Technology and cost trends in on- and offshore wind energy

CYCLE DE FORMATION ÉNERGIE – ENVIRONNEMENT
SÉMINAIRE 2013-2014

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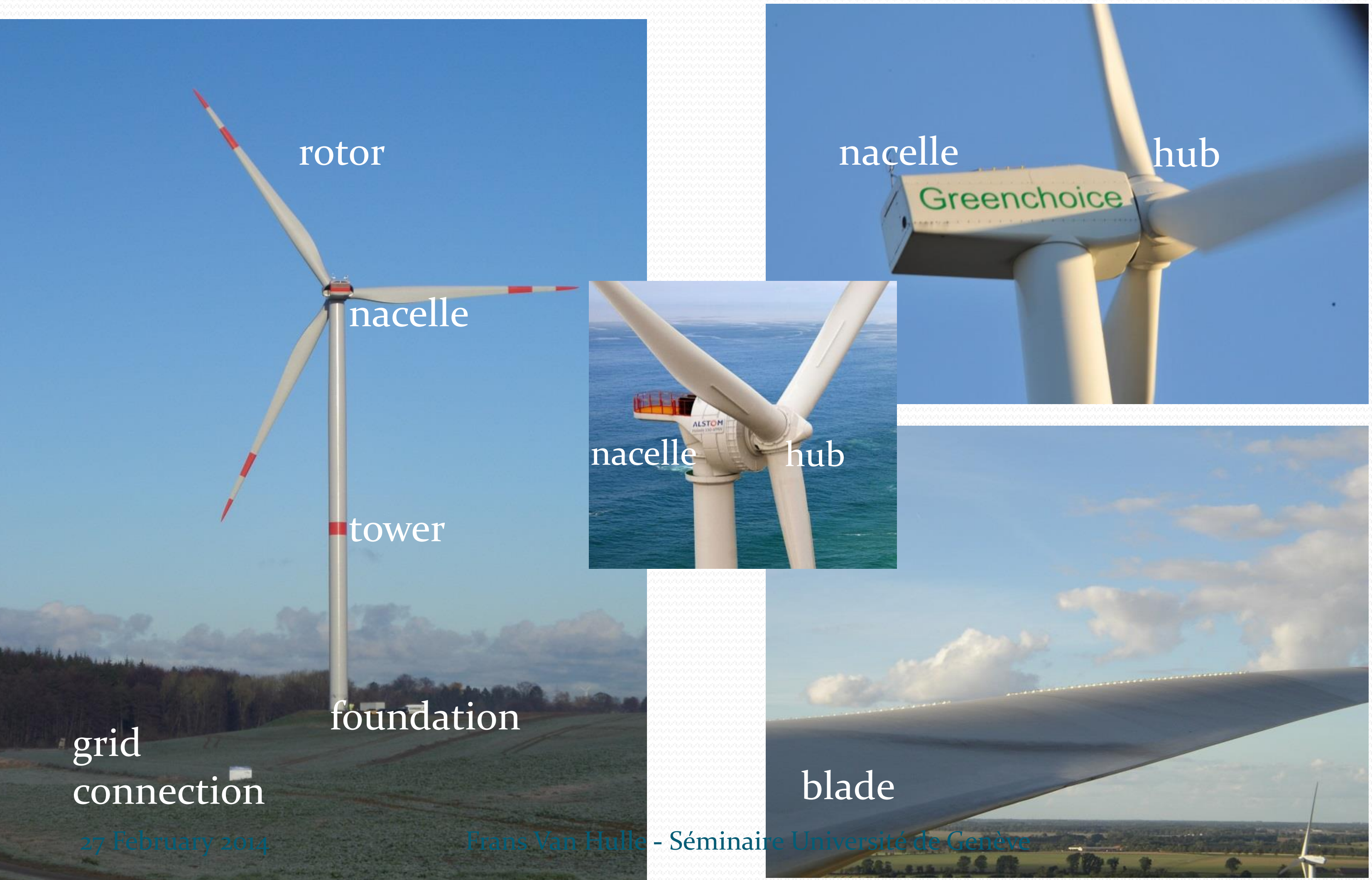
Genève, 27 February 2014

Agenda

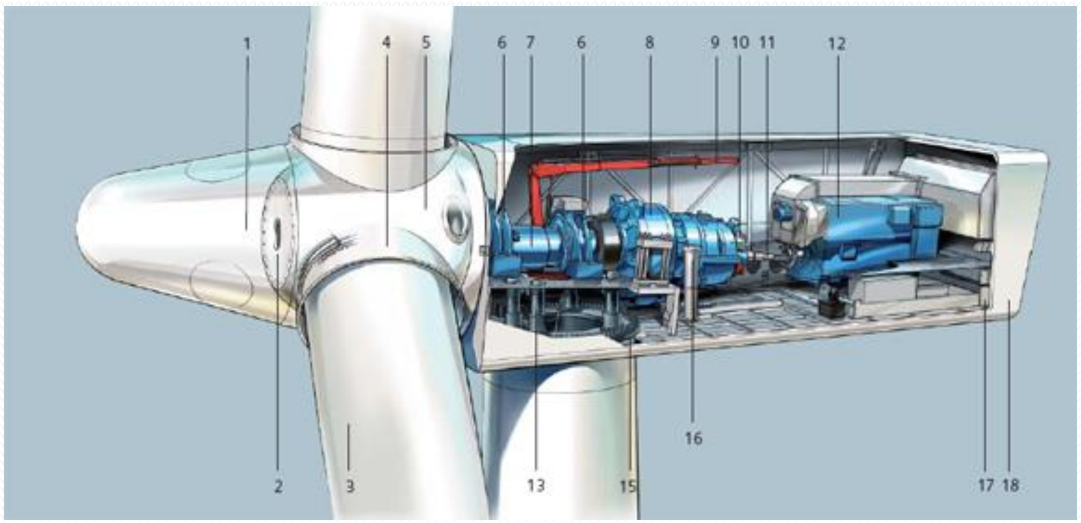
- Wind turbine technology
- Wind farm technology: onshore / offshore
- Energy and power from wind
- Costs of wind energy
- Wind power market figures

