Wind Power Introduction

ESMAP—SAR—EAP
RENEWABLE ENERGY TRAINING
April 23 - 25, 2014 Thailand

Albrecht Tiedemann, Renewables Academy (RENAC) AG

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www.renac.de

Project Manger Albrecht Tiedemann

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- Since 2009: Director and lecturer at Renewables Academy (RENAC) AG; training programs on grid integration of renewable energy, wind energy and hybrid power systems; capacity building programs ReGrid and CapREG; cerfified e-learning manager
- 2003 – 2009: Project manager at German Energy Agency; grid integration of renewable energy and onshore/offshore wind energy; chairman of the German Offshore Committee
- 1989 – 2003: Scientific assistant at German Federal Environmental Agency; offshore wind energy, offshore gas/oil exploration, pulp and paper industry, life cycle assessment
- 1989: Graduated as Engineer Environmental Protection Technology at Technical University of Berlin

Agenda

1. About Renewables Academy (RENAC) AG
2. Technology overview
3. Project planning
   - Project development
   - Considerations and steps of project planning and implementation
   - Resource assessment
4. Implementation
   - Siting and permitting: introduction to environmental issues
   - Transport and construction/ installation works
   - Wind turbine testing and certification
   - Operations and maintenance activities
5. Financial modeling
   - Basic components and structure of model
   - Key performance metrics
   - Key risks

AGENDA

About Renewables Academy (RENAC) AG

About RENAC

- RENAC is a berlin-based training specialist for Renewable Energy and Energy Efficiency.
- RENAC was founded in 2008.
- RENAC is a private sector company with 24 employees.
- RENAC trained more than 4000 people from over 130 countries.
- RENAC's clients are from public and private sectors.
- RENAC offers
  - Short-term trainings (2 to 10 days)
  - Academic education (MBA-Renewables, GPE-New Energy)
  - Capacity Building Services (RENAC supports third parties to build up their own capacities for trainings)
- RENAC is independent.

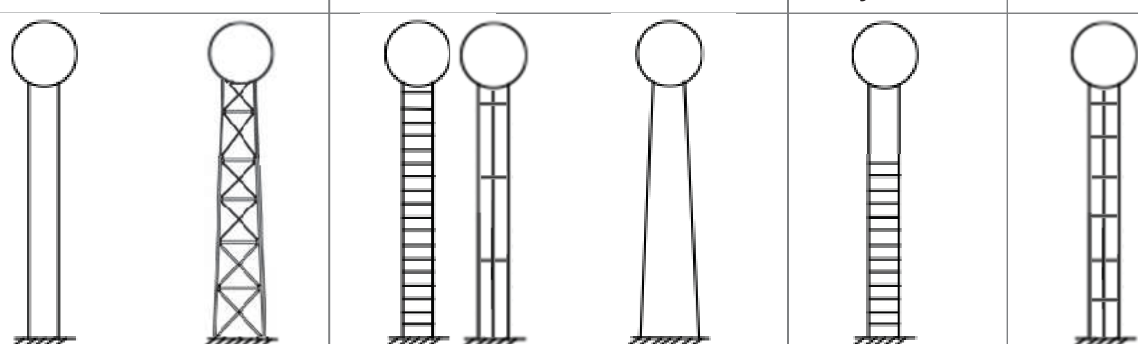
Technology overview

Rotor types of wind turbines

- Horizontal wind turbine with N blades
- Horizontal wind turbine with 3, 2 and 1 blades
- Vertical wind turbine
- Vertical wind turbine – Darrieux
- Vertical wind turbine - Savonius

Typical tower designs for wind turbines

Steel		Concrete		Hybrid	Wood
Cylindrical tower	Lattice tower	Pre-fabricated segments (different designs)	On-site concrete (in situ concrete)	Pre-fabricated segments and steel tube	Pre-fabricated segments (different designs)
Also as guyed tower					



Tower advantages/disadvantages

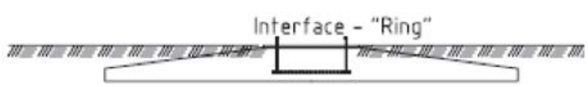
Lattice tower
- + Material cost
- + Transport
- - Assembly time and maintenance costs

Steel tube tower
- + Service
- + Assembly time and dry interior
- - Transport (large elements)

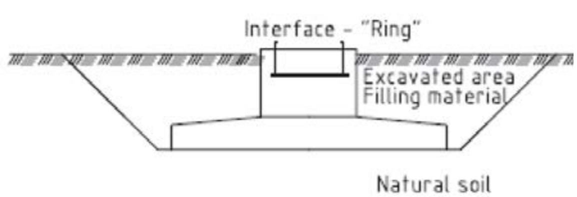
Concrete tower
- + Transport (rings and slabs)
- + High damping and dry interior
- - Assembly time

Different types of foundations for wind turbines

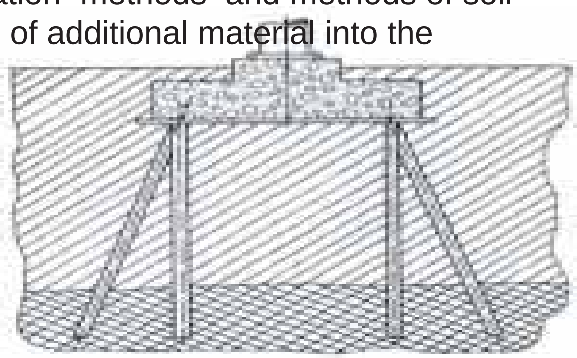
- Spread foundation
  - Shallow foundation



  - Gravity foundation

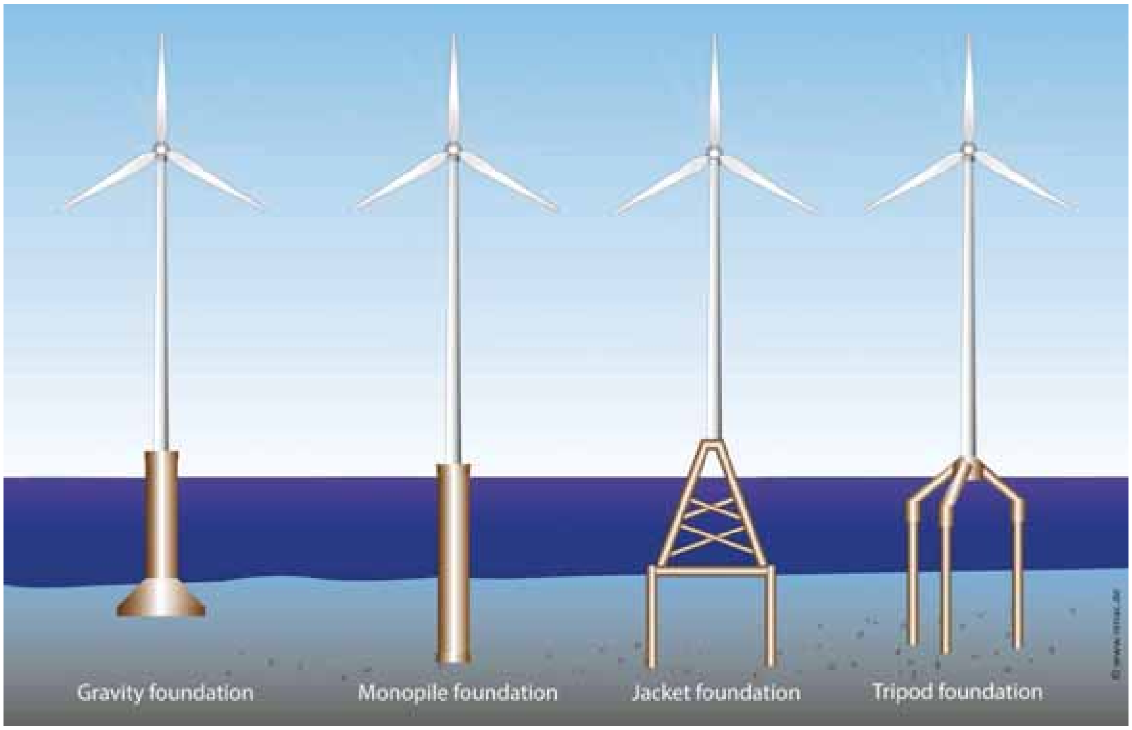


- Soil stabilization (compaction/densification methods and methods of soil reinforcement through the introduction of additional material into the ground)
- Piled foundation
  - Piling to bedrock
  - Piled-raft foundation (combination of spread foundation and piling).

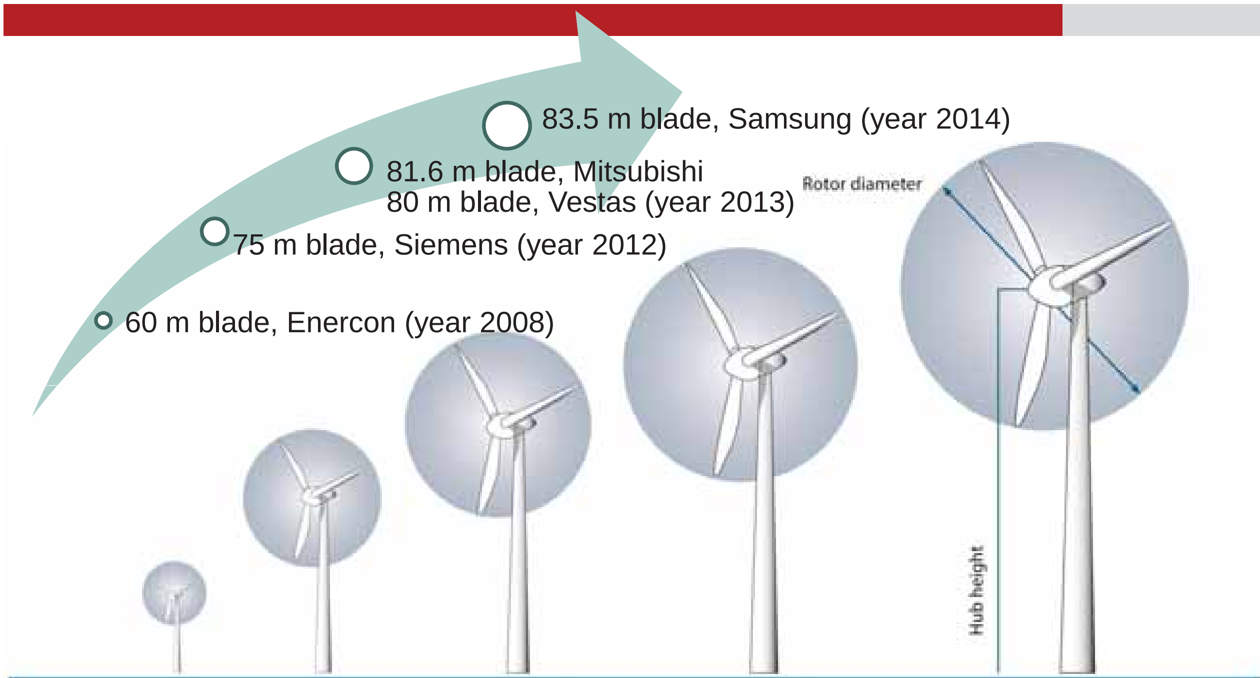


HENRIK SVENSSON: DESIGN OF FOUNDATIONS FOR WIND TURBINES, Sweden 2010; Source Gasch Twele 2010

Foundation for offshore wind turbines



Development wind turbine rotor diameter and hub height



	1980	1985	1990	1995	2000	2005	2008	2011	2013
Rated power:	30 kW	80 kW	250 kW	600 kW	1.500 kW	3.000 kW	6.000 kW	7.500 kW	8.000 kW
Rotor diameter:	5 m	20 m	30 m	46 m	70 m	90 m	126 m	127 m	164 m
Hub height:	30 m	40 m	50 m	78 m	100 m	105 m	135 m	135 m	site specific (offshore)

Trend towards longer rotor blades

$$P = \frac{1}{2} \times \rho \times A \times v^3$$

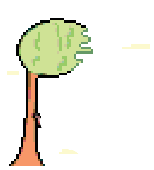
- P = power of wind (watt; joule per second)
- ρ = air density (kg/m^3; kilogram per cubic meter)
- A = area (m^2; square meter)
- v = wind speed (m/s; meter per second)

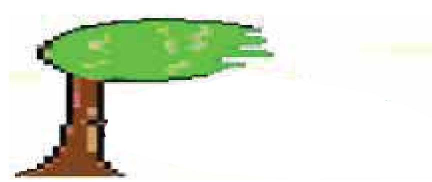
Advantages	Disadvantages
Reduction of production costs due to scale effects	Transport limitations, narrow streets (therefore rotor blade in two pieces)
Increase of energy yield per turbine and power of wind turbine	Higher road construction cost in complex wind farm terrain (hills, mountains)
Increase of full load hours, capacity credit and capacity factor of turbines	Challenge: high stiffness needed to avoid collision with tower during strong gusts
Economic use of site with relatively bad wind resource is possible	Stronger forces at the rotor lead to stronger foundations/towers

Source: Neue Energie, 02/2014, page 24ff

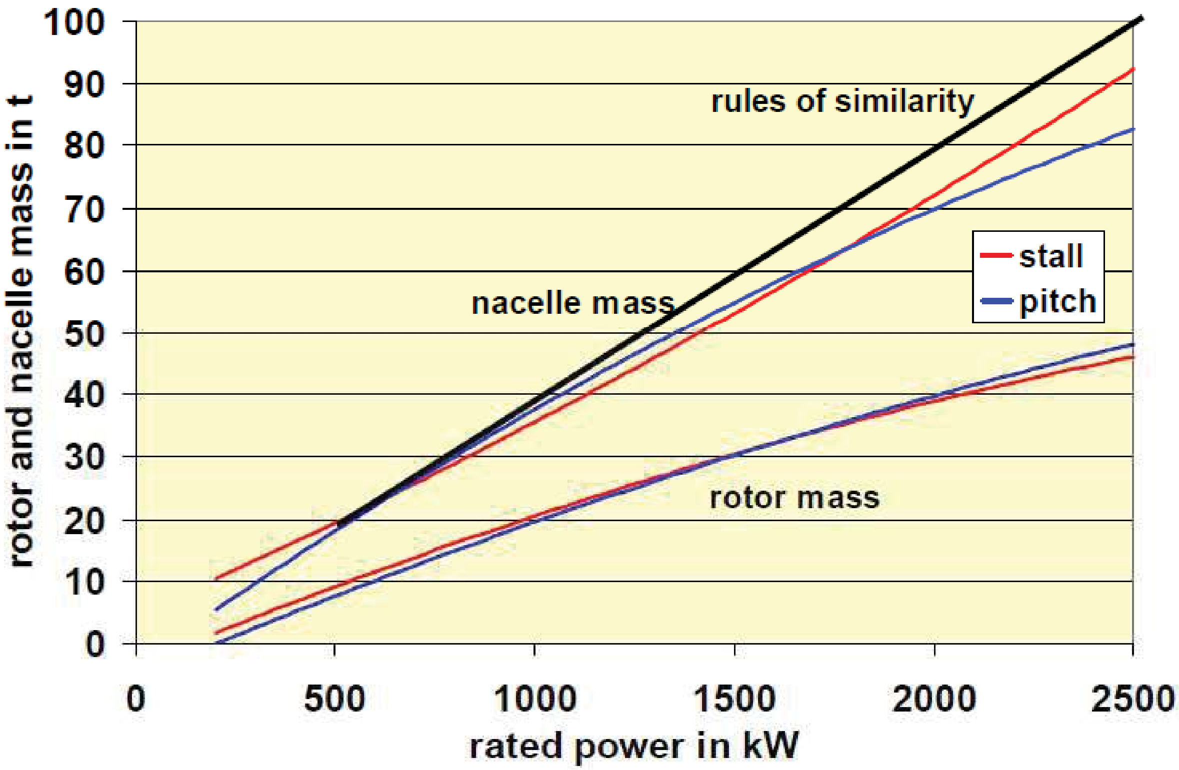
Exercise: doubling of wind speed

- Let's double the wind speed and calculate what happens to the power of the swept rotor area. Assume length of rotor blades (radius) 25 m and air density 1.225 kg/m^3).
- wind speed = 5 m   wind speed = 10 m



