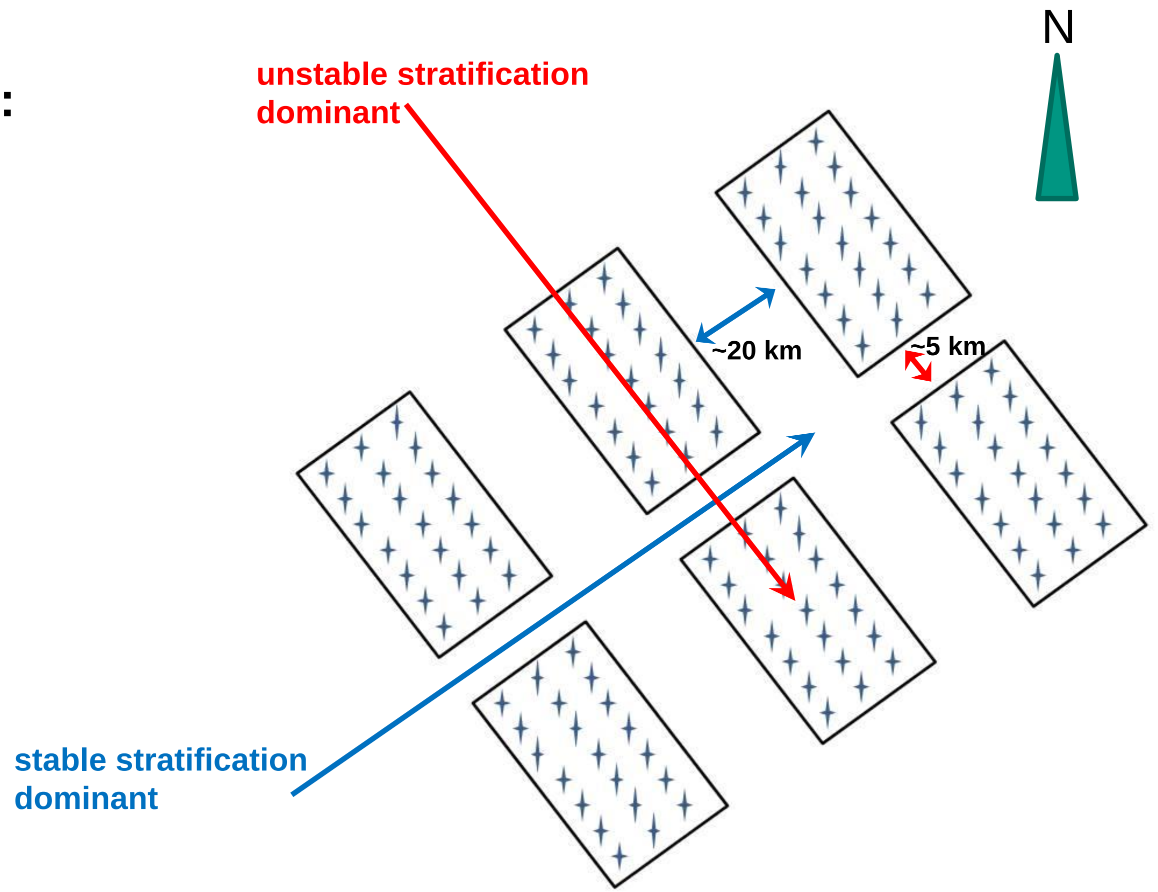
Correlation of wind direction and thermal stability in the marine ABL

stabile conditions dominate in the main wind direction



suggestion:

adapted farm layout:



(3) higher mean and extreme wind speeds

Wind Statistics

Extreme value statistics

Fisher-Tippett type 1 (Gumbel) distribution

$W(x) = \exp(-\exp(-(x-a)/b))$ — wind speed x, constants a and b

$w(x) = (1/b) \exp(-(x-a)/b) \exp(-\exp(-(x-a)/b))$

$-\ln(-\ln(W(x)) = (x-a)/b = x/b - a/b$ — equation of a straight line with slope 1/b

example: 10 min mean values ➔ 52 560 values per year
a 50 yr extreme ➔ one in 50*52560 = 2 628 000 values

$$= -\ln(-\ln(1-1/(2628000)) = -\ln(-\ln(0.999999619)) = -\ln(3.8 \cdot 10^{-7}) = 14.78$$

Emeis and Türk, 2009: Ocean Dynamics 59, 463–475.