Wind to electrical power

Wind turbines: they all look very much alike



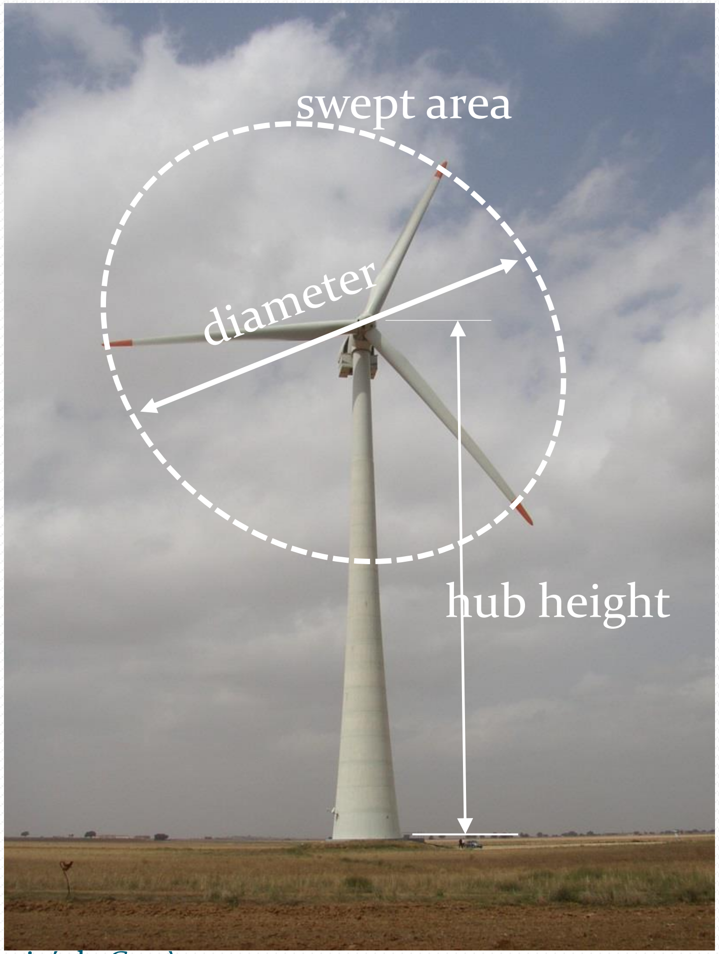
Parts inside the nacelle



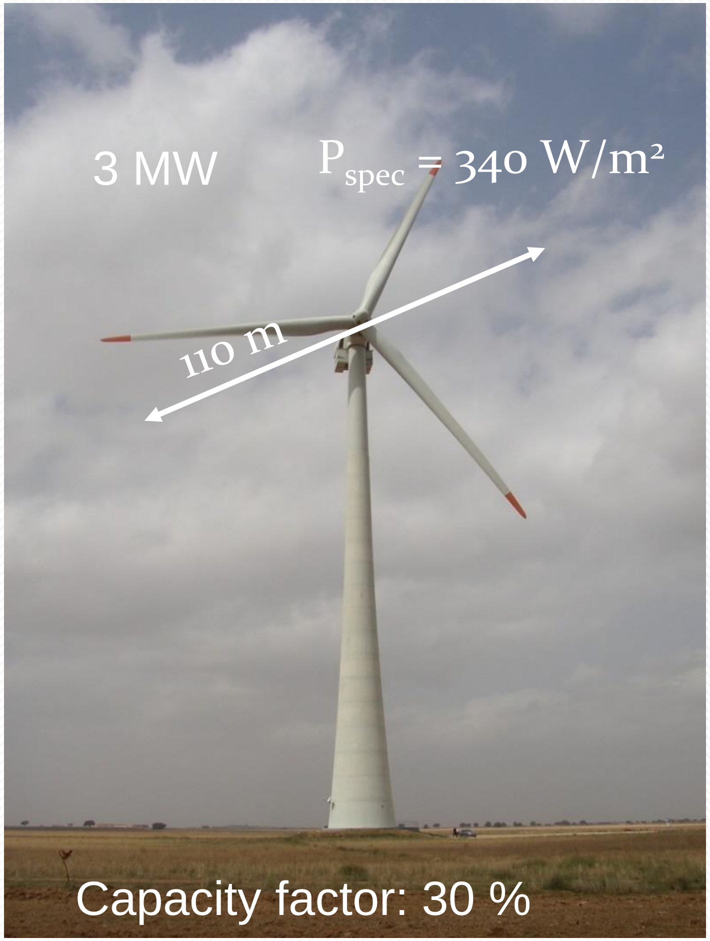
- Drive train
  - Hub with pitch motors
  - Main shaft
  - bearings
  - gearbox
- Machine bed frame
- Electrical generator
- Auxiliary equipment
  - Yaw motors
  - Switchgear …