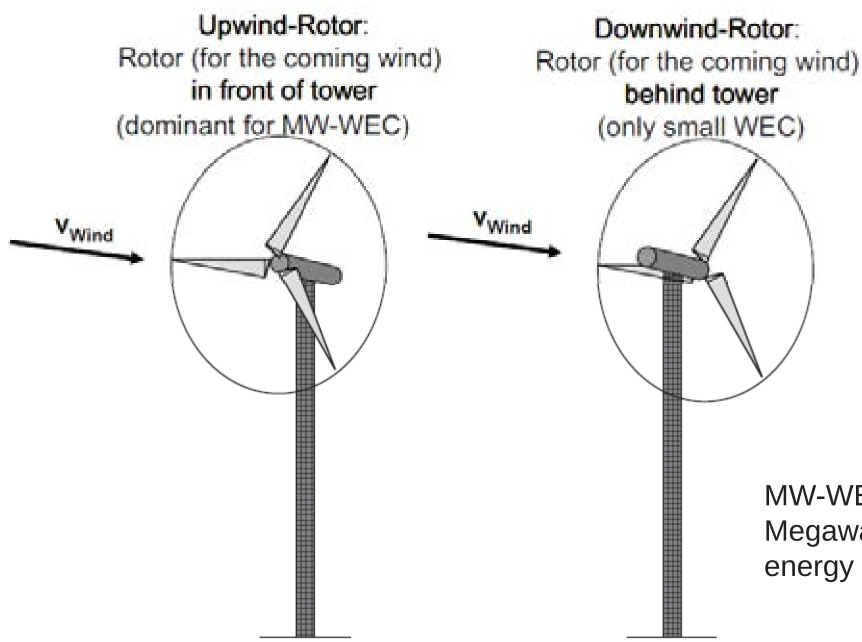


Rotor and nacelle mass with rotor diameter



J.Iiersch; KeyWindEnergy, 2009

Upwind and downwind horizontal turbines



MW-WEC = Megawatt wind energy converter

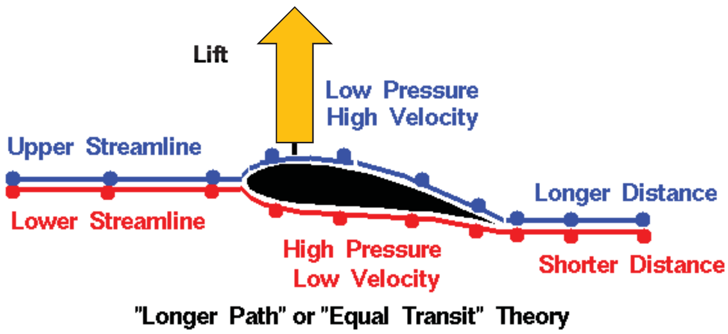
Lift and drag principle

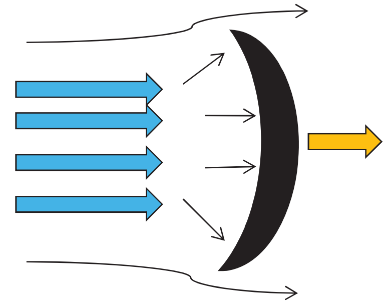
Lift principle

- The deflection of initially parallel wind flow causes a difference in pressure and therefore a lift force.

Drag principal

- The deceleration of the perpendicular flowing wind causes a drag force.

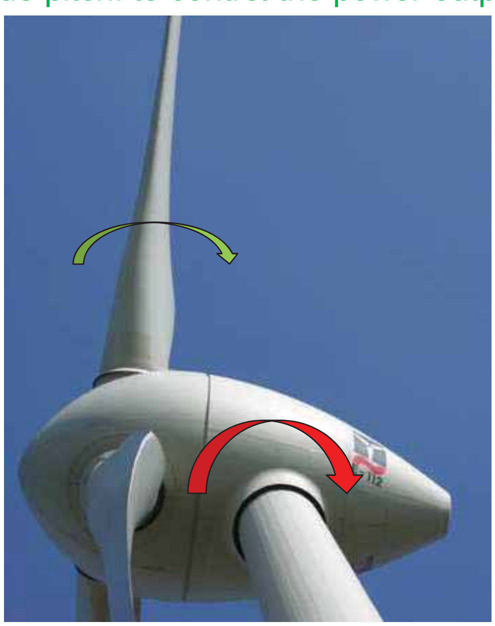


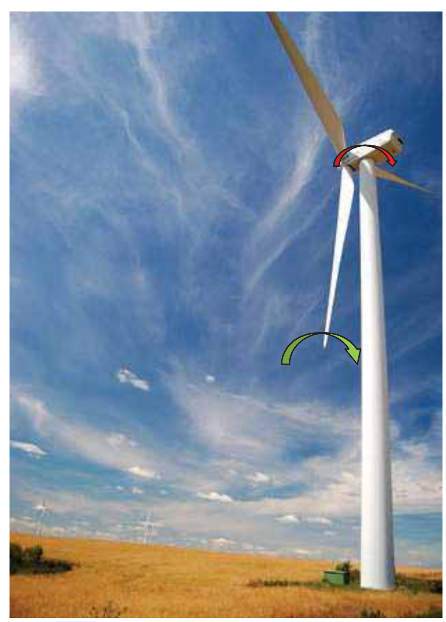


Quelle: Quelle: http://en.wikipedia.org/wiki/File:Equal_transit-time_NASA_wrong1.gif

Automatic yawing and blade pitch

Yawing of nacelle: to change the orientation of the rotor (towards the wind)
Blade pitch: to control the power output of the wind turbine

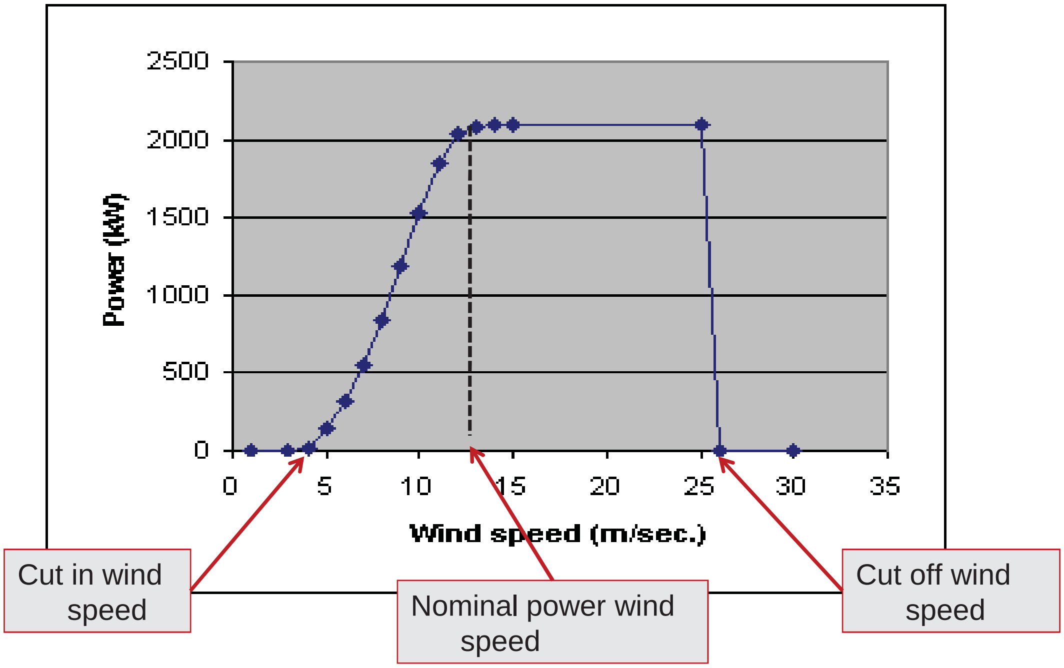




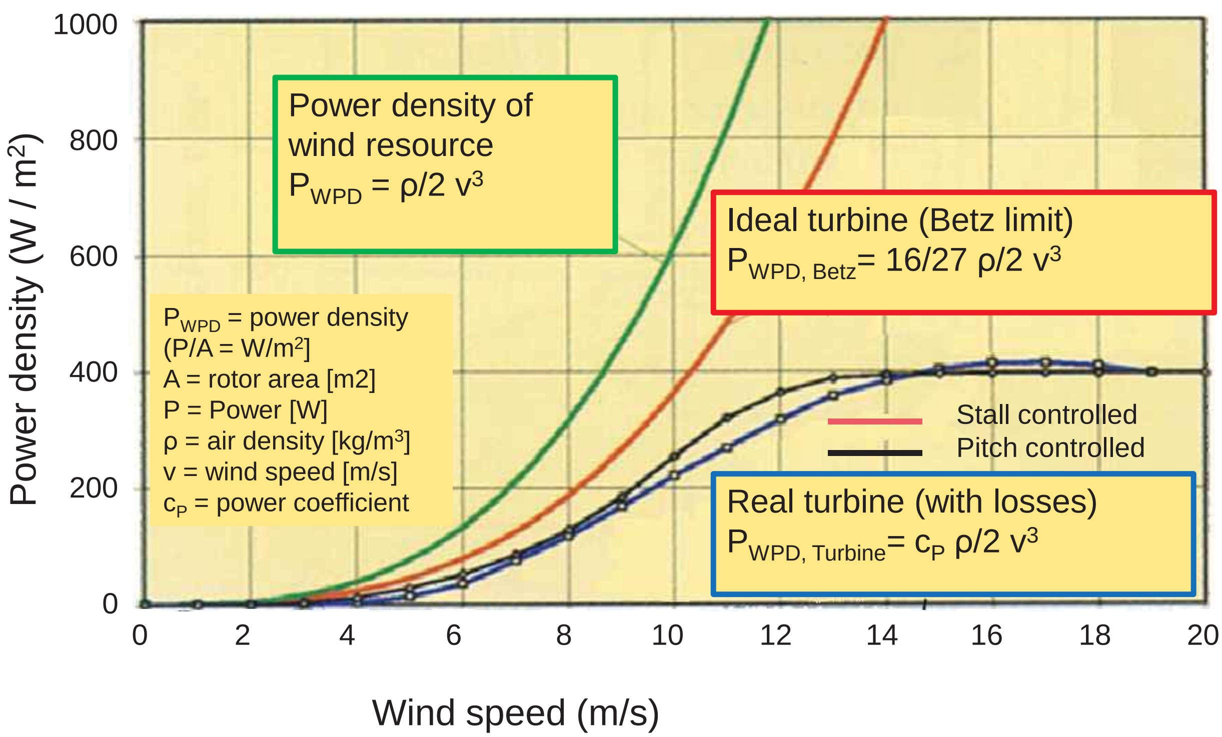
Quelle: www.wind-energie.de

Wind turbine power curve – pitch controlled

- Power curve of a 2.1 MW turbine

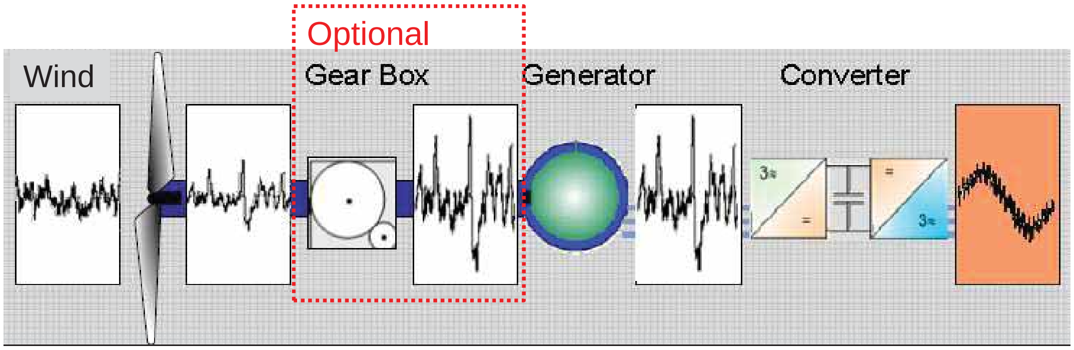


Maximal power density of wind resource, Betz limit and power curves of real wind turbines



Source: KWE, 2009; amended by RENAC

From turbulent winds to constant AC frequency



Turbulent wind → Variable rotor speed → Variable shaft speed → Variable AC frequency → DC → Constant AC frequency

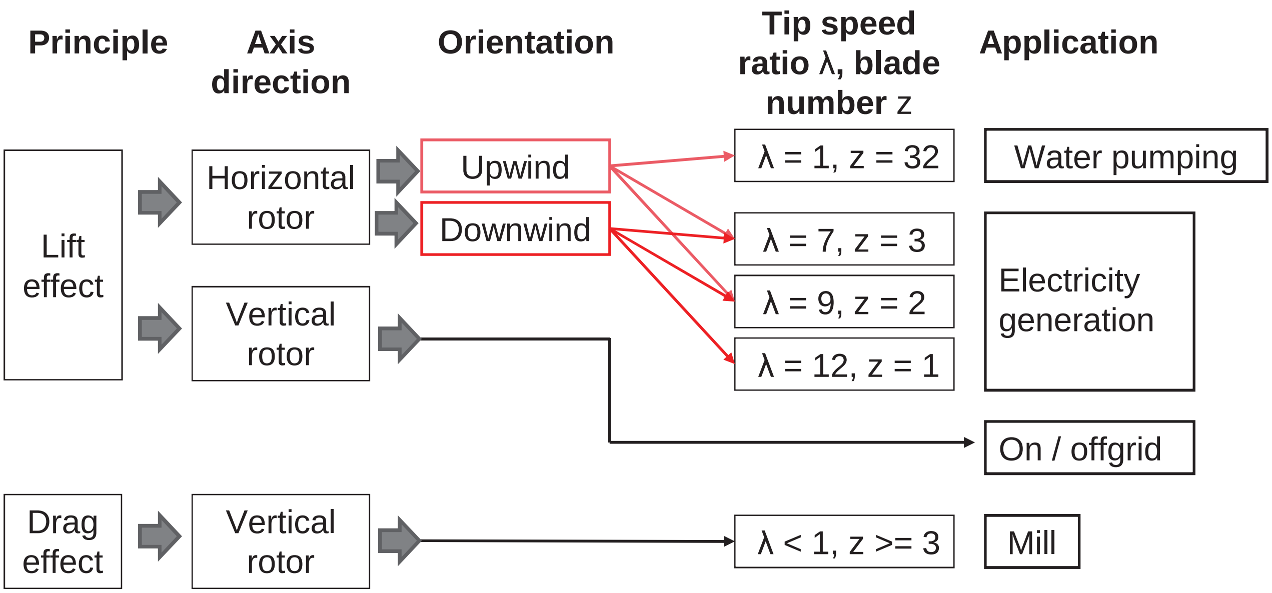
AC = alternating current, DC = direct current