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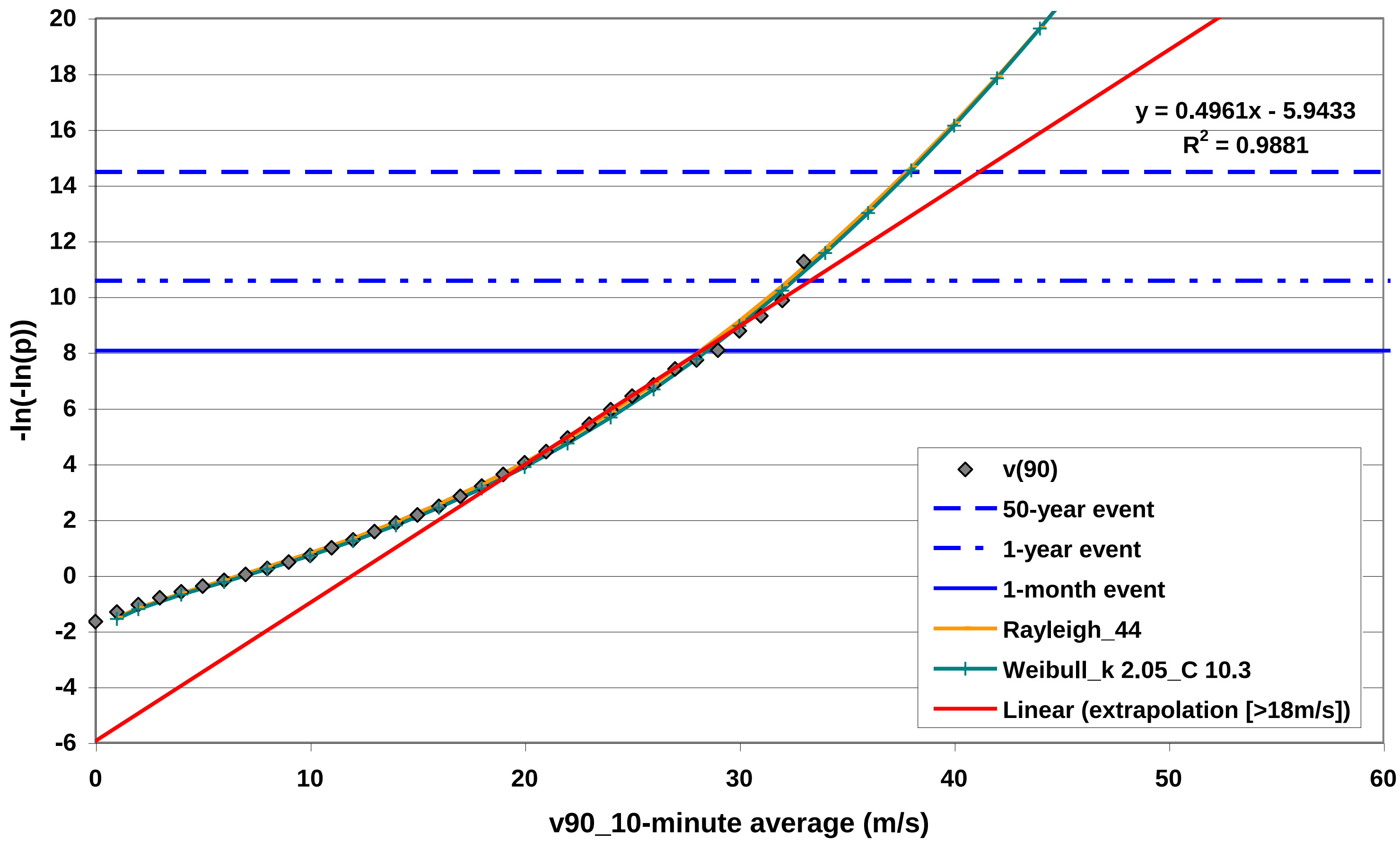
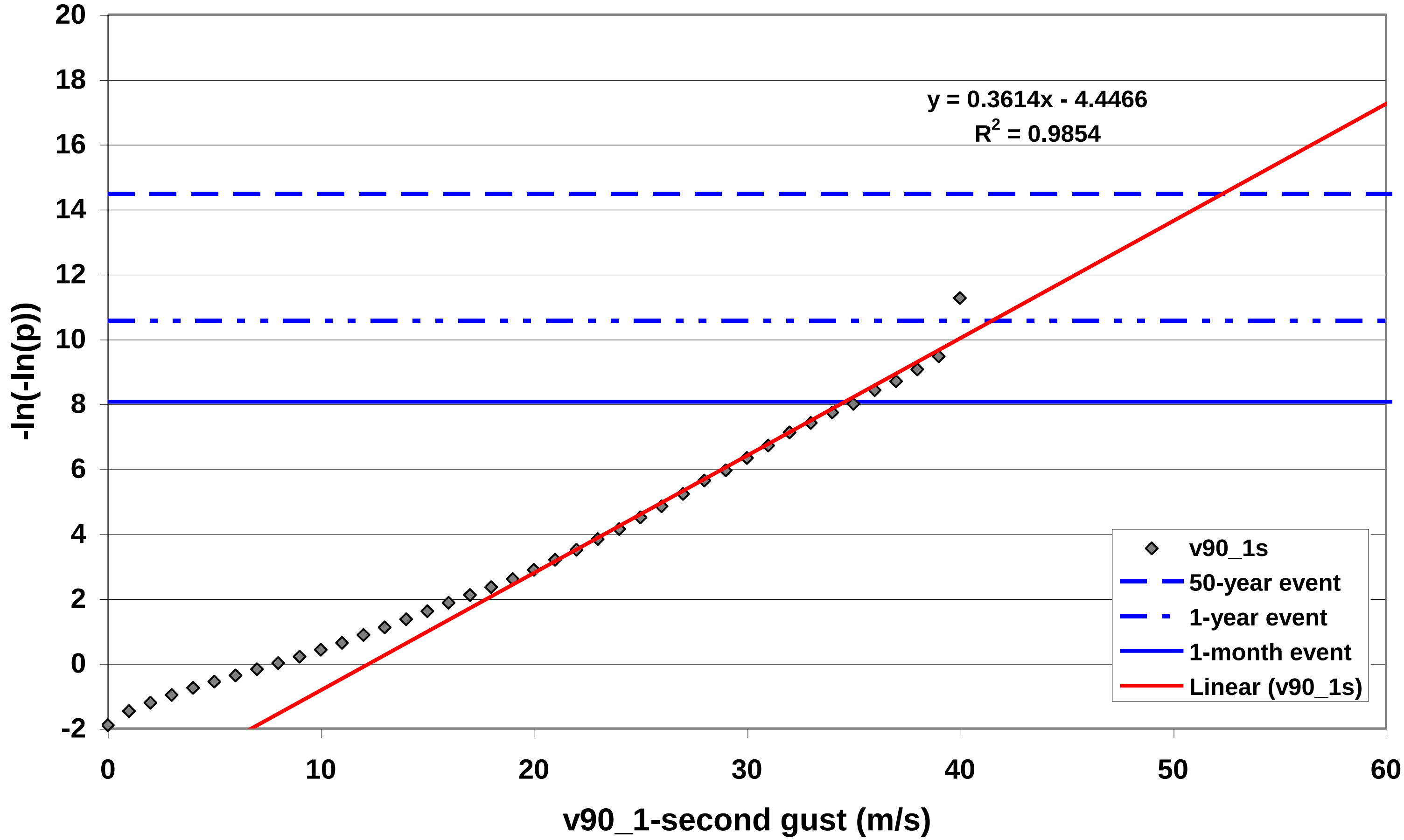
Extreme mean wind speeds