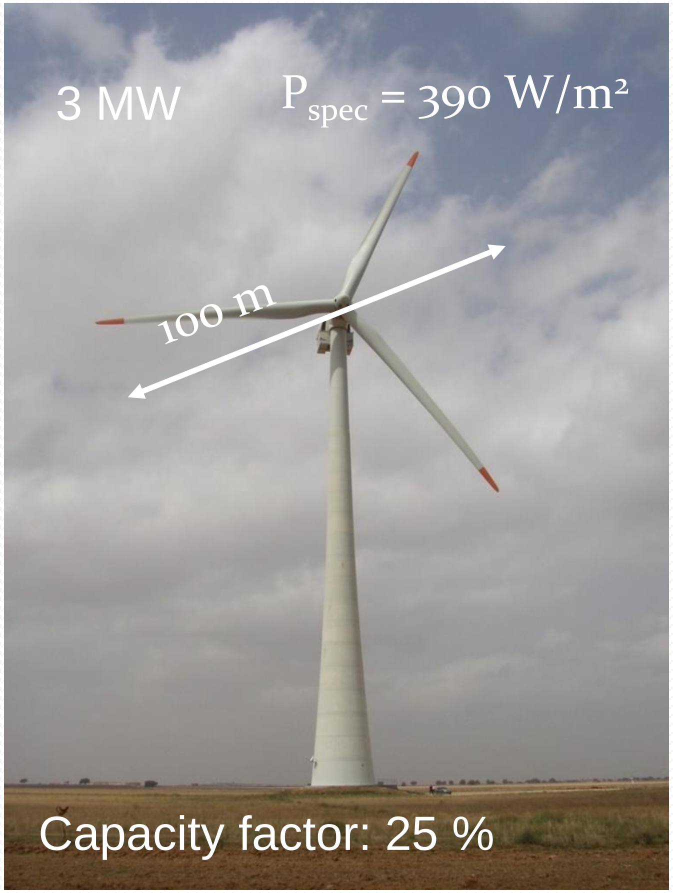
Wind turbine principal dimensions

Typical values!	
Diameter (m)	100 – 160
swept area (m^2)	8000 - 20000
hub height (m)	100 – 150
rated capacity (MW)	2 – 7
wind speeds (m/s) in/rated/out	3/12/25
rotor speed (rpm)	variable (4-20)



The rotor diameter (and not the installed power) determines energy yield in a given wind regime





Main wind turbine classes

- According to the ‘site wind conditions’
  - Low wind turbines / high wind turbines
  - Four IEC wind turbine classes according site conditions
  - Basic variable: rated power per sqm rotor area (determining also the load spectrum)

- According to Electrical Conversion system
  - Two major systems (largely equivalent in performance/cost):
    - Limited variable speed DFIG, partial inverter
    - Fully variable speed SG, PMG and full size inverter

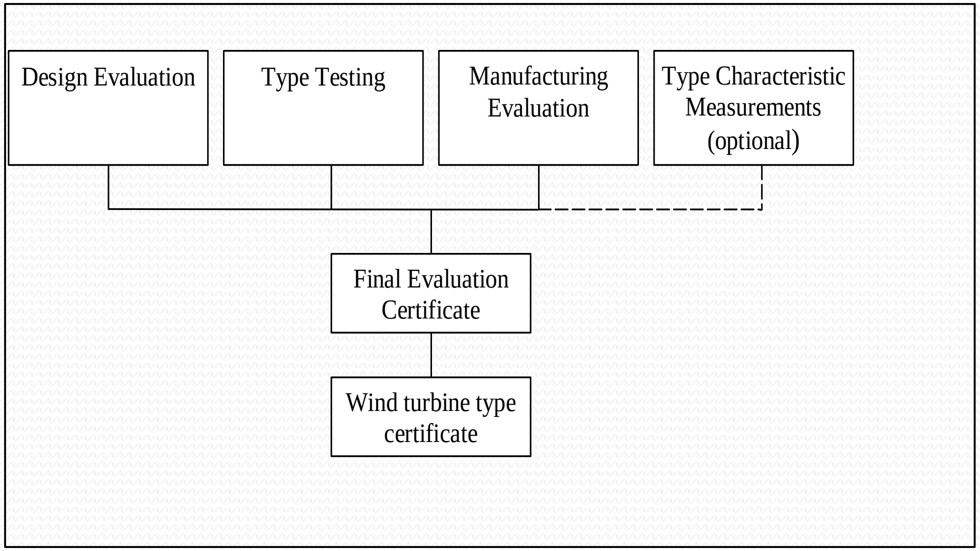
- Onshore and offshore applications : design standard IEC 61400-1 or IEC 61400-3

IEC Wind turbine classes

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

Standards and design tools

- Full set of design standards implemented (IEC)
- 20 years design life
- Validated design tools for calculation of structural loads (Bladed, Flex5 etc.)
- Checking and testing by accredited institutes (certifyiers, testing labs)