Source: WinDrive – Large Wind Turbines without Frequency Converter, Andreas Basteck, Voith Turbo Wind GmbH & Co. KG

Old / new wind turbines

	Old turbines	New tubines
Tower height and rotor diameter	▪ Up to 80 m	▪ Up to 160 m
Generator	▪ Fixed speed	▪ Variable speed and decoupling from wind speed variations
Voltage support (static and dynamic)	▪ No / limited support ▪ Reactive power consumption ▪ Fixed power factor	▪ Full fast support ▪ Reactive power generation ▪ Adjustable power factor
Frequency control	▪ No contribution	▪ Automatic control ▪ Manageable by grid operator
Capacity factor (annual energy generation/ theoretical maximum)	▪ Small capacity factor ▪ Good at strong wind sites	▪ High capacity factor even for weak wind sites (due to large rotor + small generator)

Typology of wind tubines and typical applications



λTip speed ratio = $V_{BaldeTip}$ / $V_{WindUpstream}$; Quotient of the circumferential speed at the blade tip ($V_{BladeTip}$) to the wind speed far upwind the rotor to the undisturbed wind velocity upstream of the rotor ($V_{WindUpstream}$)

Project development, steps of project planning and implementation

Identifying priority areas for wind farms

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Wind energy yield simulation

↓

Potential areas with high wind energy yield

↓

Excluding areas for other land uses (settlements, airports, industry, roads, overhead lines, military, nature protected areas, others

↓

Add buffer zones (noise and nature protection, safety, visual impact)

↓

Definition of minimum wind farm size

↓

Case by case review of theoretical wind farm area

↓

Priority / suitable areas for wind power development → Pre-project planning and wind measurement campaign (>1 year) → Project licensing (project specific EIA and grid connection analysis)

Source: Dr. Marie Hanusch Spatial Planning for wind farm projectsWind Energy Fundamentals 15.-17.02.2010

Example: priority / suitable areas for wind power development - Buffer around settlements / buildings

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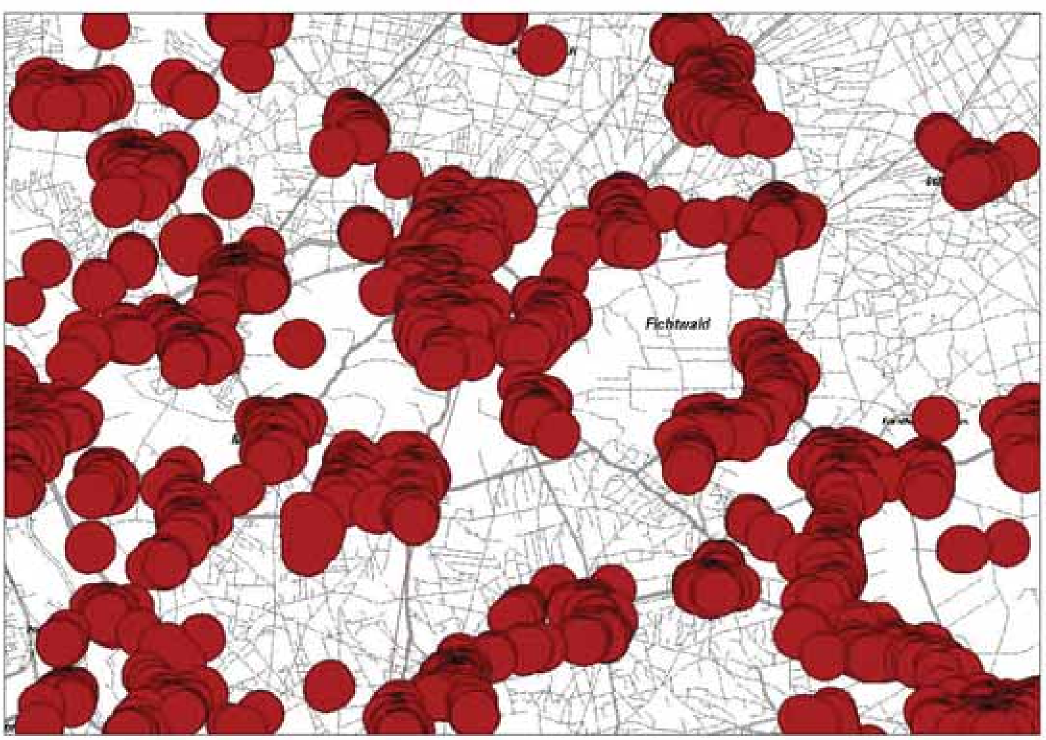
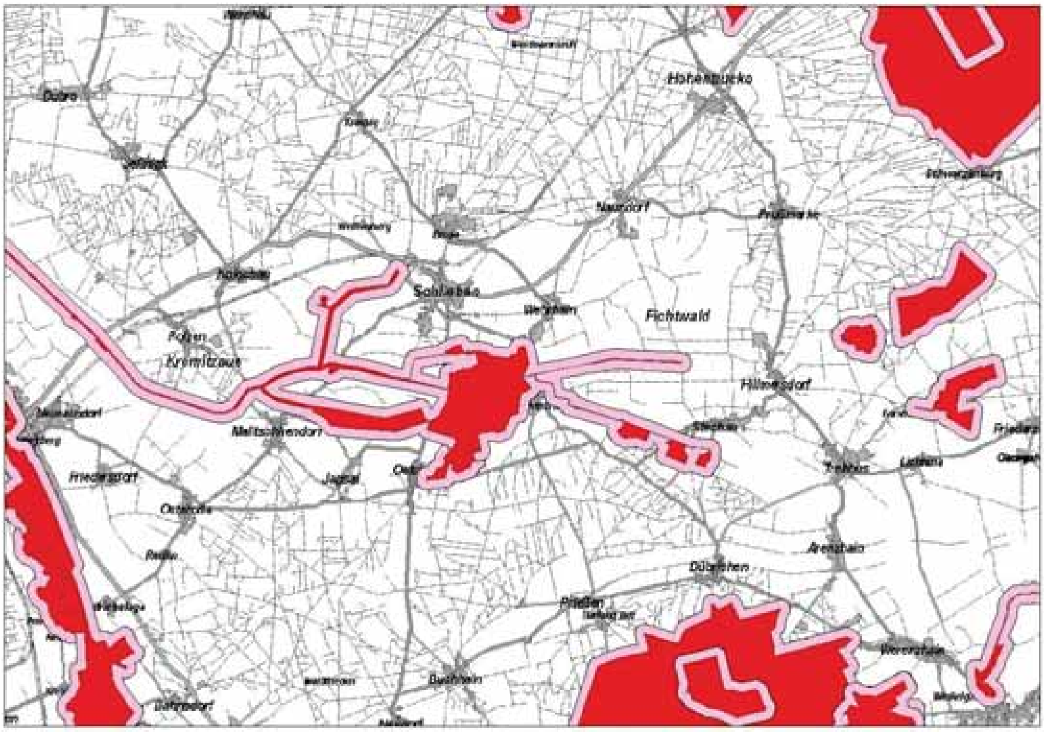


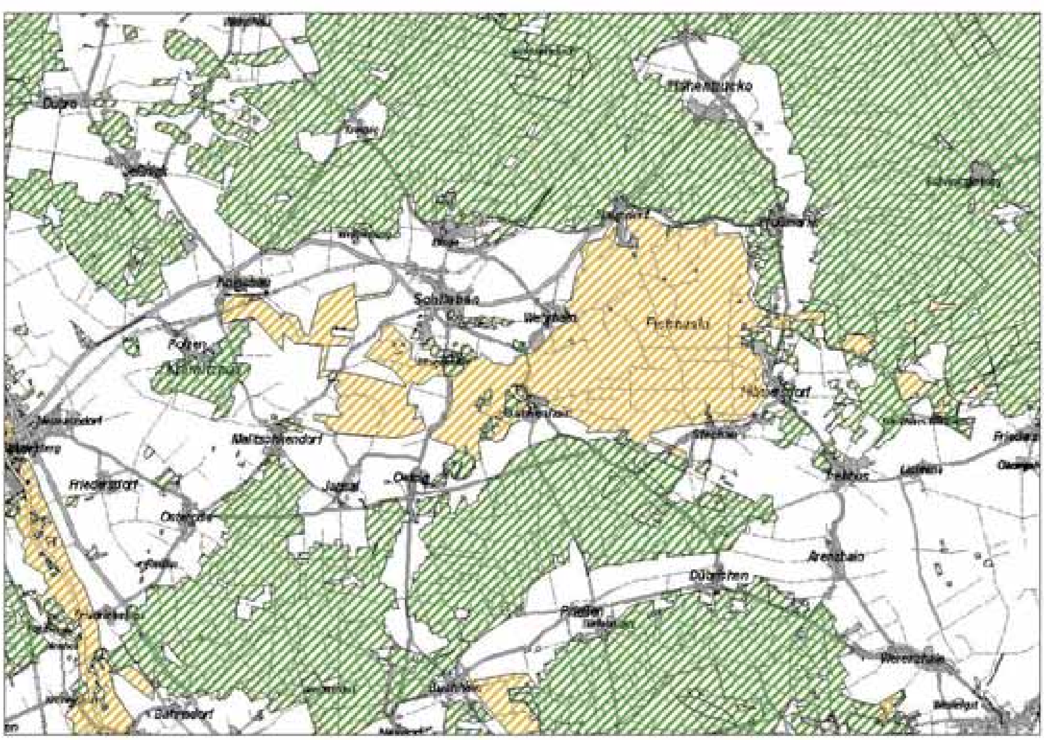
Dr. Marie Hanusch Spatial Planning for wind farm projectsWind Energy Fundamentals 15.-17.02.2010

Example: priority / suitable areas for wind power development - buffer around nature protected areas



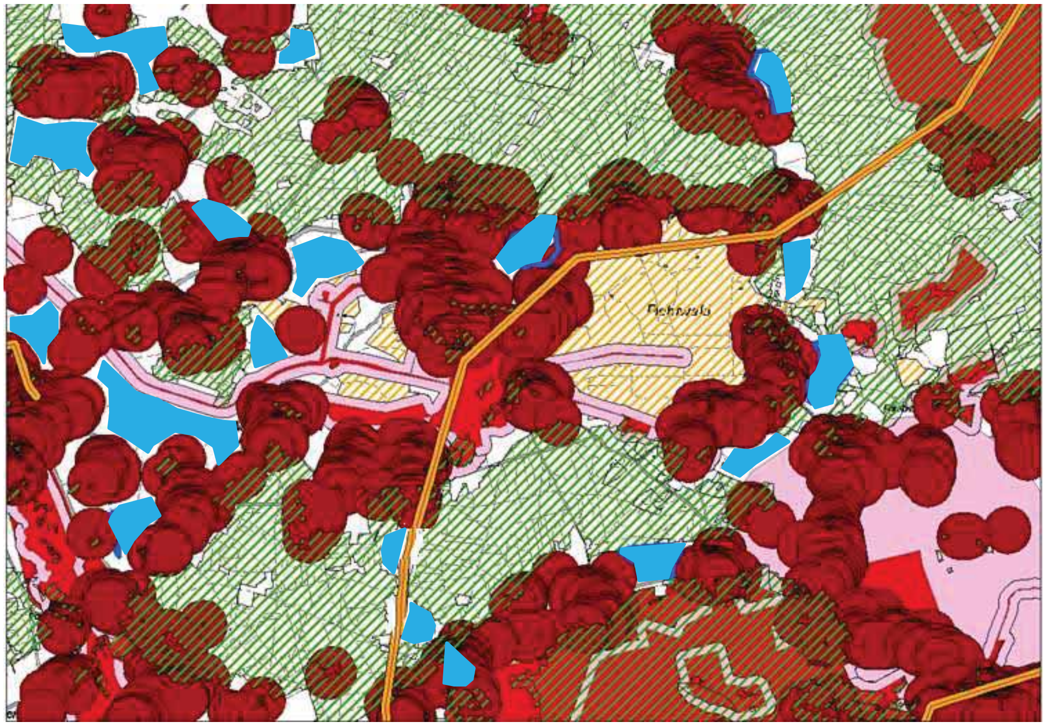
Dr. Marie Hanusch Spatial Planning for wind farm projectsWind Energy Fundamentals 15.-17.02.2010

Example: priority / suitable areas for wind power development - forest biotope network areas



Dr. Marie Hanusch Spatial Planning for wind farm projectsWind Energy Fundamentals 15.-17.02.2010

Example: priority / suitable areas for wind power development – summary with low conflict areas (blue)



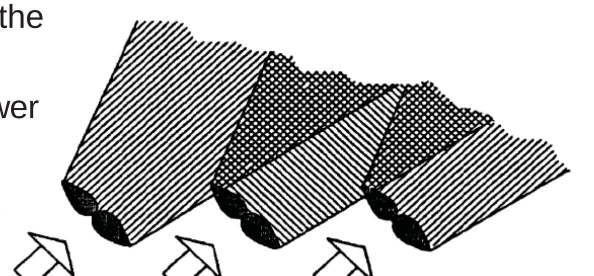
Dr. Marie Hanusch Spatial Planning for wind farm projectsWind Energy Fundamentals 15.-17.02.2010, changed

Example: priority / suitable areas for wind power development - selected priority areas for wind (green)

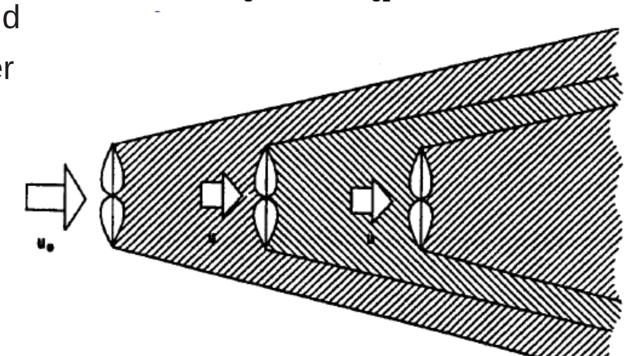
Dr. Marie Hanusch Spatial Planning for wind farm projectsWind Energy Fundamentals 15.-17.02.2010, changed

The most problematic obstacle for a wind turbine is a wind turbine

- Downwind of a wind turbine the wind speed is reduced (less energy in the wind, up to 40 %)
- Back-row wind turbines losing power relative to the front row
- Wind turbines with unfavorable distances between them and with unfavorable wind directions cause increased loads and reduced yield
- Wind farm efficiency always lower than of single wind turbine