10 min extreme wind speed at FINO1



Extreme gusts

1 sec extreme wind speed at FINO1

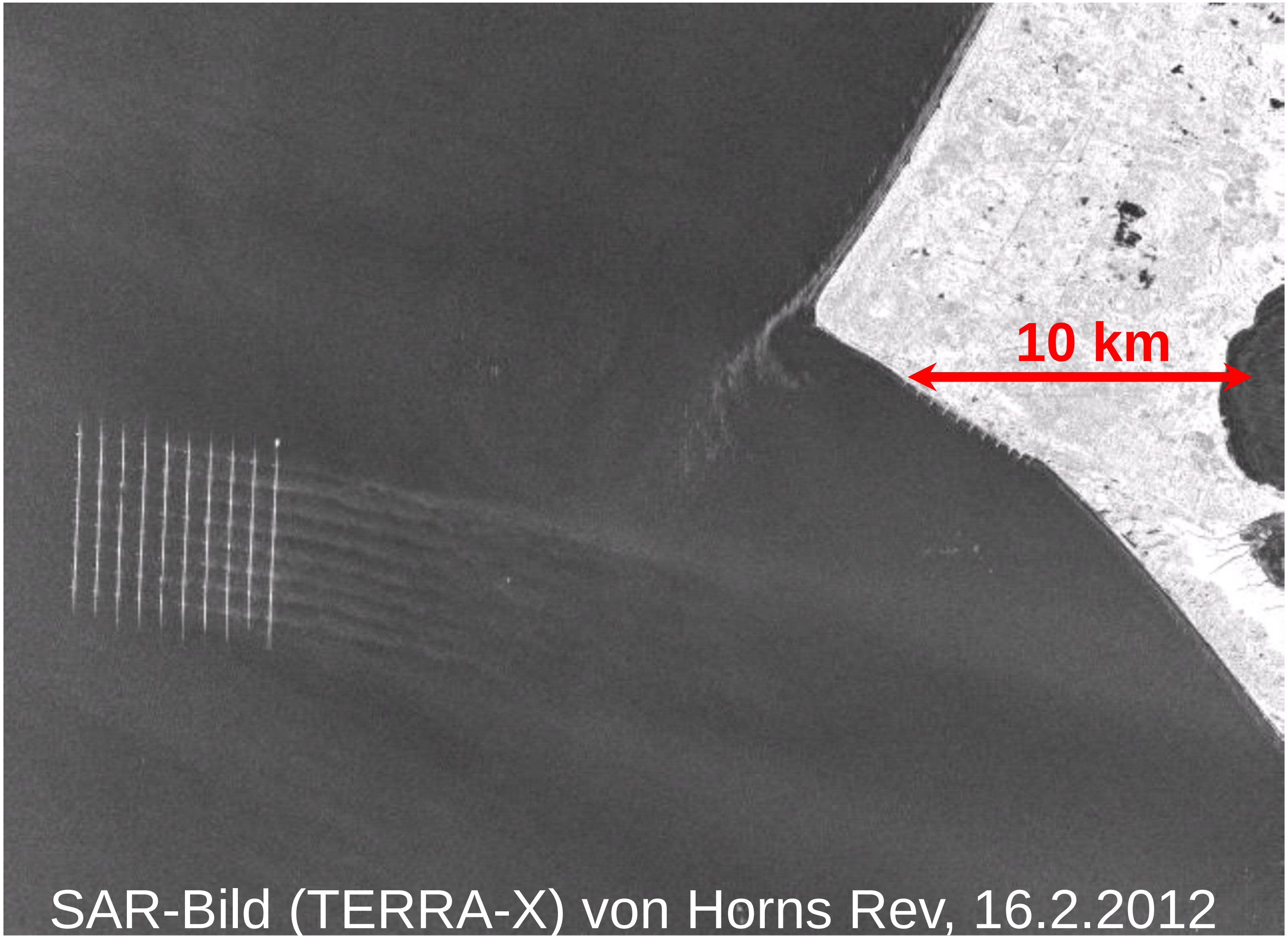


(4) longer wakes

Wakes: turbines wakes and park wakes