Technology trends

Historical wind turbine size growth

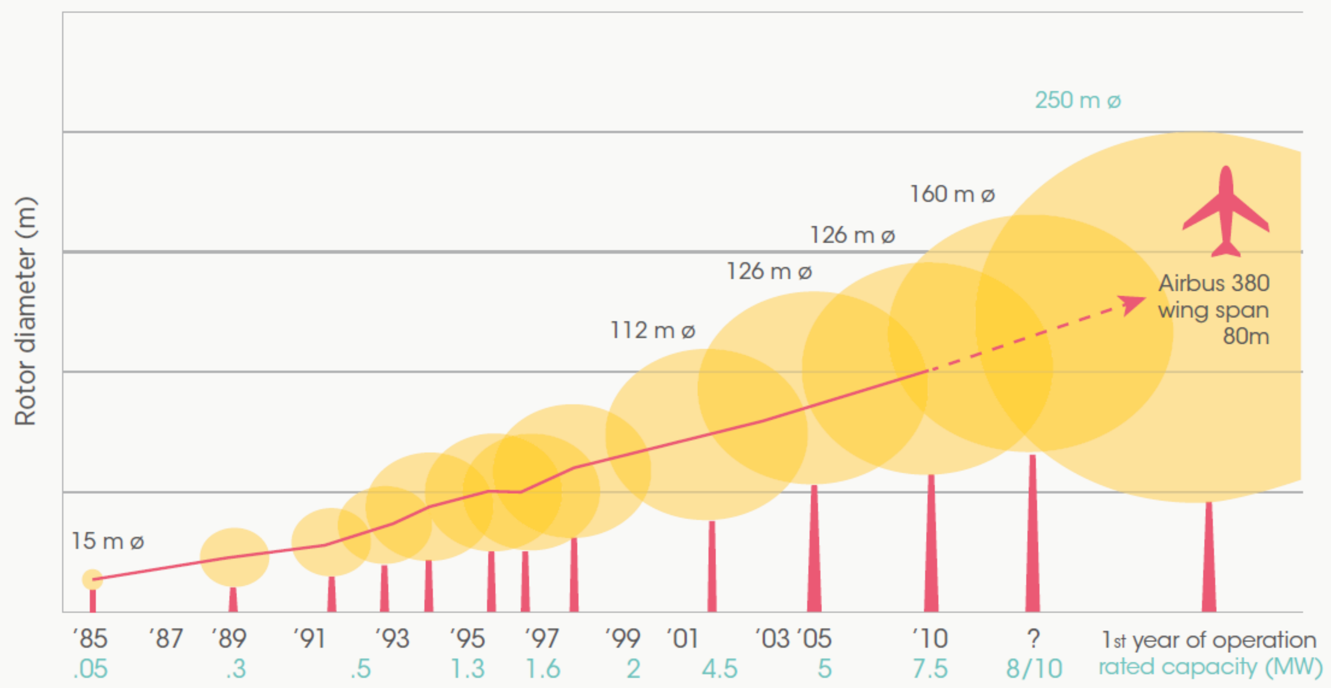
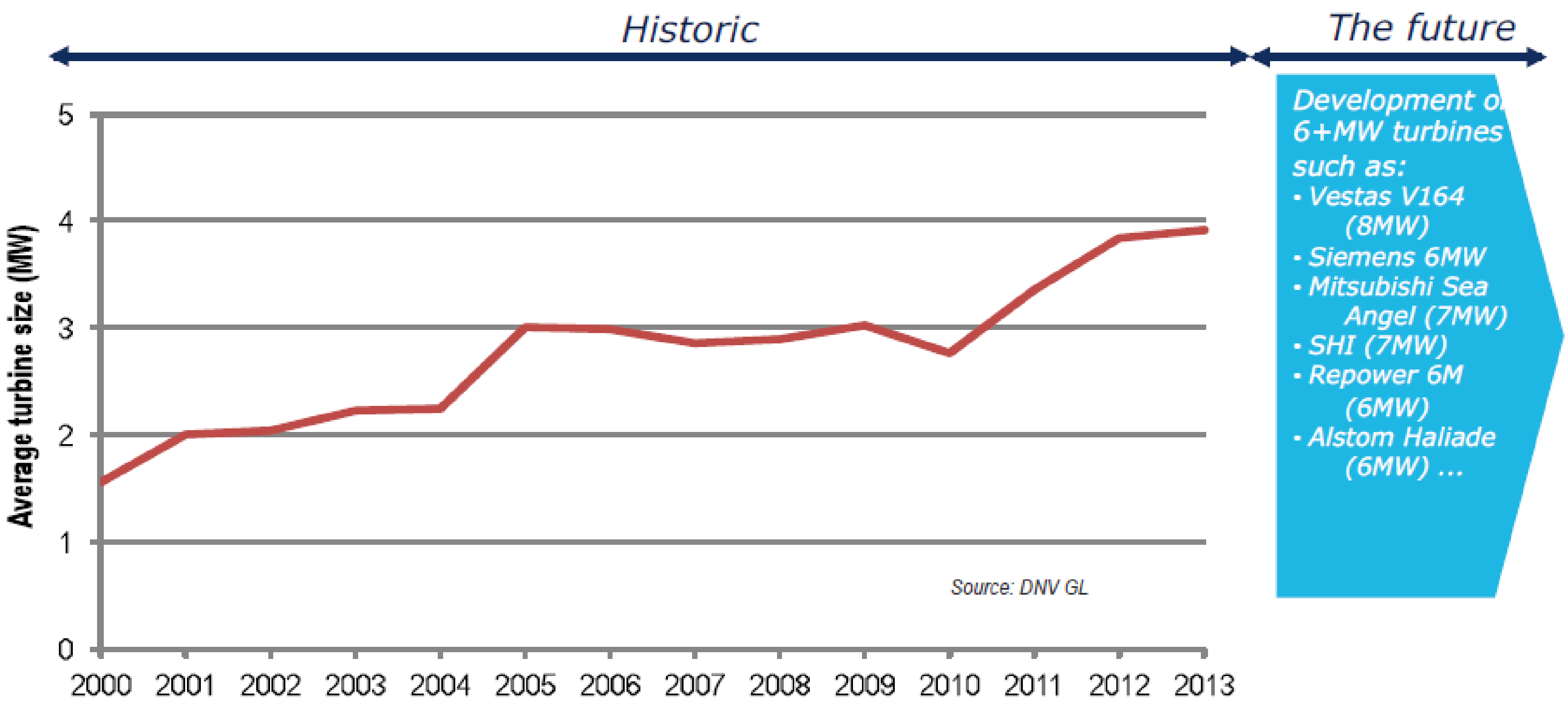


FIGURE 2.1: GROWTH IN THE SIZE OF WIND TURBINES SINCE 1985

Source: UpWind, 2011.

Global offshore wind turbine size trend: 6 MW on its way to new standard ...



Technology trends

- **Onshore concept:**
  - "frozen" (3 bladed HAT) and works (high Technology Readiness Level)
- **Offshore concept:**
  - Turbine part nowadays based on onshore concepts
  - potentially open for radical change (floating)
- **Size growth**:
  - may impact concept: square cube law to indicate the cost challenge
- **Optimisation besides energy also grid support:**
  - strict Grid Code requirements applied and ancillary services readiness
- **Standardisation and certification:**
  - Market introduction of new types universally accompanied with thorough testing and certification according to international standards
- **Uniform concept/technology development** worldwide:
  - EU, USA, Asia etc.

Rotor blades

Rotor blades

- Function: capture energy / control power / aerodynamic brake
- blade length: towards 90 m (10 MW)
- assembled into one part – very few split designs
- materials: FRP (glass fibre reinforced resin)
- Some add-ons for flow control
- Integrated lightning protection
- Future: smart blade with automatic geometric changes for control
- Static and fatigue test prior to commercial series production