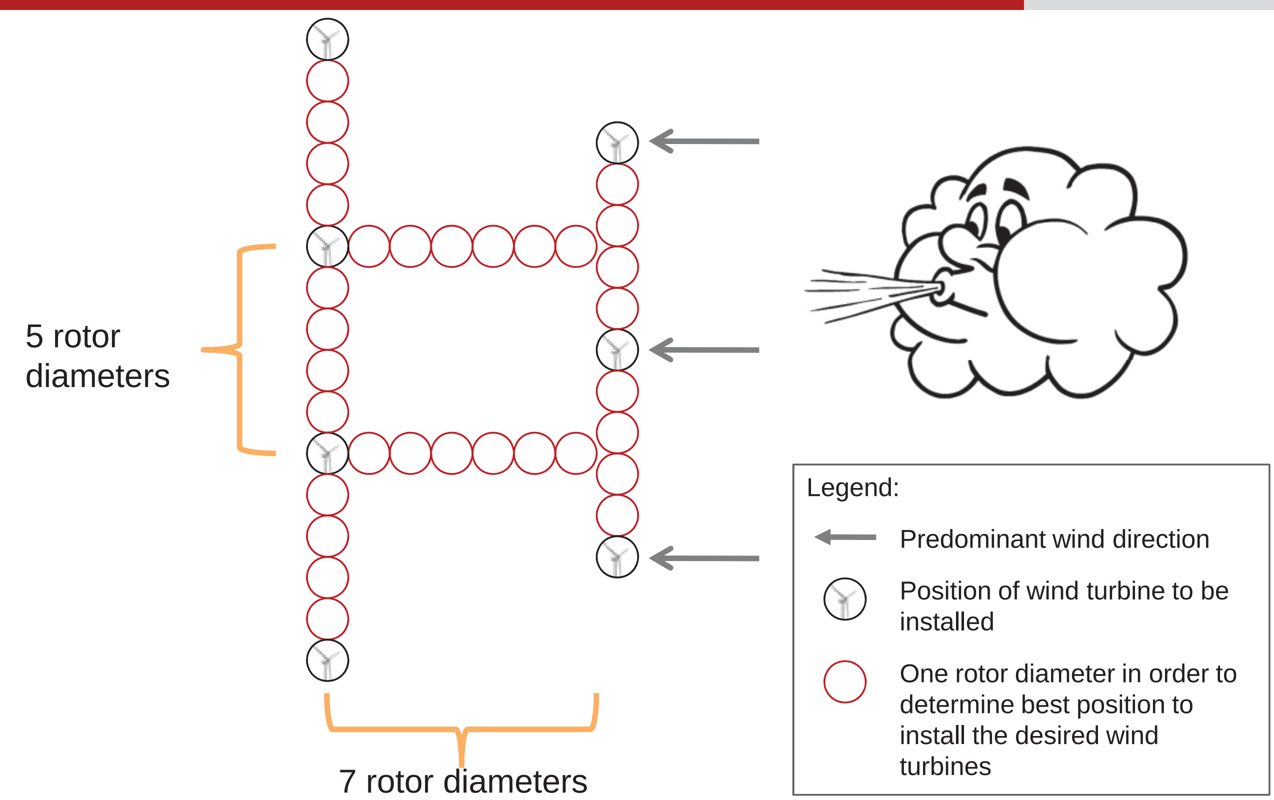


Source: DEWI



Source: KWE, 2009

Rules of thumb to estimate the distance between wind turbines



Software tools for micro siting

- To find the most efficient configuration and to optimize the production of a specified number of turbines within limited area software tools are necessary, like for example:

- **WAsP –***Wind Atlas Analysis and Application Program from Wind Energy Division*, Risø, DTU, Denmark PC
- **WindFarmer** by energy consultant Garrad Hassan
- **WindPRO,** by energy consultant EMD International A/S
- ***openWind***®, created by AWS Truepower

The life cycle of a wind farm project

Phase	Duration
Pre-planning phase (including wind resource assessment)	>1 + x years
Project development (including grid connection layout)	6 months to 1 year
Permission and contracts	½ year to x years
Construction and commissioning	some weeks + x***
Operation	20 + x years
Dismantling	some weeks + x***

*** depending on size and complexity of the project as well as number of teams working in parallel

Main processes during planning / permission and contracts from the developers point of view

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Technical	• Pre-feasibility study • Feasibility study (including wind measurements) • Basic design
Administrative	• Government and municipalities • Environmental (birds, landscape, noise, shadow, etc.) • Grid access / grid connection • Public information • Use of resources and infrastructure (water, roads, affected plots, etc.)
Contractual	• Tendering process • EPC and O&M contracts • Shareholders and financing agreements • Land Lease Agreement , Power Purchase Agreement • Main supplies agreements
Consulting	• Consulting and advisory (legal, technical, insurance, market, financial) • Due Diligence (legal, technical, insurance, market, financial)

Main processes during construction / commissioning from the developers point of view

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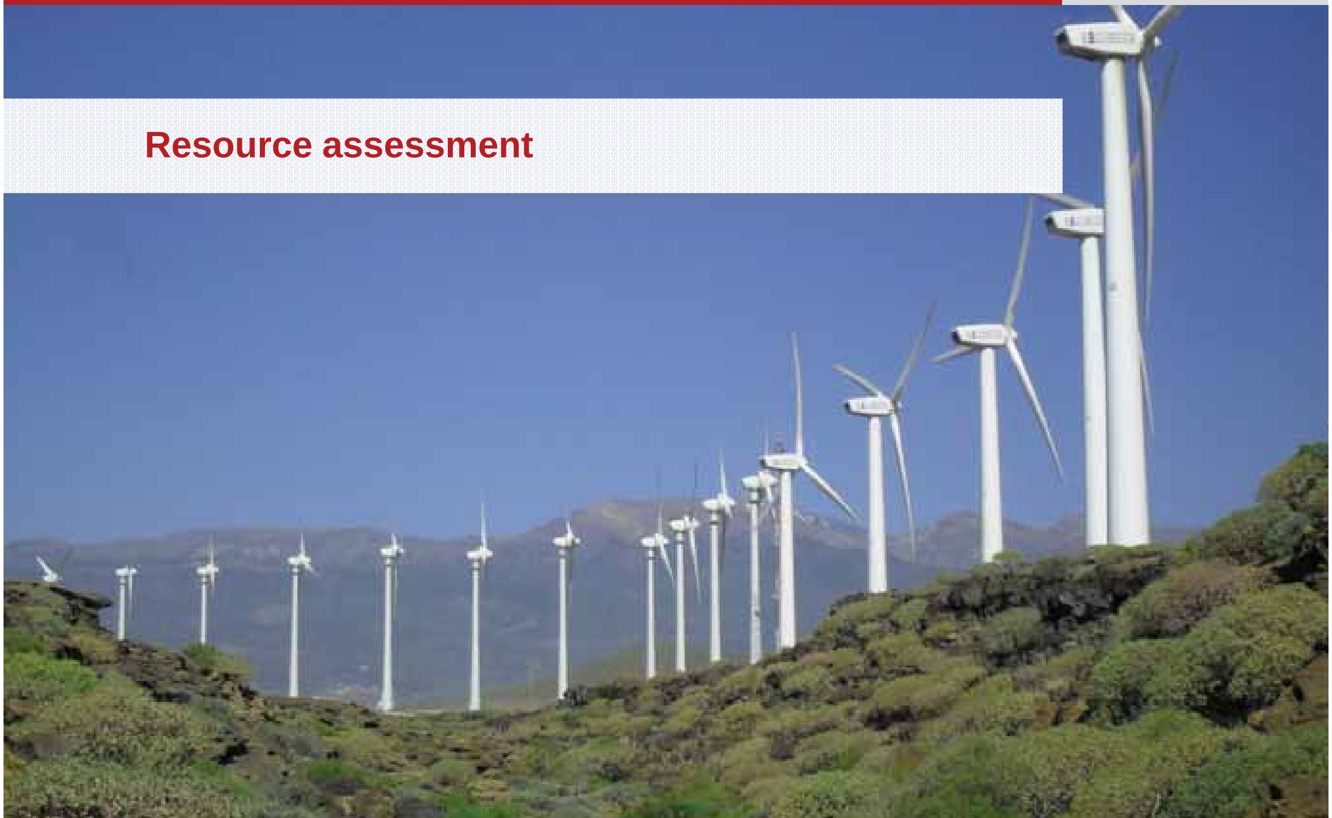
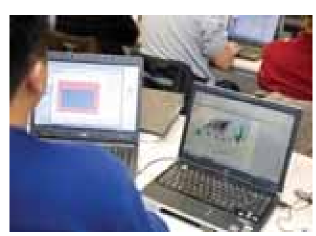
Start	• Road access / construction • Groundbreaking and earthworks
Engineering	• Review of basic engineering (re-evaluation) • Performing of detailed Engineering
Procurement	• Issuing of request for quotation, purchase orders • Manufacturing (monitoring of procedures- QA) • Check at reception of equipment condition and packing lists
Construction	• Civil works • Electrical and mechanical works • Instrumentation and control works • Pre-commissioning of components and sub-systems
Start-up	• Commissioning • Provisional acceptance tests

Resource assessment



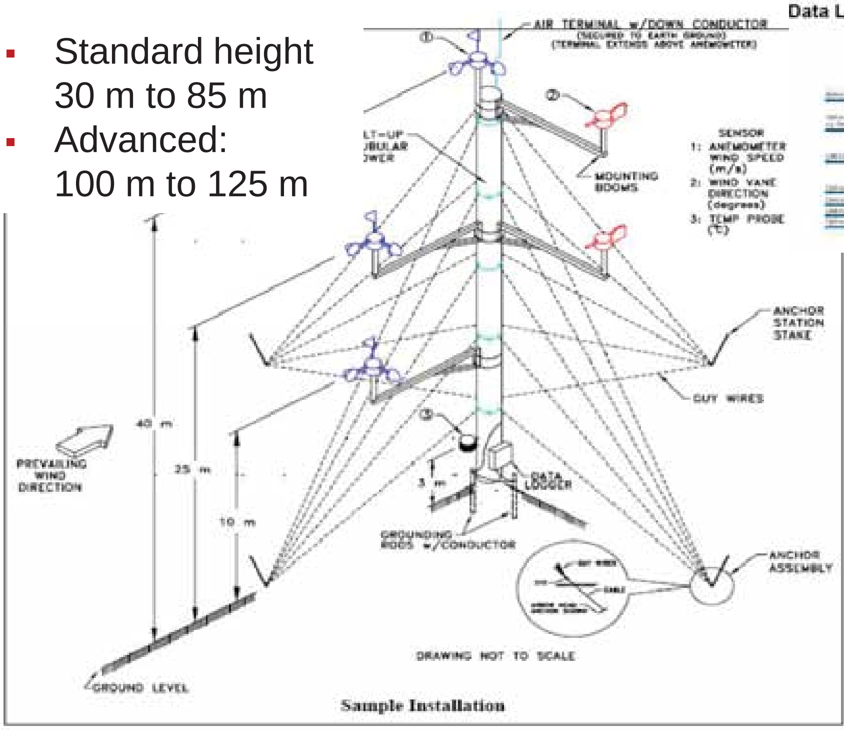
Wind measuring campaign

- Because $P_{Wind} \sim v^3$ small wind speed measurement errors have large effects on predicted power output → monitor **at least for 1 year** - to be on the safe site (some projects measure for several years)
- Monitor wind speed, wind direction, temperature, humidity, ambient air pressure and more…
- Correlate the data with other nearby sites is useful
- High quality wind measurement is extremely important for
  - Site selection for wind farm
  - Micro-siting of individual turbines
  - Choosing the best wind turbine for a specific site
  - Annual energy production prediction
  - Cash flow analysis and
  - Bankable wind report



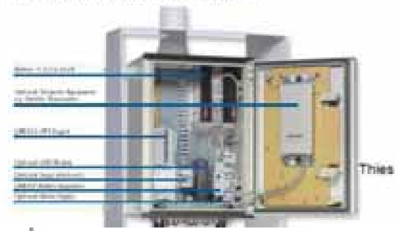
Wind monitoring equipment

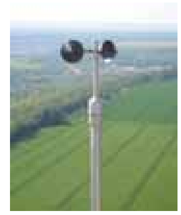
- Standard height 30 m to 85 m
- Advanced: 100 m to 125 m



Sample Installation

Data Logger for data recording





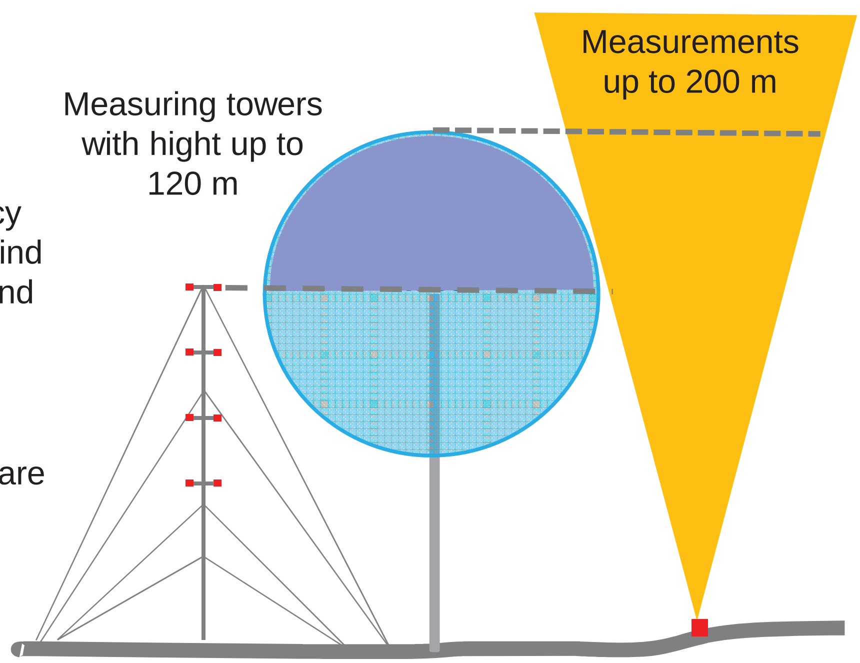
Source: windtest grevenbroich gmbh

Source: National Renewable Energy Laboratory (NREL)

J.liersch; KeyWindEnergy, 2009

Sonic / light detection and ranging (SODAR/LIDAR)

- Emits sound up and measures the sound/light that is reflected back
- The reflected sound changes its frequency proportional to the wind speed along the sound propagation path, according to the 'Doppler Effect'
- SODAR and LIDAR are used in addition to measuring towers



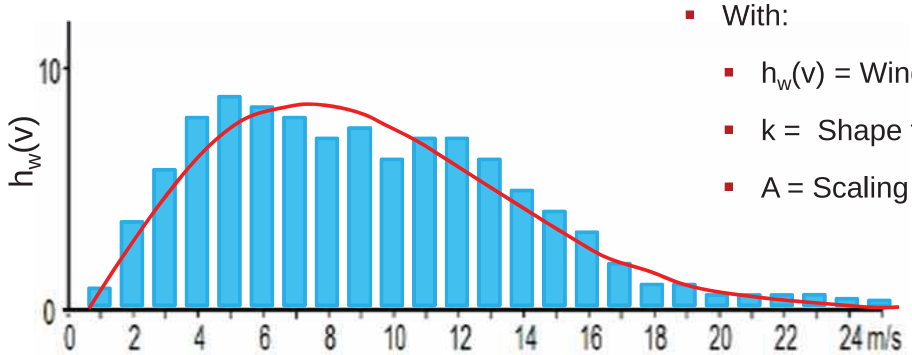
Source: „Measuring Wind Speeds using SoDAR technology: Engaging farmers in NS COMFIT for small wind" Adam Wile, Kenny Corscadden