Horns Rev, 12 February 2008, Photographer Christian Steiness, Vattenfall

this turbine was not operating!



SAR-Bild (TERRA-X) von Horns Rev, 16.2.2012

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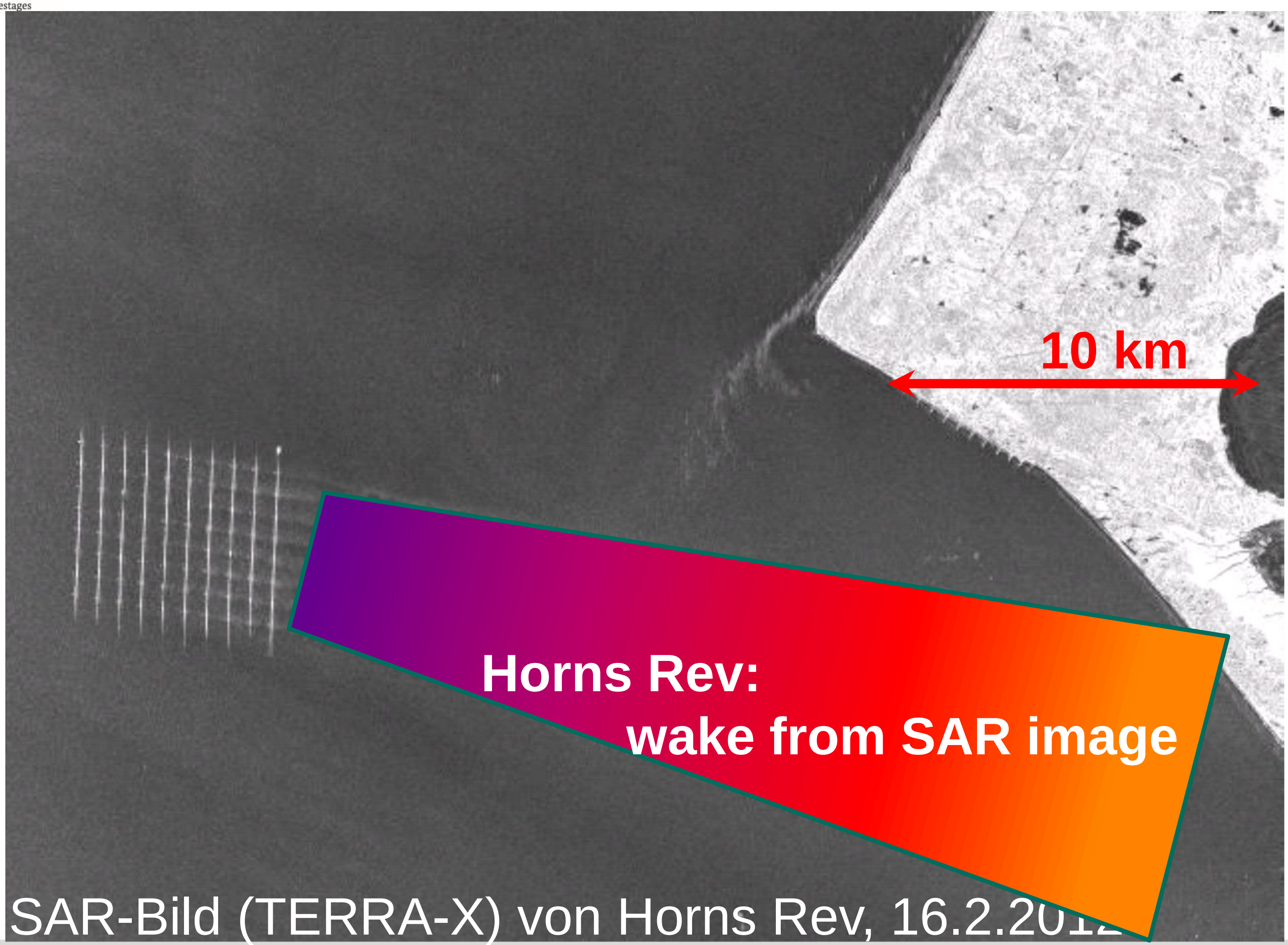