Drive trains: 3 schools

classical gearbox drive train

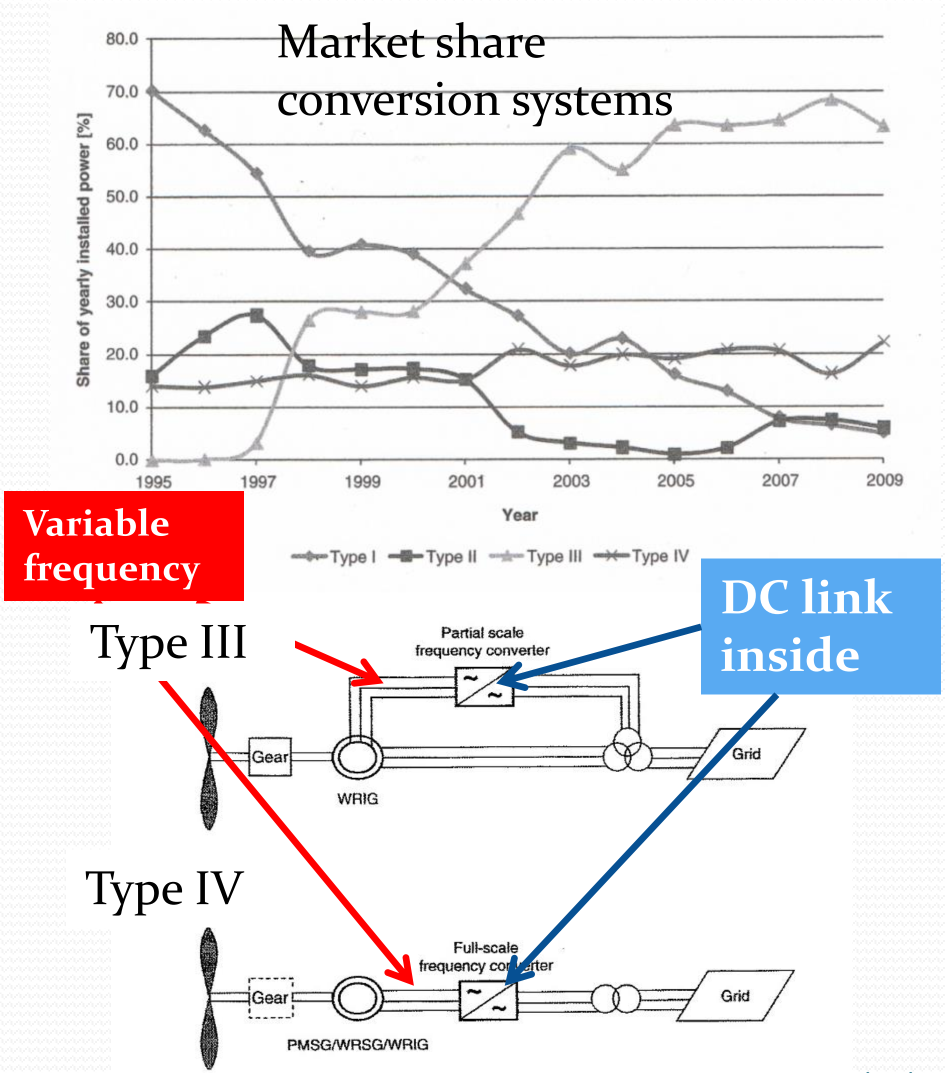
Direct drive

Hybrid drive train

Tower

- Vertical wind profile: significant increase of wind speed with height above ground
- Classical: “tubular” (steel or concrete)
- Nowadays tower heights ca 100 m
- Alternatives for heights above 130 m:
  - Hybrid (concrete / steel)
  - lattice

Electric conversion system: 2 schools



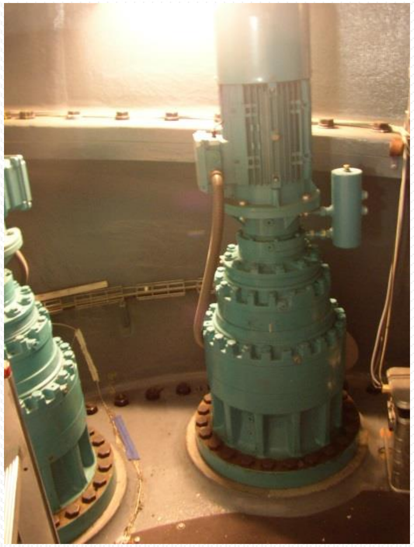
- 2 main type classes now
  - Type III: DFIG + part. inverter
  - Type IV: SG + full size inverter
- Consequences of power electronic inverters in the network:
  - Very good control possibilities (e.g. voltage)
  - turbine speed is decoupled from network 50 Hz frequency (non-synchronous generation) – no automatic contribution to grid inertia

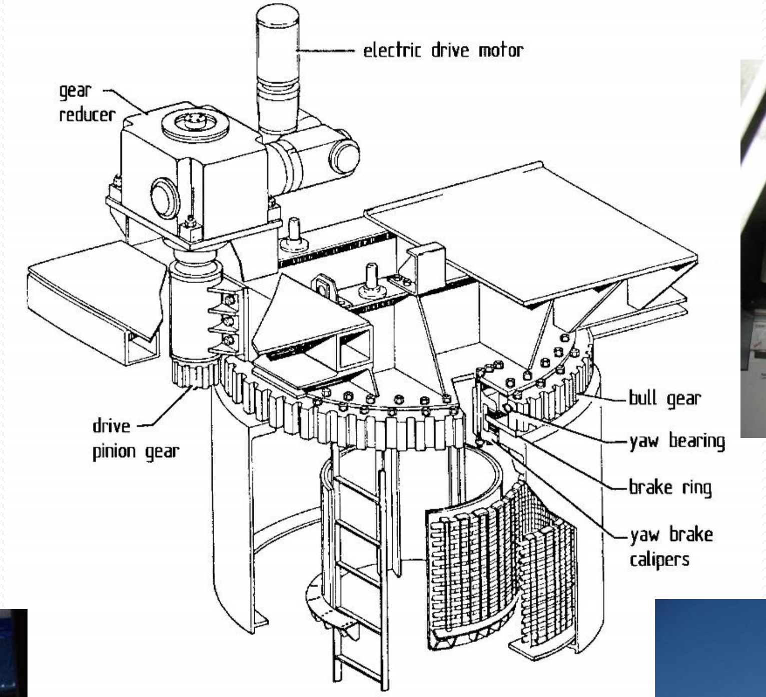
Control system: individual and power plant