Result: measured wind speed data

- Wind speed data of one year (ore more) are classified (wind speed bands)
- Approximation of wind speed distribution with a Weibull-curve

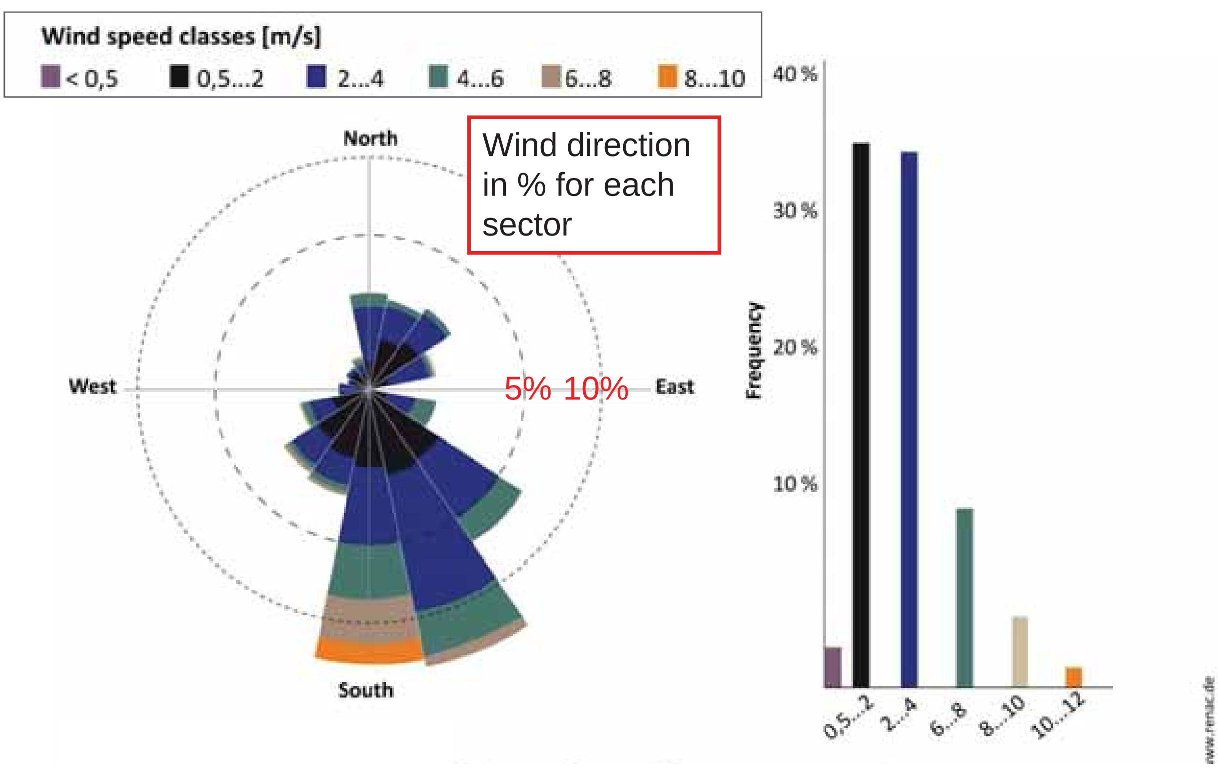
$$h_{w,i}(v_i) = \frac{k}{A}\left(\frac{v_i}{A}\right)^{k-1} \cdot \exp\left[-\left(\frac{v_i}{A}\right)^{k}\right]$$

- With:
  - $h_w(v)$ = Wind speed distribution
  - k = Shape factor (dimensionless)
  - A = Scaling factor (in m/s)

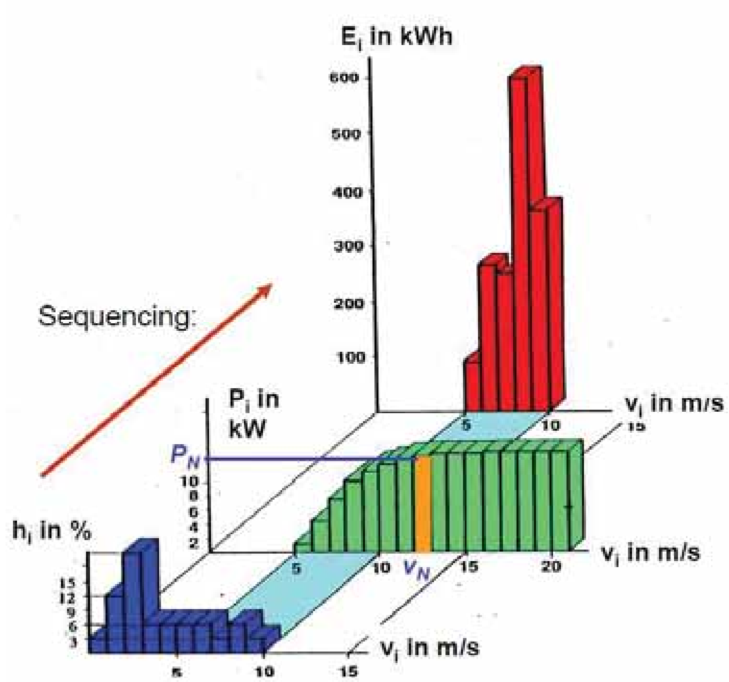


J.Iiersch: KeyWindEnergy, 2009

Wind direction



Calculation scheme for annual energy production



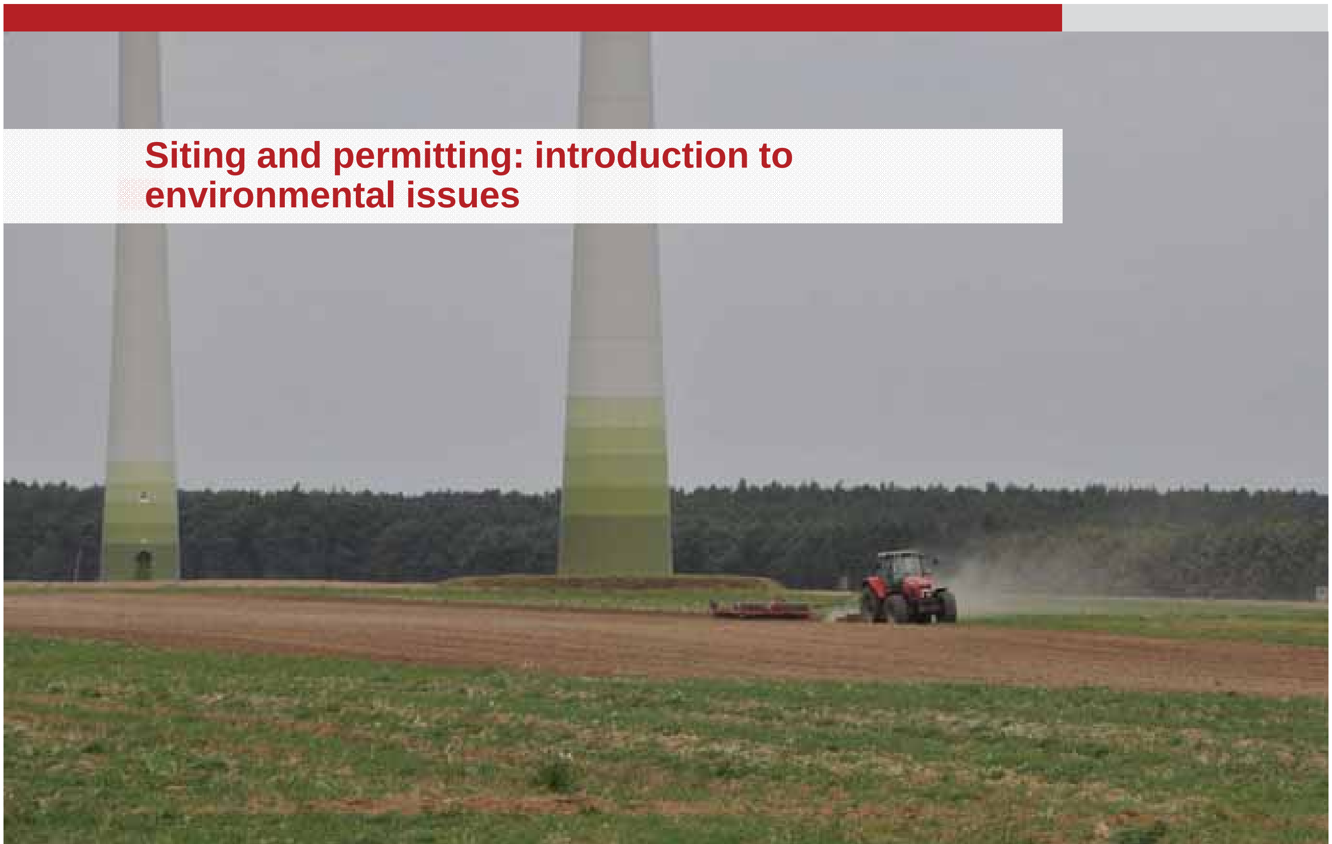
$$E_i = P_i(v_i) \times t_i$$

$$E_\Sigma = E_1 + E_2 + \ldots + E_n$$

- E_Σ = Energy yield over one year
- E_i = Annual energy yield of wind class [Wh, watthours], i = 1, 2, 3 …n
- t_i = duration of wind speeds at wind class [h/a, hours/year]
- $P_i(v_i)$ = Power of wind class v_i of wind turbine power curve [Watt; joule per second]
- v_i = wind class [m/s]
- P_N = Nominal power of WEC [kW] at nominal wind class v_i [m/s]
- h_i = relative wind class frequency in %

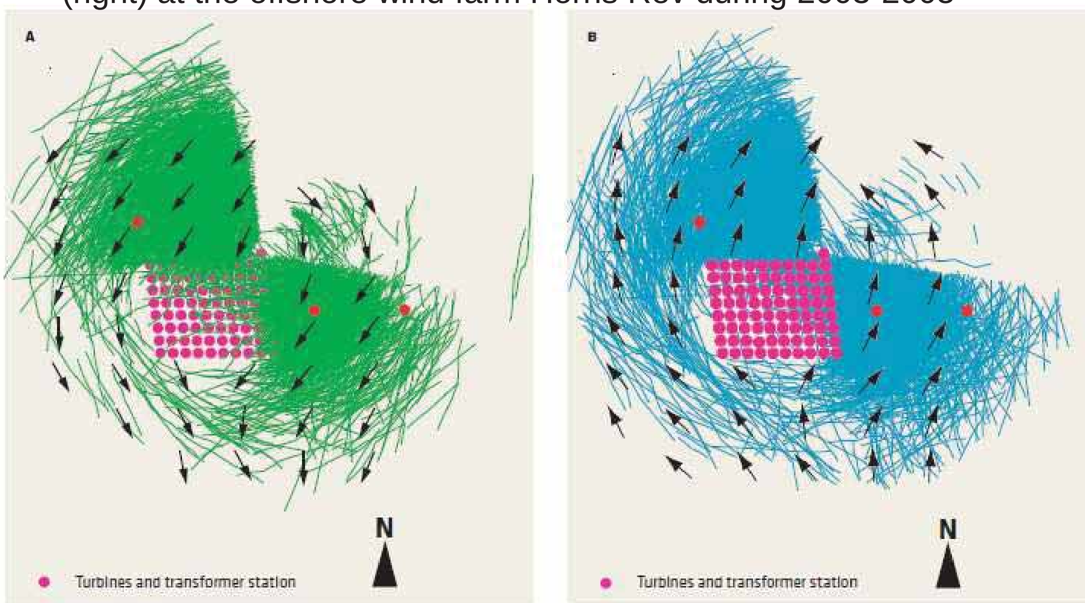
J.liersch; KeyWindEnergy, 2009

Siting and permitting: introduction to environmental issues



Radar tracks of birds/bird flocks

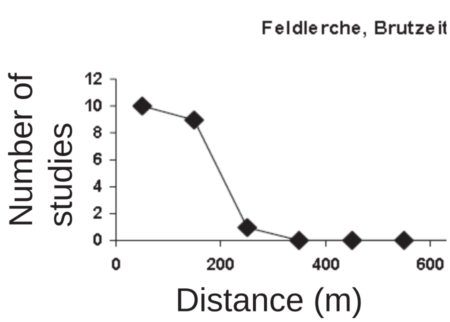
- Radar tracks of birds migrating southwards (left) and northwards (right) at the offshore wind farm Horns Rev during 2003-2005

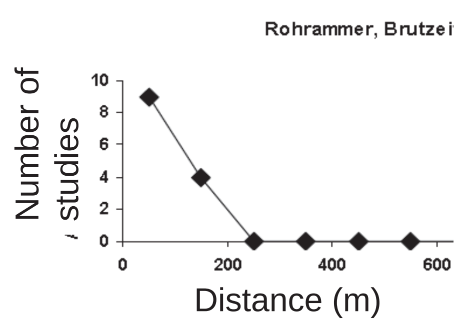


Source: Danish Off shore Wind, – Key Environmental Issues, Published by DONG Energy, Vattenfall, Th e Danish Energy Authority, and Th e Danish Forest and Nature Agency, November 2006

Breeding birds and bird collision

- With some exception most of the birds use the immediate surroundings of wind turbines, which often amount to minimal distances over 100 meters
- Wind energy has no statistically significant evident negative impact on most of breeding bird populations.
- Measured disturbance distance (data from Germany):





Sources: Helterlein et al, Vilm, 2008; Hötker, Repowering und Windenergie, 2006

Estimation of bird collision mortality / risk

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- Results from German wind farms (analysis of collision rate measurements in 45 wind farms)
  - 0 to over 64 victims per turbine per year
  - mean 6.9 casualties per turbine per year
- Results of US wind farms 2005 (0,5 to 1.5 MW)
  - 0.6 to 7.7 birds per turbine per year
  - 1 to 11.7 birds per MW per year
- Particularly high collision occurs on barren mountain ridge (USA, Spain) and on wetlands.
- Birds are more likely to collide with structures during poor visibility in rain or fog.

Sources: Drewitt and Langston 2006, Huppop et al. 2006) ; Dr. Hermann Hötker, Michael-Otto-Institut imNABU: Repowering im KontextNaturschutzfachlicher Ziele, 2008

How to avoid collisions of birds with wind turbines?