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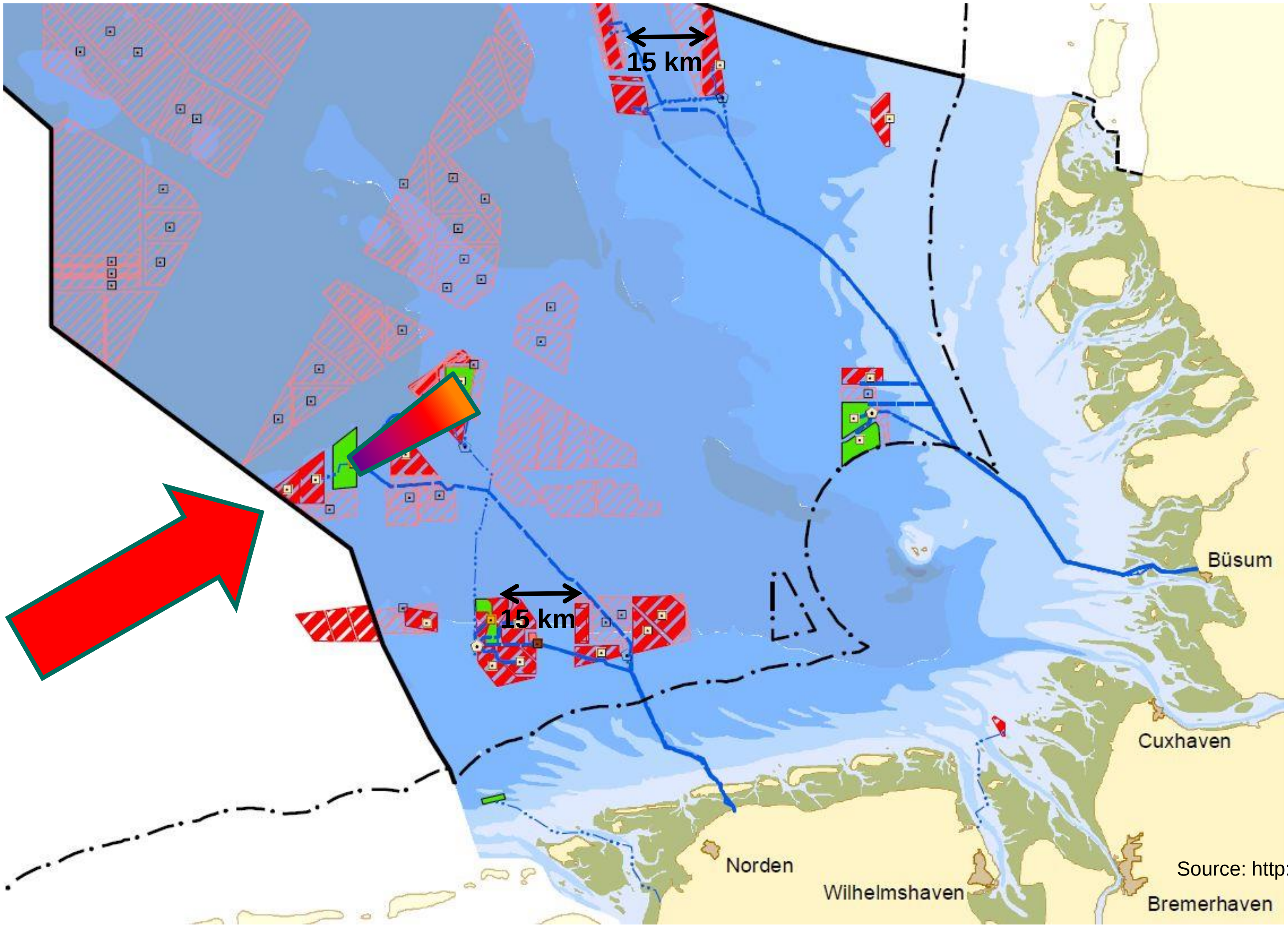

Source: http://www.bsh.de

Park Wakes

wind speed reduction: offshore stronger than onshore

➔ (partial) compensation of higher offshore wind speed
➔ offshore requires a larger distance between turbines

offshore wake length is several times larger than onshore

➔ offshore requires larger distances between wind parks

analytical wake models are strongly simplified

➔ only for rough estimation, exact simulations with numerical models necessary (e.g., WRF)

further research necessary!!!