- Control system shall ensure:
  - Fully automatic unattended operation: start, operate, shut-down, follow the wind
  - Optimum power generation
  - Minimising mechanical loading
  - On demand of electrical network: active power, frequency response, voltage control etc.
- Control actors:
  - blade (changing pitch angle)
  - electrical control – explanation of importance blade angle / rotor speed
  - Yawing system, mechanical brake etc.
- Control at wind turbine level communicates with higher levels (wind farm level, TSO)

REserviceS
ECONOMIC GRID SUPPORT FROM VARIABLE RENEWABLES

Wind turbine orientation (yawing)



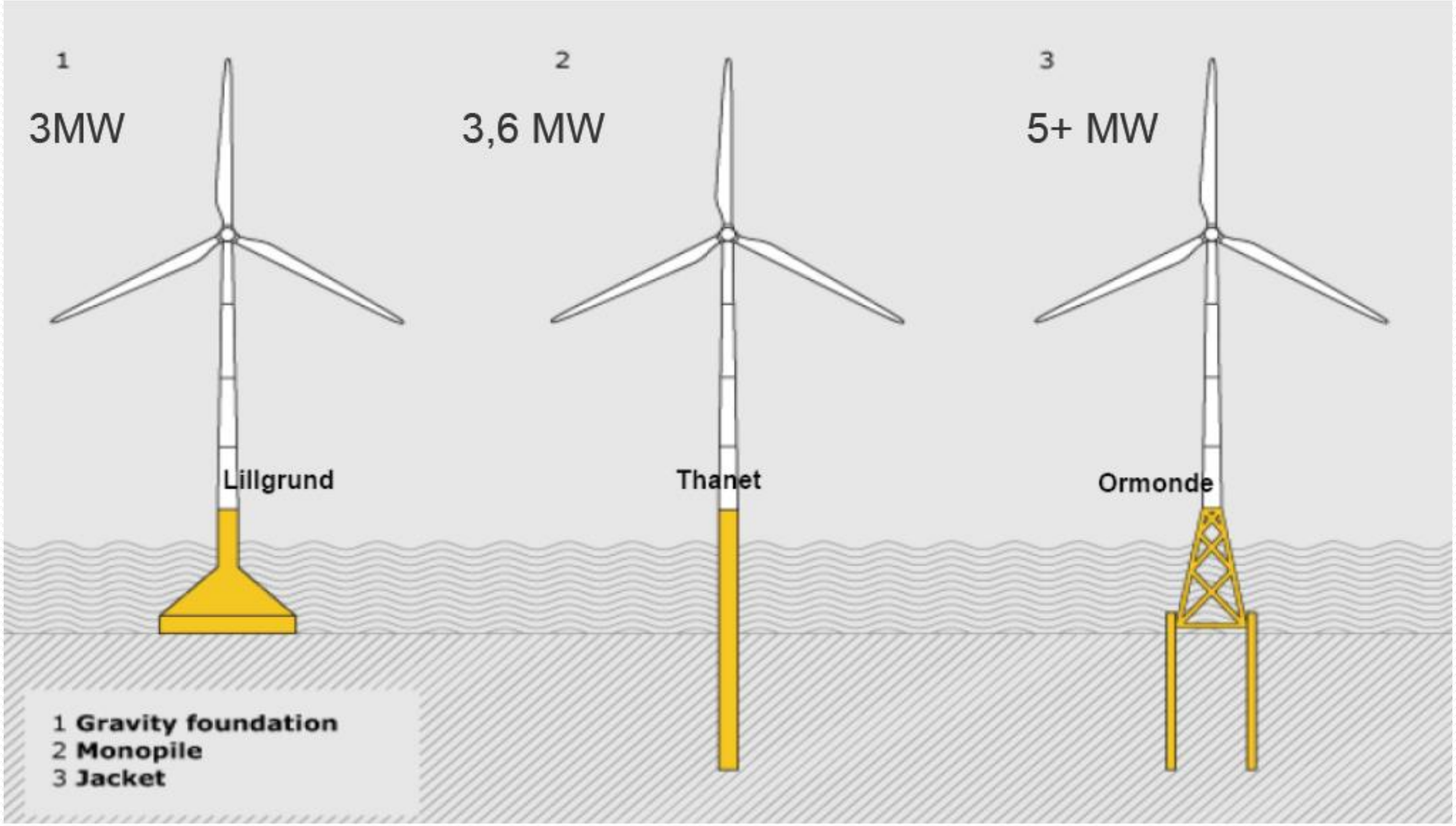


Protection system

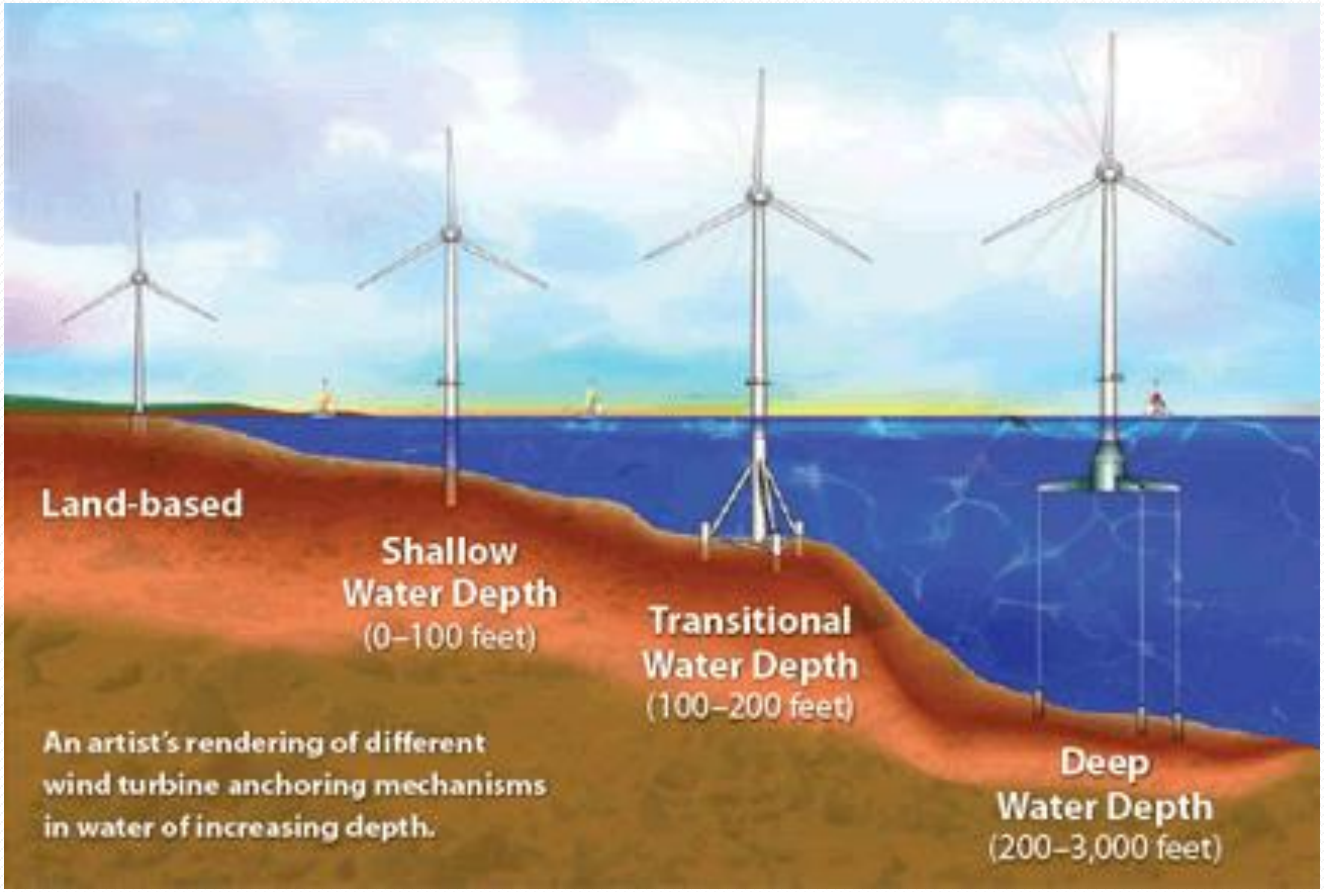
- Protection: to keep the wind turbine within design limits even in case of failure in the control and protection.
- Situations (mandatory standard!)
  - Speed limit
  - Faults in the system
  - Vibrations
  - etc.
- Protection agents:
  - Fast blade pitch
  - Other braking systems