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- Avoid alignment perpendicular to main flight paths and to provide corridors between clusters
- Free migration corridors by leaving several kilometers between wind farms; turbines should not be placed within frequently used flight paths
- Increase the visibility of rotor blades
- White or green flashing lights (strobes) appear to be better than red lights?
- Intermittent lights less attractive to birds than constant light.
- Learn from post-development monitoring programme

Sources: Drewitt and Langston 2006, Hüppop et al. 2006)ari; Birds, bats and coastal wind farms development in Maine: a literature review, *BioDiversity Research Institute, 2008a*

Bats

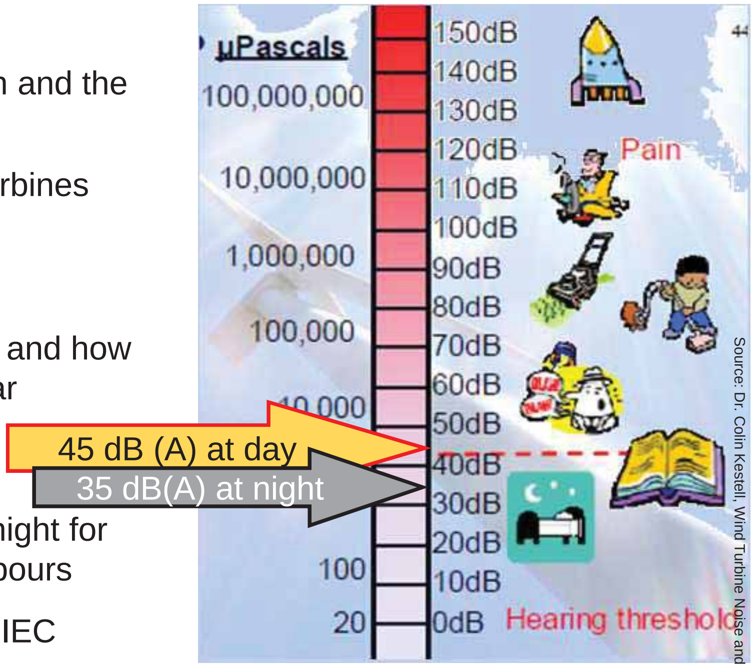
- Wind turbines may be a significant hazard to bats
  - Direct strikes during migration
  - Pulmonary lesions caused by pressure changes around turbine
- Bats can detect turbines through echolocation, this same ability offers no protection toward pressure drops
- Of all bats that encountered turbines, 100% had pulmonary lesions and nearly all had internal hemorrhaging, regardless of external wounds

Source: de.wikipedia.org

Source: Kunz et al. 2007, Arnett et al. 2007, (Baerwald 2008).

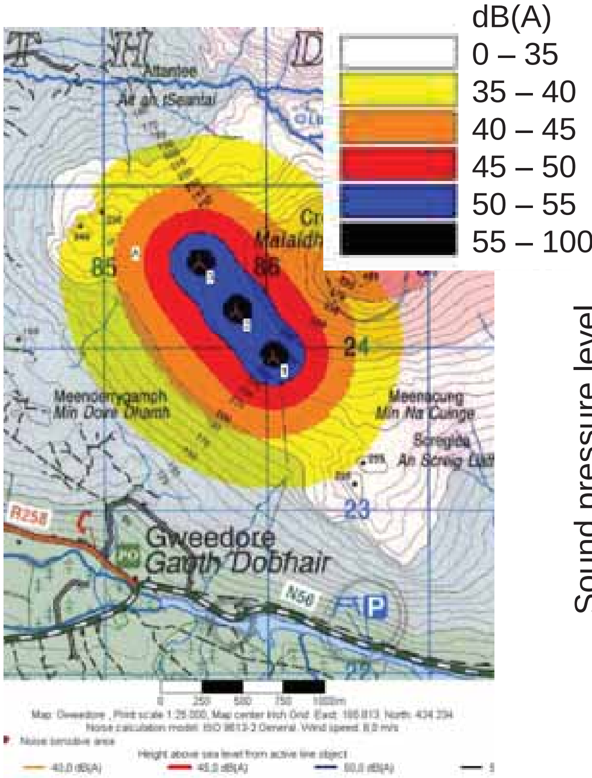
Quiet or noisy ? ~ distance & type of noise

- Sound power level:
  - describes noise emission and the strength of the source
  - typical values for wind turbines 90-105 dB(A)
- Sound pressure level:
  - describes noise imission and how much recipients may hear
  - typical limit values for wind turbines < 45dB(A) at day and 35 dB (A) at night for residential areas / neighbours
- Measurement according to IEC 61400-11

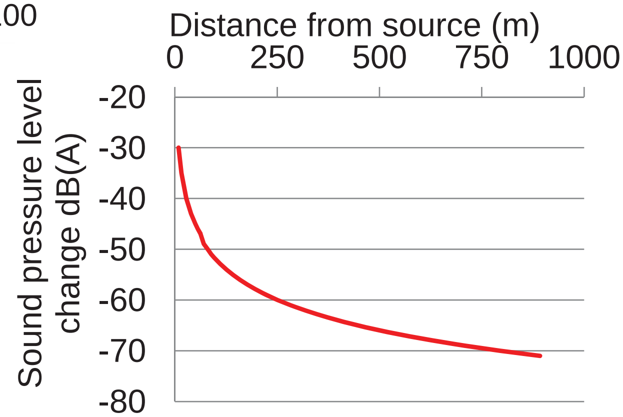


Source: Dr. Colin Kestell, Wind Turbine Noise and Vibration

Mapping wind farm noise imission

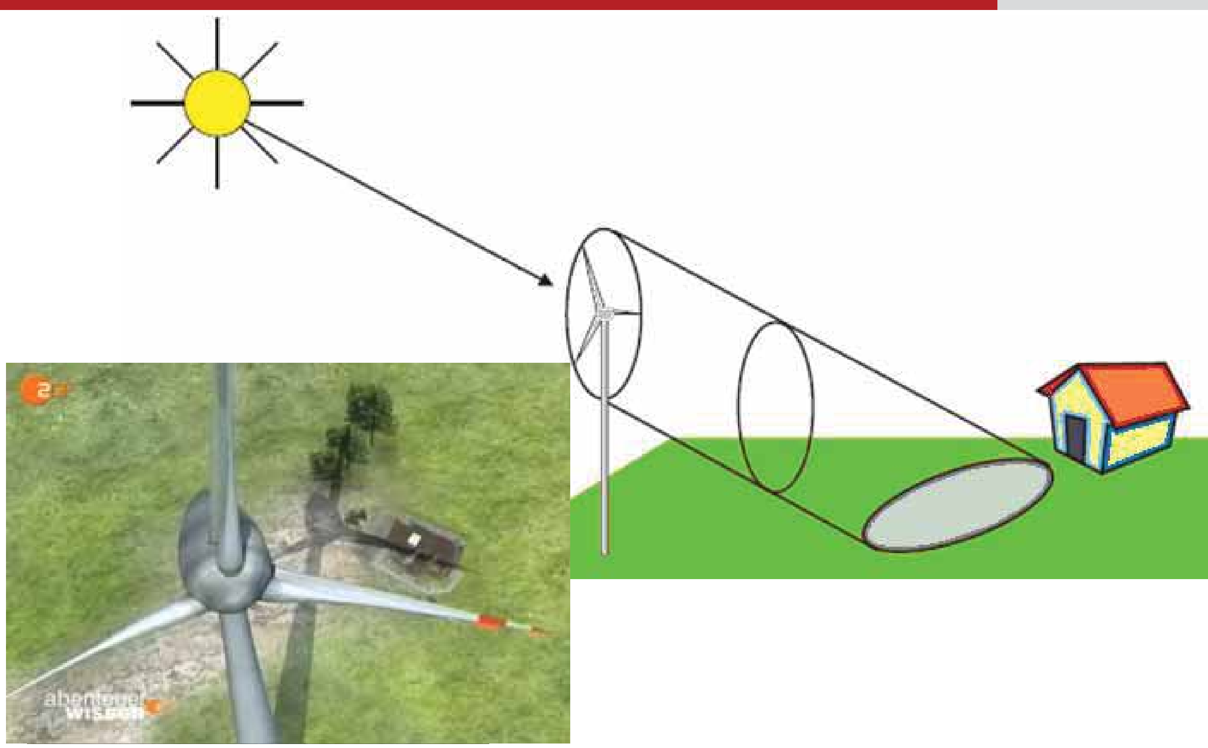


- The sound pressure decreases by approx. 6dB(A) every time the distance to the source of the sound is doubled



Source: http://www.emd.dk/WindPRO_odules/PDF/UK/EN_decibel.pdf, 2010

Effects of the rotating shadows of the blades



Source:http://video.aol.co.uk/video-detail/abenteuer-wissen-windkraft-ohne-grenzen/1675288588 and Source: www.al-pro.de/hp/pdf/AL-PRO-brochure.pdf

From an aesthetic point of view?

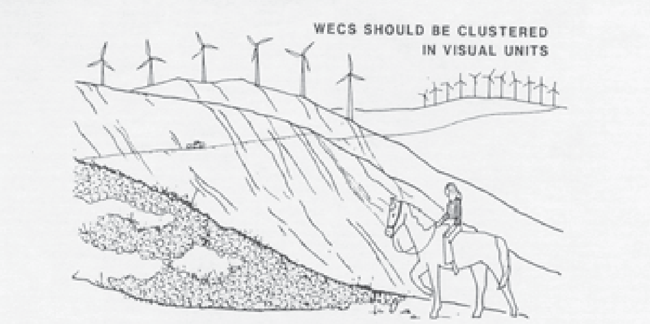


Figure 8.18. Visual units. Arrays of turbines of similar design and similar size clustered into distinct visual units eliminates clutter on the landscape. (Courtesy of CalPoly.)

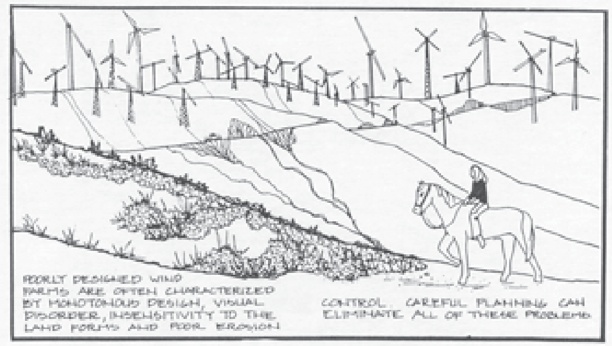


Figure 8.15. Visual clutter. Road cuts, erosion scars, and the jumble created by different types and sizes of wind turbines create visual chaos. (Courtesy of CalPoly.)

- A few large wind turbines are an advantage in the landscape, because
  - of lower rotational speed (rounds per minute) compared to small turbines
  - they not attract the eye the way fast-moving objects generally do
- 10 x 3 MW turbines have much lower visual impact than 50 x 600 MW turbines although the installed capacity is the same

Permits for wind power plants: details to consider and decisions to make

- A decision to take: approve or reject an application
- Topics to consider:
  - Land-use planning
  - Construction requirements (statics, distances, ice, turbulences)
  - Maintenance of occupational and industrial safety
  - Air traffic
  - Directional radio line and other communications facilities
  - Emission control: noise and shadow (monitoring)
  - Water pollution control and soil protection, waste handling
  - Preservation of sites of historic interest
  - Nature protection
  - Environmental impact assessment

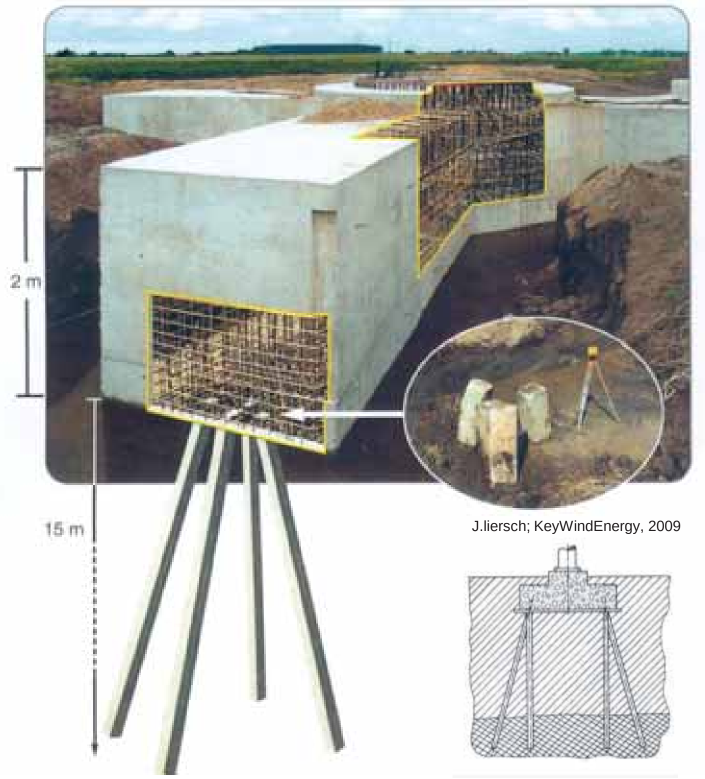
Source: Sander, 2010

Transport and construction (installation works)

Road constrution

J.liersch; KeyWindEnergy, 2009

Piled foundation



J.liersch; KeyWindEnergy, 2009

Transport of large wind turbines

Tower and rotor blade transport

© Heiko Jessena

Foto: Steil Kranarbeiten, Stefan Dürr

© Heiko Jessen

Crane works

Rotor hub


Source: BWE


Source: BWE


Source: BWE

Telescopic crane

Foto: Steil Kranarbeiten, Stefan Dürr

- Crane LTM 1500
- 75m maximum hub height of wind turbines
- 50 t maximum weight of rotor or nacelle

Crane work, Enercon E66 (1.8 MW)

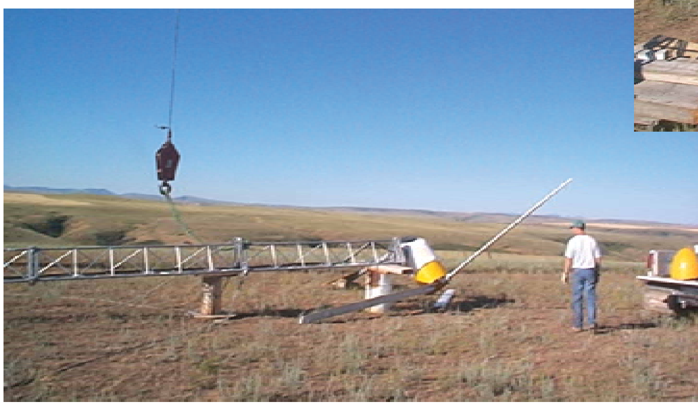
Base pad construction for small wind turbines

Source: Bergey Windpower Co. "Small Wind Systems"; Photos courtesy of Pine Ridge Products, Great falls, MT

Guy wires and turnbuckles

Source: Bergey Windpower Co. "Small Wind Systems"; Photo courtesy of Pine Ridge Products, Great falls, MT

Turbine assembly



Source: Bergey Windpower Co. "Small Wind Systems"; Photo courtesy of Pine Ridge Products, Great falls, MT