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WIPAFF

Newly started research project WIPAFF (WInd PArk Far Fields)

11.2015 – 02.2019

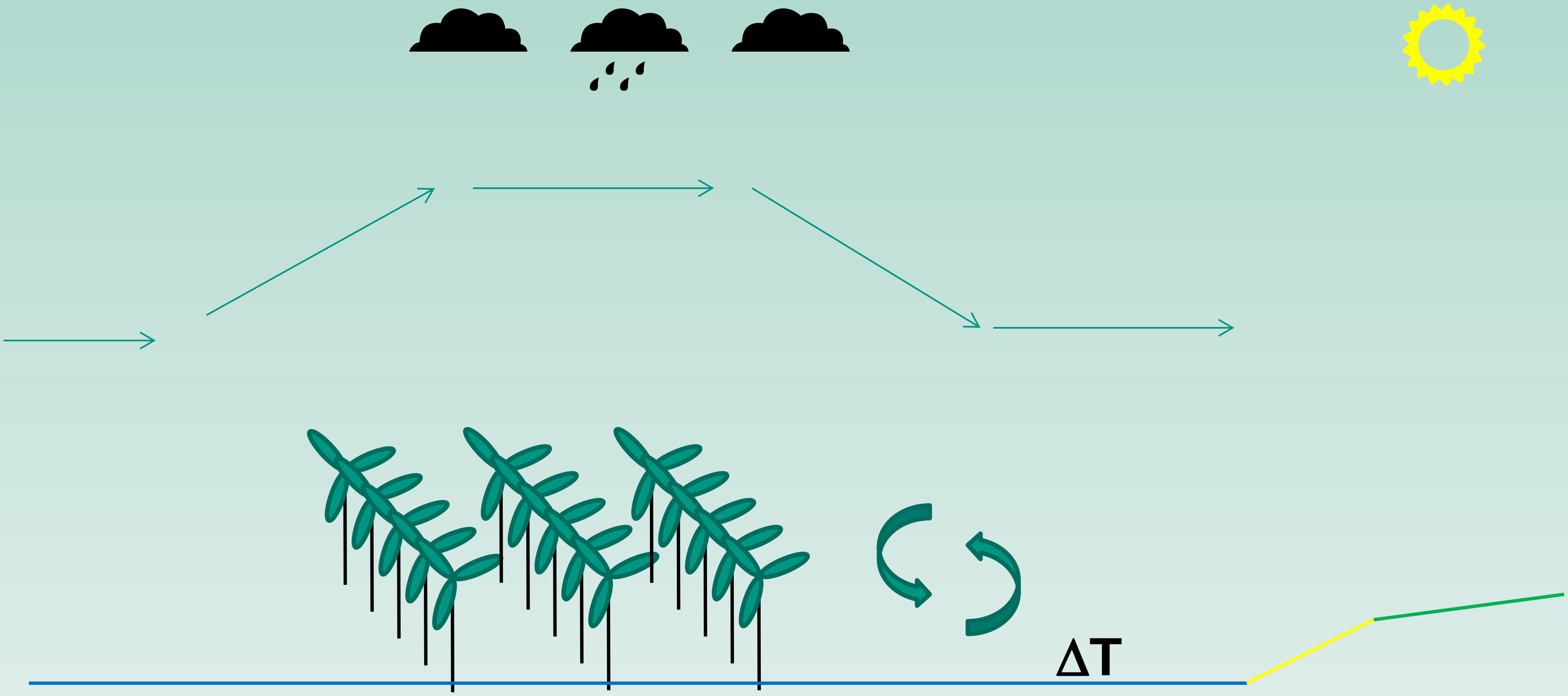
5 Partners: **KIT, Institute of Meteorology and Climate Research**
Technical University of Braunschweig
Helmholtz Centre Geesthacht
UL International GmbH (ex: DEWI)
University of Tübingen

Aircraft (Do 128) observations in the wakes
Analysis of satellite SAR data of wakes
Mesoscale wind field modelling with WRF (wave model, park parametrisation)
Adjustment of analytic and industrial wind park models

assessment of impact on regional climate

Impact on regional climate

cloud formation,
modification of precipitation patterns
modification of sun shine duration
modification of wind fields
…