foundations

Offshore foundation types



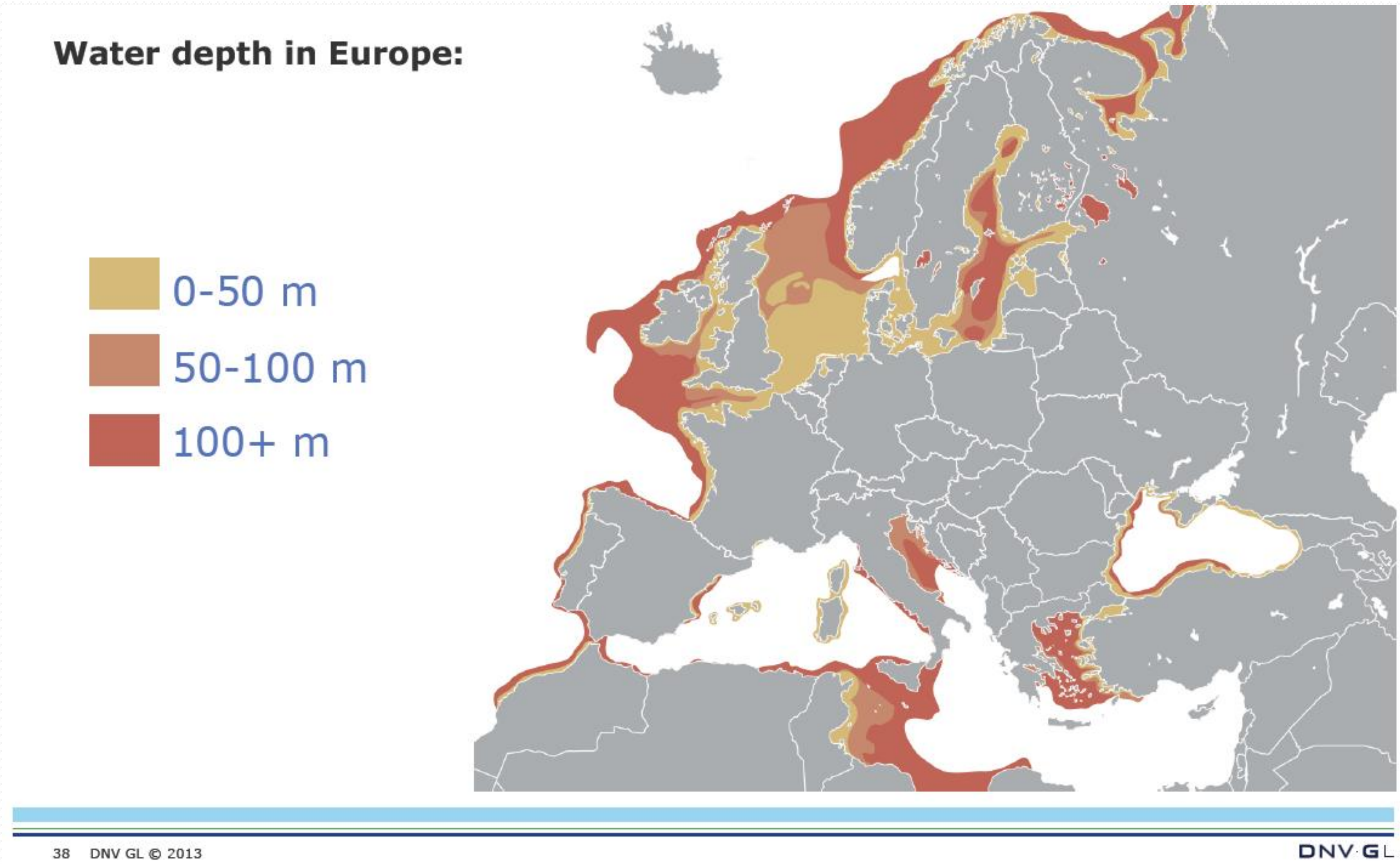
Foundations: from shallow to deep



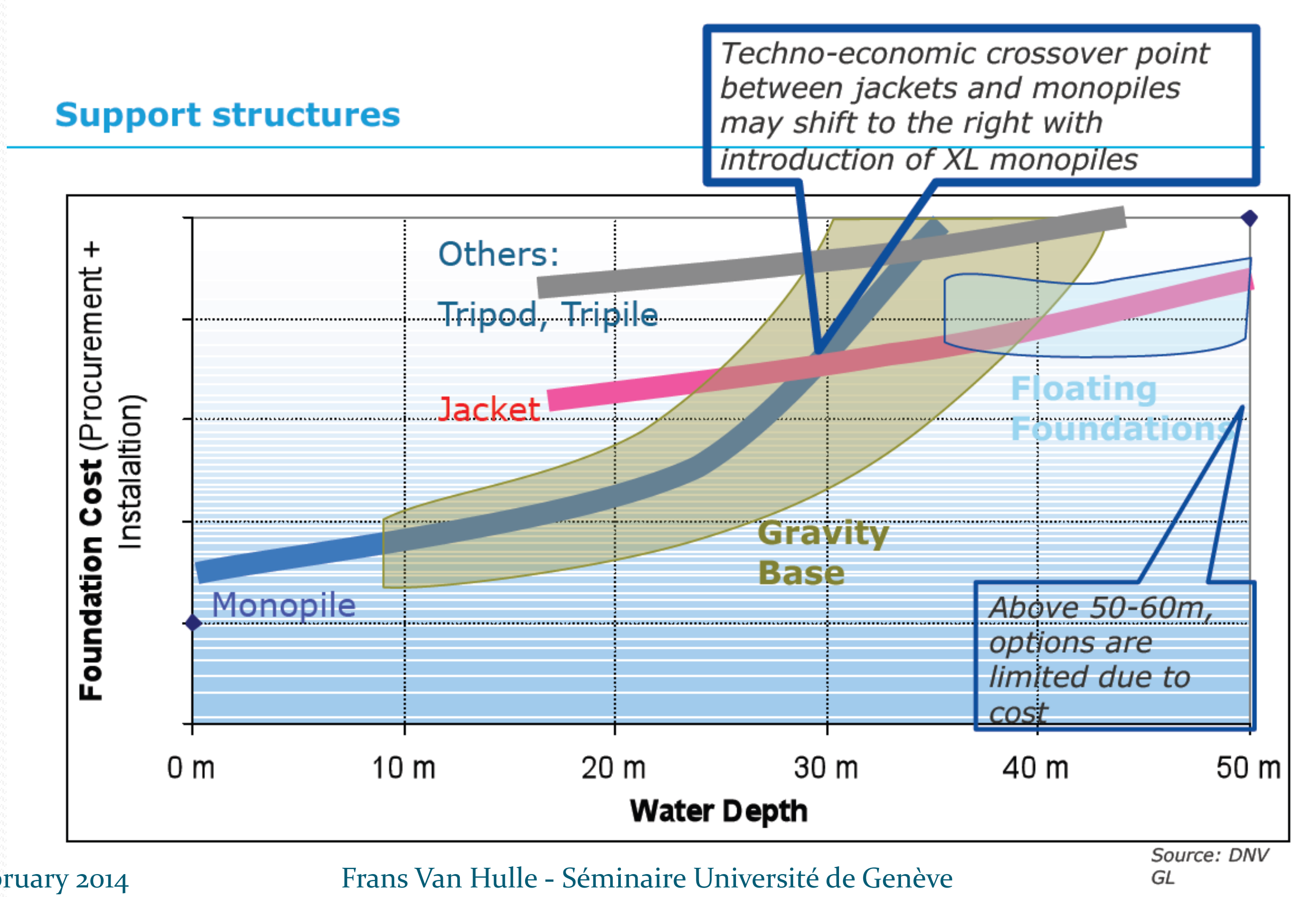
Floating offshore advantages

- High potential