Raising tower & turbine, crane works

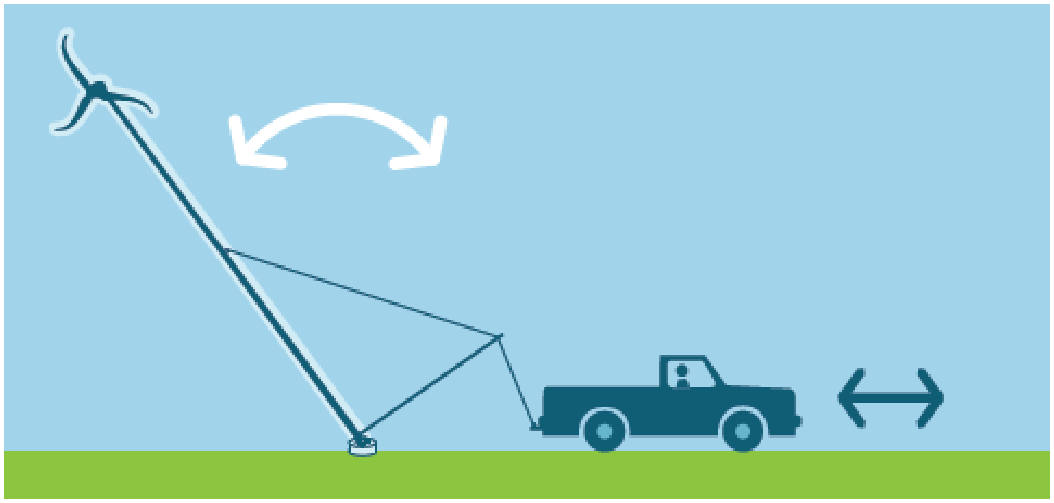
Source: Bergey Windpower Co. "Small Wind Systems"; Photo courtesy of Pine Ridge Products, Great falls, MT

Erecting small wind turbines

- Aerosmart 5
- 5.1m hub height, 20m^2 swept area, 5.7 kW

http://www.oeko-energie.de/downloads/aerosmart.pdf

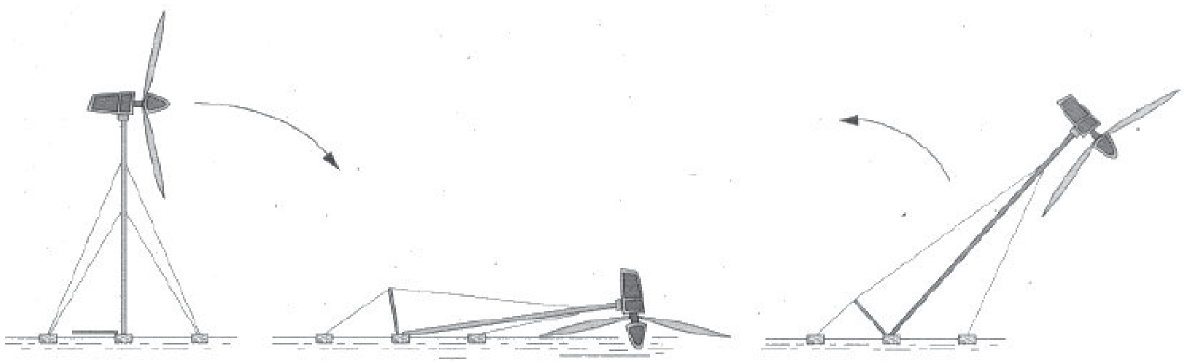
Using a pickup to raise and lower a monopole tower



Source: Skystream: “Siting Wind Generators“

Tiltable towers for small wind turbines

- for maintenance
- for tropical wind conditions

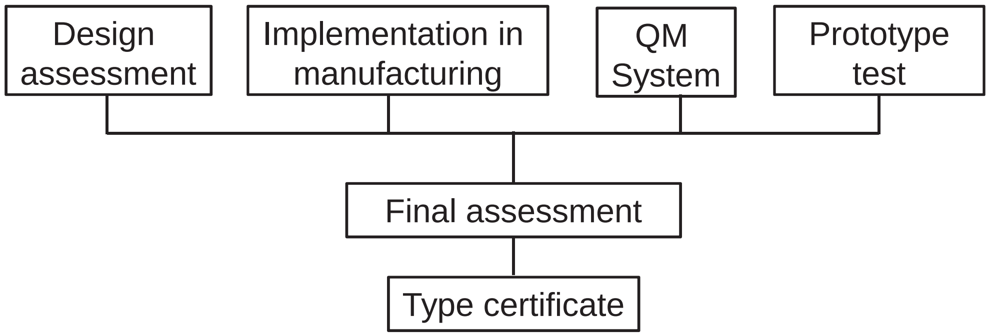


Source: SWIIS (Small Wind Industry Implementation Strategy) Consortium

Wind turbine testing and certification

Type certification and project specific assessment

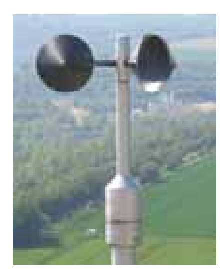
- Wind turbine type certification



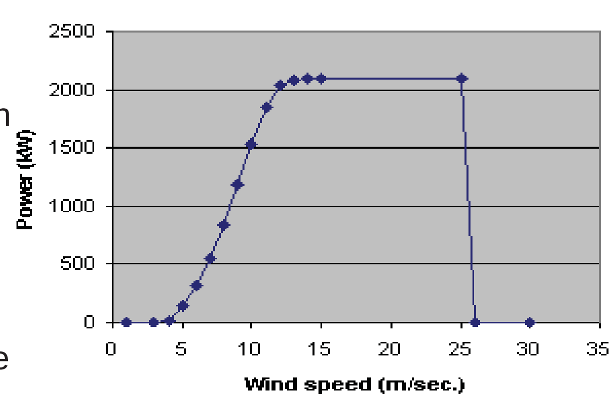
- IEC 61400 standards for wind power certification
- Wind farm specific assessment (complex site conditions)
- Due diligence of wind farm (applicability of design assumptions, energy yield prognosis, prospective guarantee and service concepts)

Certification of power output of wind turbines

- Measurement of the power curve (power performance):
  - *IEC 61400 Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*
  - Provide a uniform methodology that will ensure consistency, accuracy and reproducibility in the measurement and analysis of power performance by wind turbines
  - Testing of wind turbine prototype in a wind farm under realistic condition
- Key element of power performance testing is the measurement of wind speed.
  - *IEC 61400 Wind turbines-part 12-1* prescribes the use of cup anemome to measure the wind speed



Source: windtest grevenbroich gmbh



Rotor blade testing

- Materials
- Blade sub-components
- Whole blades
- Ultimate load testing
- Fatigue testing of new rotor blade designs

Blade testing at LM Glasfiber, which have long been the world's largest independent blade supplier.

Standards for certification

- IEC 61400
  - IEC 61400-1 Design requirements
  - IEC 61400-2 Design requirements for small wind turbines
  - IEC 61400-3 Design requirements for offshore wind turbines
  - IEC 61400-4 Gears
  - IEC 61400-5 Wind turbine rotor blades
  - IEC 61400-11 Acoustic noise measurement techniques
  - IEC 61400-12 Wind turbine power performance testing
  - IEC 61400-13 Measurement of mechanical loads
  - IEC 61400-14 Declaration of apparent sound power level and tonality values
  - IEC 61400-21 Measurement and assessment of power quality characteristics of grid connected wind turbines
  - IEC 61400-22 Conformity testing and certification
  - IEC 61400-23 Full-scale structural testing of rotor blades
  - IEC 61400-24 Lightning protection
  - IEC 61400-25 Communication protocol
- Guidelines for certification of wind turbines by Germanischer Lloyd
- Guidelines for design of wind turbines by Det Norske Veritas
- Regulation for wind energy conversion systems, actions and verification of structural integrity for tower and foundation by German Institute for Civil Engineering (DIBt)

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Operation and maintenance

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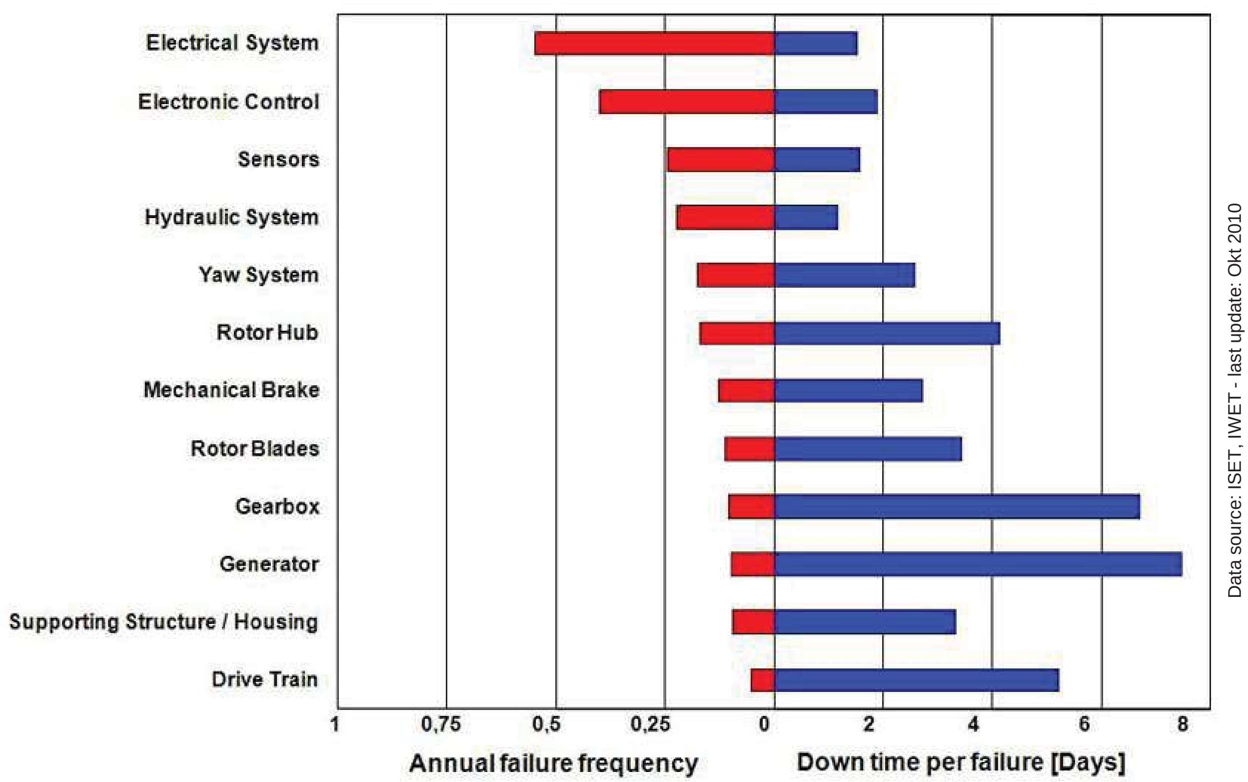
Reliability and downtime of large wind turbines



Long-term view on O&M

- Project finance requires a long-term view an the project
- Manufacturer traditional offer two to five years warranty periods
- After end of this contract an end-of-warranty inspection is necessary but what happens after that time?
  - Continuous O&M is needed to cover years six to ten and more importantly from year ten out to the end of the loan period
  - Banks want to see that there is technical experience and financial backing behind the maintenance concept
  - Full service contract with manufacturer, covering all eventualities with one single long-term contract, 12 -17 years up to lifetime

O&M tasks of the technical wind farm management

- First rule of operating wind farms: “keep them spinning…”
- Tasks of the technical management from the **view of the owner:**
  - High (energetic) availability of wind turbines
  - Reduction of costs for service / repair
  - Long life time of wind turbines
  - Conservation of evidence for negotiation with manufacturer and insurance
  - Prompt acquisition of basic data for controlling purposes and transparent presentation of improvement actions to share holders / owners

Source: KWE „Onshore Wind Energy Fundamentals, Operation and Maintenance of wind fams

O&M tasks of the technical wind farm management

- From the point of view of the **technical operator:**
  - Optimization of time based availability by short reaction time in case of failures
  - Early detection of problems by own and independent inspections
  - Schedule inspections and preventive maintenance
    - Visual inspections 2 - 4 times a year with changing aspects
    - Periodic inspections should be done twice a year. Wind turbines larger than 500 kW every 3 months
  - Shift necessary measures that need shutting down the wind turbine, i.e. that reduce availability (e.g. service on wind turbine to a time of low predicted yield)
  - Acquisition and statistical analysis of all available operating data of the wind turbine

Source: KWE ‚Onshore Wind Energy Fundamentals, Operation and Maintenance of wind fams

O&M costs and payment

- Overall onshore wind O&M costs are the range of 10 – 20 US$/MWh (onshore wind, offshore wind is factor 2 – 3 higher)
- Payment of an annual fee for the provision of the base services
  - generally include the cost of all consumables and spare parts required as part of the scheduled and unscheduled maintenance
  - exceptions apply e.g. if a spare part is required due force majeure
  - In addition incentive payments where the annual average availability of the wind farm exceeds a pre
- Warranted minimum level of availability for the WTGs within the wind farm

Basic components and structure of cash flow model

Investment costs for a 1 MW wind turbine (example)

	INVESTMENT (€1,000/MW)	SHARE OF TOTAL COST %
Turbine (ex works)	928	75.6
Grid connection	109	8.9
Foundation	80	6.5
Land rent	48	3.9
Electric installation	18	1.5
Consultancy	15	1.2
Financial costs	15	1.2
Road construction	11	0.9
Control systems	4	0.3
TOTAL	1,227	100

Source: EWEA, 2013

Input to wind cash flow model

Park Output Potential	**MWh@P90**
Availability Losses	fixed value
Electrical Losses	fixed value
Other Losses	fixed value
Net Output	MWh
Capacity Factor	%
Full Load Hours	hours
Electricity Price	EUR/MWh
Electricity Revenues	EUR '000
Interest Income	EUR '000
Total Income	EUR '000
O&M Rate	€/MWh
Operation Maintenance	EUR '000
Land Leases	EUR '000
Management	EUR '000
Taxes other than on Income	EUR '000
Auditing	EUR '000
Decommissioning Reserve	EUR '000
Total Operating Costs	EUR '000
Trade Tax	EUR '000
EBITDA	EUR '000
Income Tax	EUR '000
EBITDA after Tax	EUR '000

- EBITDA = earnings before interest, taxes, depreciation and amortization
- EUR = Euro
- MWh = Megawatt hours
- MWh@P90 = Probabilities of exceeding certain energy yield levels. It can be derived from the annual energy production´s distribution curve taking into account uncertainties.
  - p(90): Annual energy production exceeded with a probability of 90 %
  - p(75): Annual energy production exceeded with a probability of 75 %
  - p(50): Annual energy production exceeded with a probability of 50 %

Source: Boensch, Enertrag, 2010a

Input to wind cash flow model

Redemption	EUR '000
Interest	EUR '000
Debt Service	EUR '000
Cash before DSRA	EUR '000
Cash incl. DSRA	EUR '000
Target	EUR '000
Actual	EUR '000
Flow to Equity	EUR '000
DSCR	
DSCR (incl. DSRA)	

Key Information Input Data		Year
Ø-DSCR	1,39	---
Min-DSCR	1,14	2

DSRA	**50%**
Interest Income (DSRA)	**true**
Interest rate (DSRA)	**3,00%**

MWh@P50	**28.540**
MWh@P70	26.594
MWh@P75	26.038
MWh@P90	23.785
Overall Uncertainty	**13%**