Outlook and Innovations

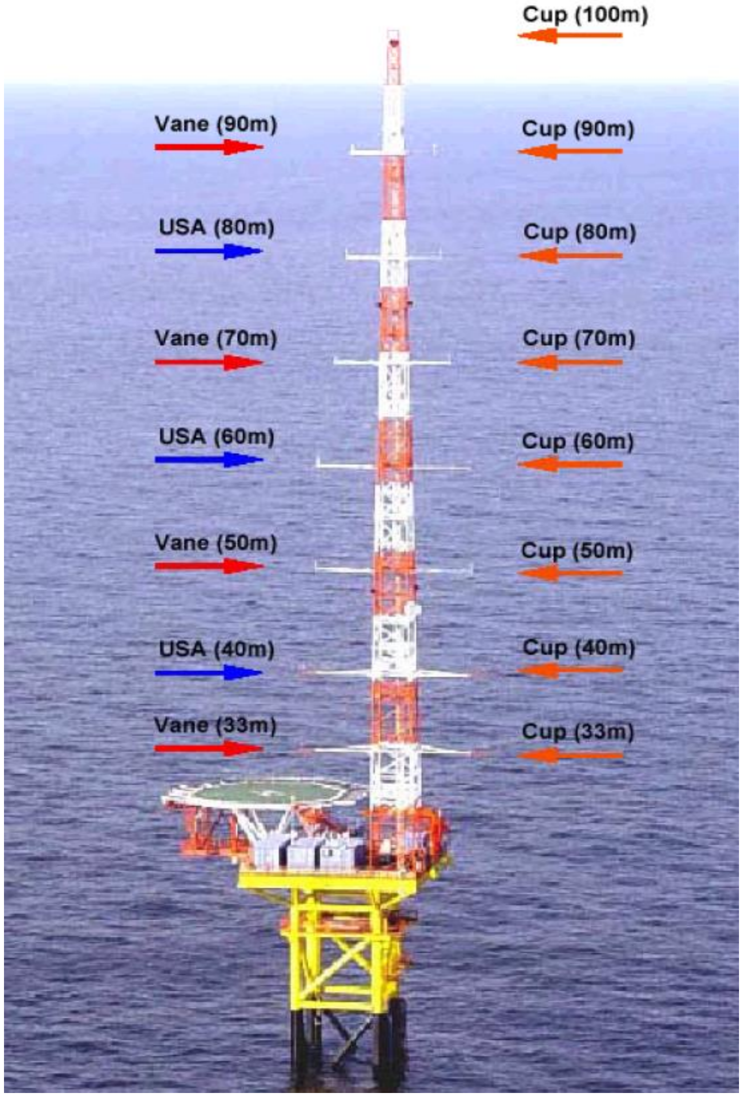
Measurements

In situ versus remote sensing

In situ: masts

remote sensing: platforms and buoys
(wind lidar)

http://www.rwe.com/web/cms/de/86182/rwe-innogy/presse-news/pressemitteilung/?pmid=4014556



Neumann, T., K. Nolopp, 2007: DEWI-Magazin 30,
http://www.dewi.de/dewi_res/fileadmin/pdf/publications/Magazin_30/08.pdf

Types of Wind Turbines

Future developments:

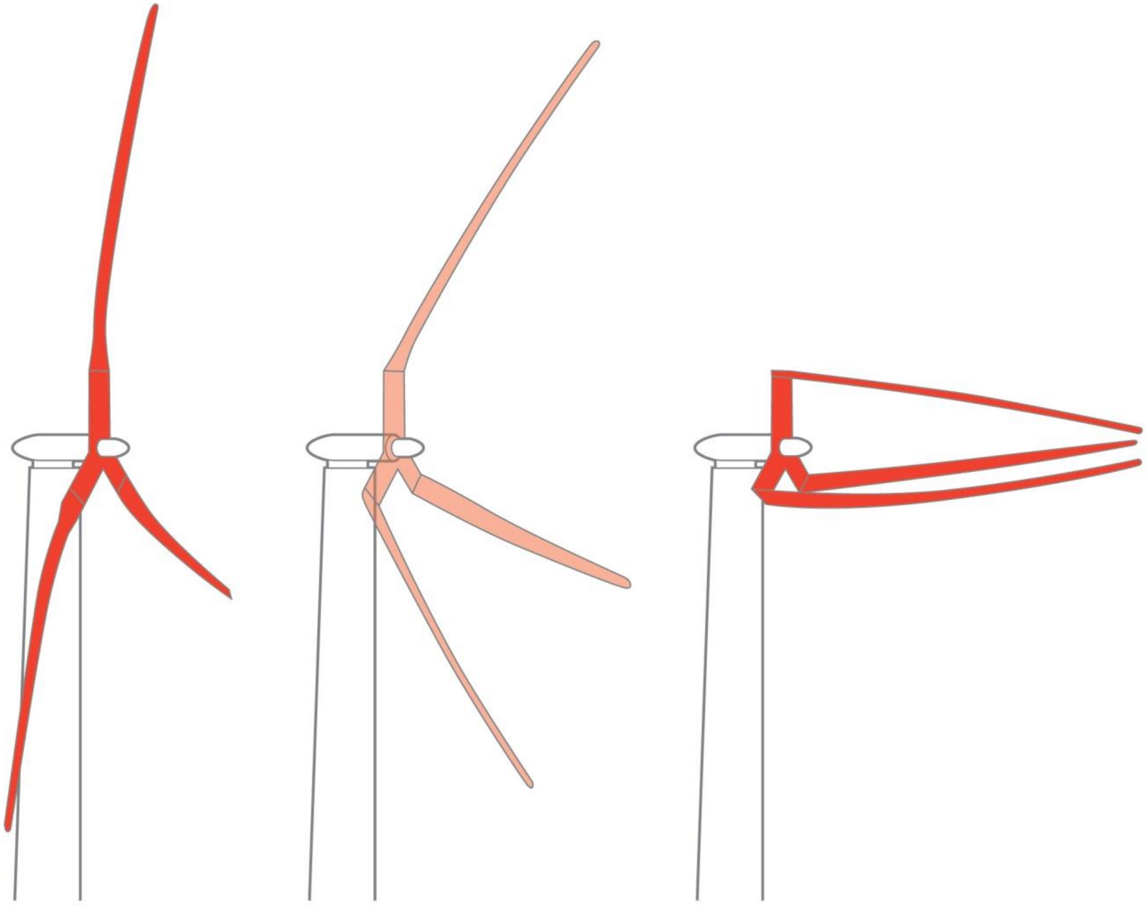
100 m rotor blades
10 MW

200 m rotor blades
50 MW

Segmented Ultralight
Morphing Rotor
(SUMR)

segmented rotor blades
palm-tree inspired
design

(Sandia Nat'l Lab)



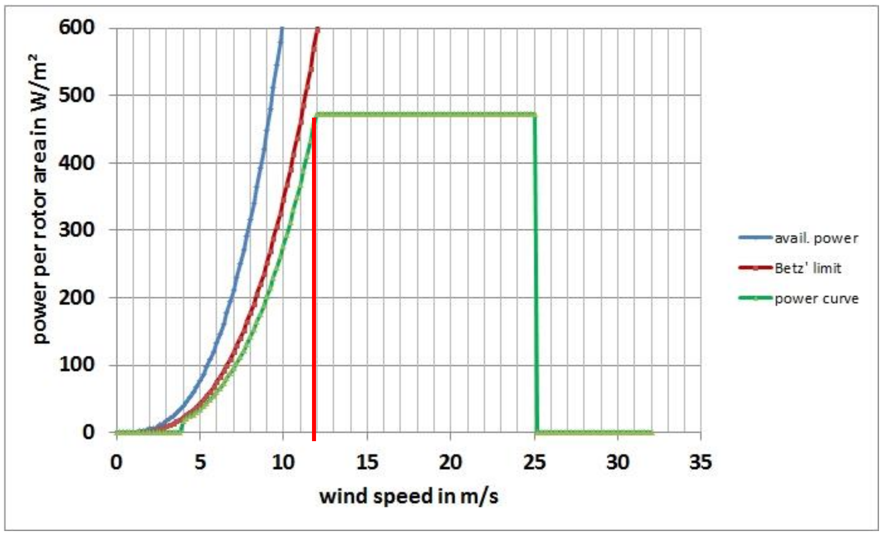
Source: https://share.sandia.gov/news/resources/news_releases/big_blades/#.VrNDfE0wcQ8

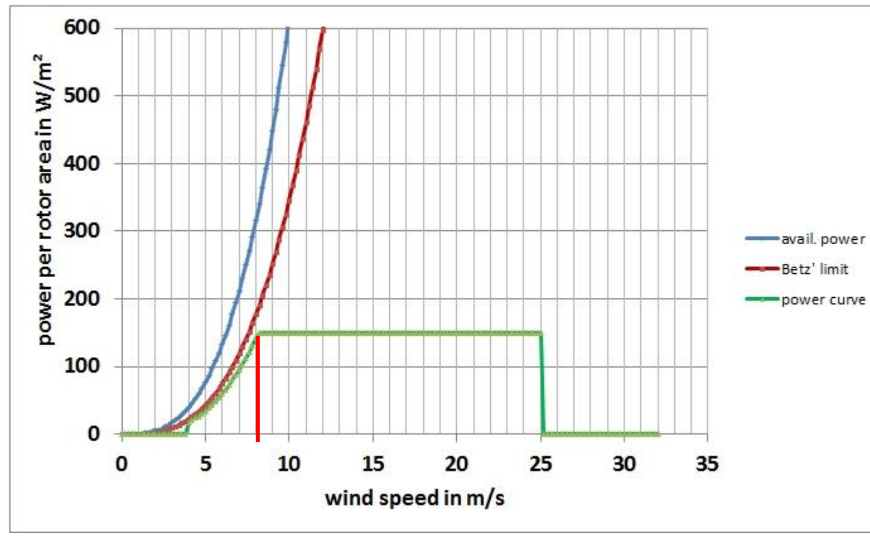
Types of Wind Turbines

Future developments:

turbines not optimized for maximum yield (left, which is harvested rarely)
turbines optimized for uniform yield (right, which can be delivered for long periods)

➔ better grid operation





3 MW, 90 m rotor diameter, 472 W/m² rated power from 12 to 25 m/s

3 MW, 160 m rotor diameter, 150 W/m² rated power from 8 to 25 m/s

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Types of foundations

Future developments:

floating foundations

http://www.offshorewindindustry.com/news/swimming-lessons-wind-turbines

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Thank You

for your

attention