- DSRA = The Debt Service Reserve Account works as an additional security measure for lenders as it is generally a deposit equal to a given number of months projected debt service obligations.
- DSCR = The debt service coverage ratio, also known as "debt coverage ratio," (DCR) is the ratio of cash available for debt servicing to interest, principal and lease payments.
- Overall uncertainty: takes into account errors calculating the annual energy yield

Source: Boensch, Enertrag, 2010a

Wind farm in France, cash flow forecast year 1–9

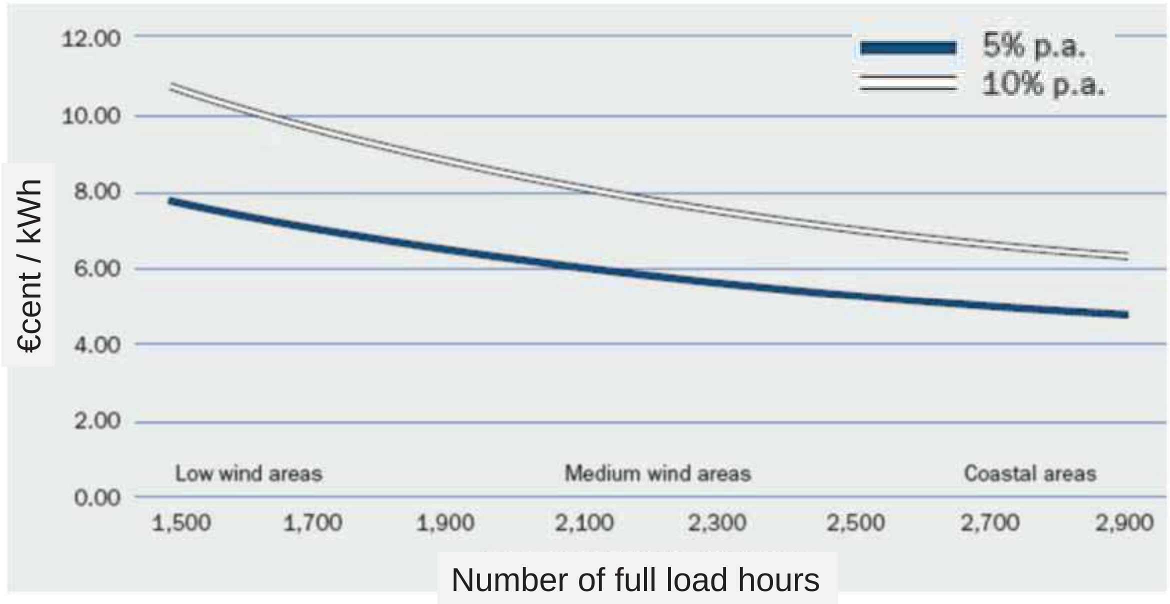
Sample Wind Farm in France	Cash out	2006	2007	2008	2009	2010	2011	2012	2013	2014
Energy Yield (P) 50	in Year 0	1	2	3	4	5	6	7	8	9
Electricity sales		2,268,079	2,301,646	2,335,710	2,370,279	2,405,359	2,133,057	2,164,626	2,196,663	2,229,173
Feed-in tarif ct/kWh		(8.36)	(8.48)	(8.61)	(8.74)	(8.87)	(7.86)	(7.98)	(8.10)	(8.22)
Interest income		18,000	30,909	27,506	25,037	25,117	24,892	24,614	24,811	24,645
Other income		0	0	0	0	0	0	0	0	0
Total revenues		2,286,079	2,332,555	2,363,217	2,395,316	2,430,477	2,157,949	2,189,240	2,221,474	2,253,818
Cost										
Land leases		44,000	44,651	45,312	45,983	46,663	47,354	48,055	48,766	49,488
Maintenance, repairs, insurance		28,622	28,909	117,985	291,602	294,710	303,584	336,660	339,926	343,224
Energy consumption		0	0	0	0	0	0	0	0	0
Management, accounting, decommissioning reserve		22,200	22,644	23,097	23,559	24,030	24,511	25,001	25,501	26,011
Taxes other than on income		7,714	10,686	18,059	18,099	18,141	18,186	17,832	17,873	17,915
Total cost		102,537	106,890	204,453	379,243	383,544	393,635	427,548	432,065	436,637
Sales minus cost		2,183,542	2,225,665	2,158,764	2,016,073	2,046,933	1,764,314	1,761,692	1,789,409	1,817,181
Taxe professionelle		0	0	75,557	70,563	71,643	61,751	61,659	62,629	63,601
EBITDA		2,183,542	2,225,665	2,083,207	1,945,511	1,975,290	1,702,563	1,700,033	1,726,779	1,753,579
Corporate income tax		0	0	0	0	0	0	0	0	0
Debt service										
Total interest		582,000	536,255	487,309	444,241	405,072	363,808	321,089	276,974	230,239
Total repayments		943,200	1,009,200	888,000	807,600	850,800	880,800	909,600	963,600	1,002,000
Total debt service	-12,000,000	1,525,200	1,545,455	1,375,309	1,251,841	1,255,872	1,244,608	1,230,689	1,240,574	1,232,239
Cash before reserve account		1,558,342	2,225,665	2,083,207	1,945,511	1,975,290	1,702,563	1,700,032	1,726,780	1,753,579
Reserve account (target)		1,545,455	1,375,309	1,251,841	1,255,872	1,244,608	1,230,689	1,240,574	1,232,239	1,234,042
Reserve account (actual)		1,545,455	1,375,309	1,251,841	1,255,872	1,244,608	1,230,689	1,240,574	1,232,239	1,234,042
Equity Cash Flow	-3,900,000	12,887	850,356	831,366	689,639	730,682	471,874	459,458	494,541	519,537

Credit decision-making

- Essential prerequisites for a credit decision are usually
  - two independently and accurately performed wind resource assessments for the proposed wind site from certified consultants,
  - a full-information cash flow forecast (incl. business plan) for the duration of the project,
  - a recourse-free building permit and a full set of valid project rights and contracts allowing turnkey-ready installation
  - Due diligence: before financial close is achieved and the first drawdown from the credit facility can be made, the bank, and respectively its consultants, perform a legal, technical and financial due diligence of the whole project to ensure that all major risks have been addressed
- Based on these information, the credit analyst will assign a rating to the project

Source: Aleander Boensch 2014

The costs of wind energy as a function of wind resource quality and discount rate



Source: Alexander Boensch, 2014

What is "availability" or "availability factor“?

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- Availability factor (or just "availability") is a measurement of the reliability of a wind turbine (or other power plant).
- It refers to the percentage
  - of time that a plant is ready to generate (that is, not out of service for maintenance or repairs) or
  - of the theoretical maximum energy output (wind is above cut-in and lower than cut-off wind speed).
- Downtime rate of wind farms results in loss of energy. If availability is low during times with high wind speeds the energy yield is reduced significantly (due to power curve characteristics).
- At high wind speeds repair of components such as blades can be delayed. This can cause long turbine downtime.
- Wind turbines can have an availability of more than 98%.

Source: KWE „Onshore Wind Energy Fundamentals, Operation and Maintenance of wind fams

Time and energy weighted availability of wind turbines

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Group:

Group Name	Time Weighted Availability	Energy Weighted Availability
All	94.74 %	93.00 %
Group 1	93.78 %	92.20 %
Group 2	95.67 %	93.91 %
Group 3	96.57 %	94.48 %

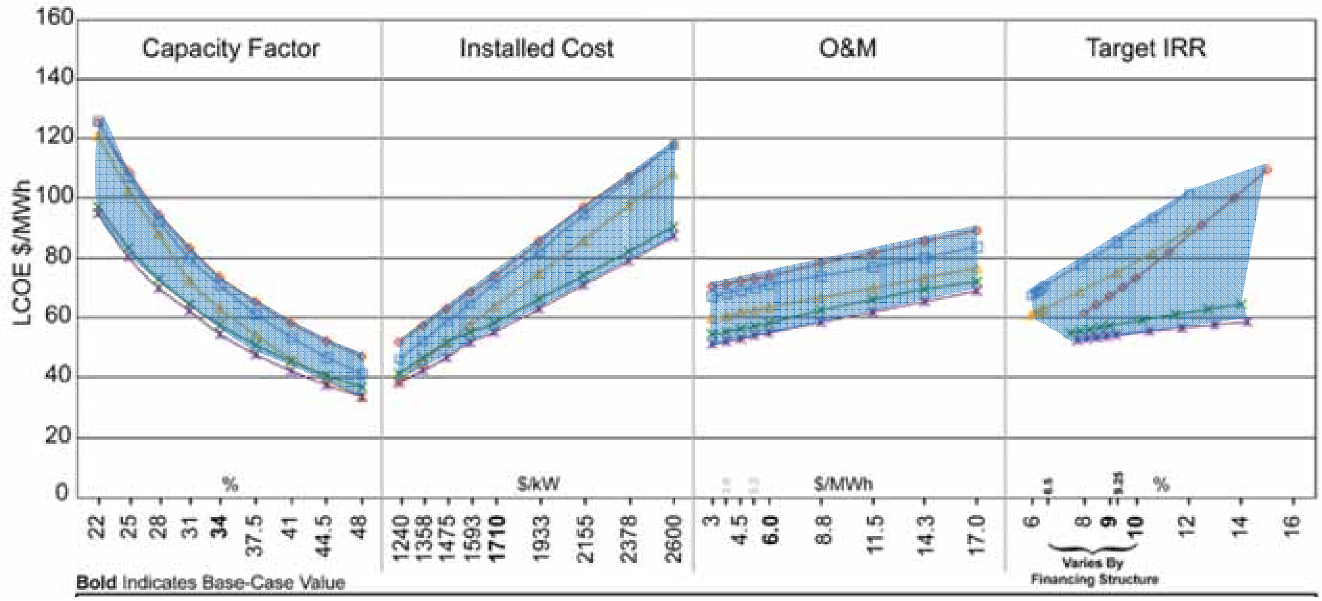
Turbines:

Turbine	Time Weighted Availability	Energy Weighted Availability
1	94.54 %	92.38 %
2	94.49 %	92.50 %
3	96.42 %	94.99 %
4	97.00 %	95.70 %
5	96.64 %	95.61 %
6	94.86 %	92.02 %
7	96.74 %	95.33 %

- Difference between time and energy weighted availability:
- Time weighted > energy weighted

Source: AWS Truepower, Take Control of Your Assets, www.awstruepower.com

LCOE sensitivities for capacity factor, installed cost, O&M, and target IRR by financing structure



Source: Wind Levelized Cost of Energy: A Comparison of Technical and Financing Input Variables Karlynn Cory and Paul Schwabe , Prepared under Task No. WER9.3550 , National Renewable Energy Laboratory

NREL- study results on LCOE

- Changes in a project’s capacity factor and installed cost have such a significant impact on the LCOE that small improvements through
  - improved R&D
  - manufacturing and
  - operation and maintenance improvements

  can yield major benefits.
- Targeted internal rate of return (IRR) can have an moderate influence on the LCOE

Key risks

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Completion risk

Risk	Potential Mitigation
▪ Late completion	▪ Contract incl. penalties for late completion with solvent plant manufacturer /experienced management
▪ Completion with higher costs	▪ Fixed price contract with solvent plant manufacturer
▪ Completion with underperforming parameters	▪ Performance guarantees (power curve, availability etc.) with solvent manufacturer ▪ Damage payment
▪ Non-completion	▪ Turn-key contract including completion guarantee and respective penalties with solvent plant manufacturer ▪ Insurances are available to cover costs of late completion

Operation and management risk

Risk	Potential Mitigation
▪ All risks during operation which might lead to under-performance ▪ Interruption or standstill of the wind farm	▪ Operation & management (O&M) contract with an experienced company – preferably with one of the project participants (manufacturer) ▪ Project life time O&M contract ▪ Incentives and penalties for contractor ▪ Availability definition: related to energy yield and wind resource (kWh/year) instead of related to time (h/year) ▪ Insurances (damage, financial loss of revenue cased by machinery damage)

Technology (functional) risk

Risk	Potential Mitigation
▪ Technology might not achieve the expected performance parameters (power curve, availability, etc.)	▪ Only a proven technology with a respective track record should be chosen ▪ Performance warranties on equipment ▪ Certified turbines according to IEC 61400 standards (International Electrotechnical Commission), i.a. "Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines" ▪ IEC-Certification carried out only by an independent institution in accordance with certain quality management standard

Market and distribution risk

Risk	Potential Mitigation
▪ The electricity cannot be sold in the expected amount and/or price ▪ Downtime of transmission lines ▪ Transmission line overload, congestion and curtailment of production ▪ Resource availability reduces firm capacity ▪ Value of green certificates changes ▪ Inflation risk	▪ Long-term contracts with solvent buyer ▪ Fixed feed-in tariff (provides the best risk mitigation) ▪ Self consumption / own grid / storage ▪ Virtual power station, pooling with other renewables

Resources risk

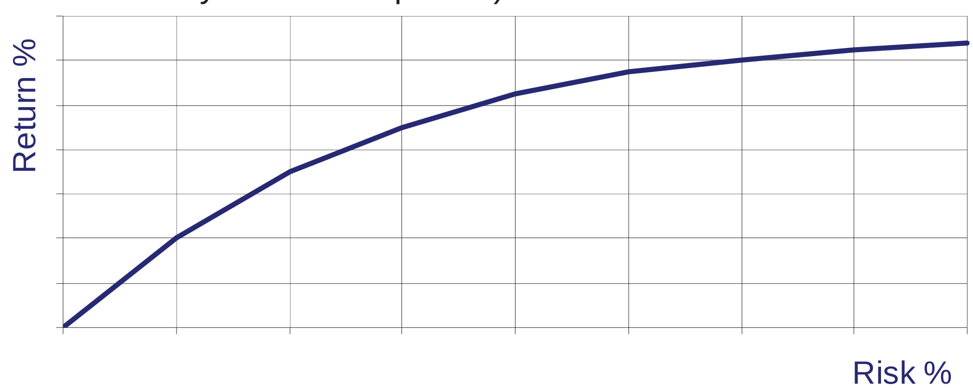
Risk	Potential Mitigation
▪ Wind speed distribution differs from wind resource study ▪ Lower wind speed than expected ▪ Extreme winds	▪ Thorough independent assessment of wind study ▪ Wind measurement at hub height instead extrapolated data ▪ Correlation of data with long term weather trends ▪ P50/75/90 approach, uncertainty analysis ▪ Wind turbine layout according to extreme winds (50/100 years wind)

regulatory framework &political stability

Risk	Potential Mitigation
▪ Change of framework conditions (e.g. feed-in tariffs, tax breaks, quota etc.) during the life time of a project. ▪ Legal uncertainty ▪ Unclear ownership rights	▪ For investors: investment only in countries with a reliable political framework ▪ For governments: provide reliable conditions to attract investments and to enable development of industry ▪ Investment in projects with short pay-back time

Understanding risks

- The greater the risk the greater the returns that banks and investors require
- Wind farm project risk summary:
  - Most important: wind resource and annual energy production forecast
  - Medium importance: quality of technology
  - Low importance: others (if political framework is stable and little inflation / currency risks are expected)



Thank you!

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