- Easier installation and commissioning
- Cheaper O&M
- Modularisation
- Siting based on energy resource
- These advantages signify enormous future potential for the floating concept

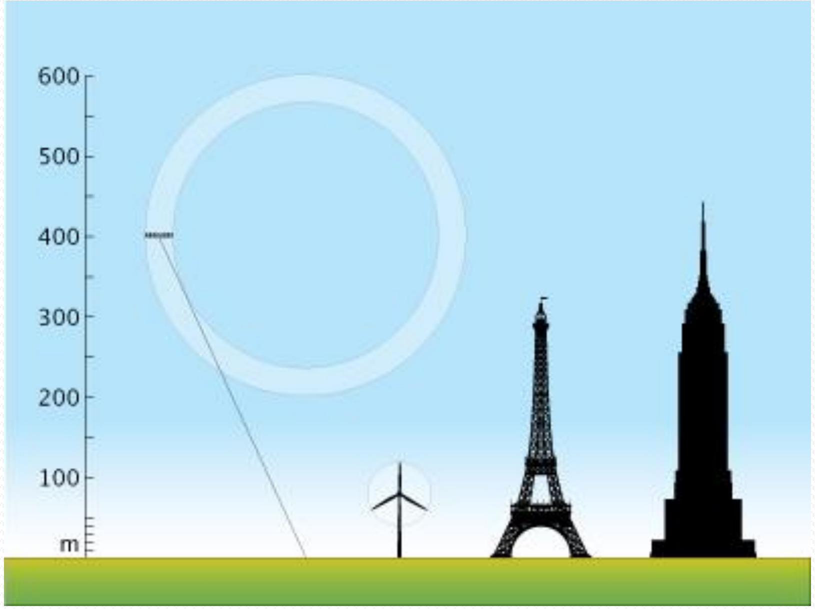
Why go deep?

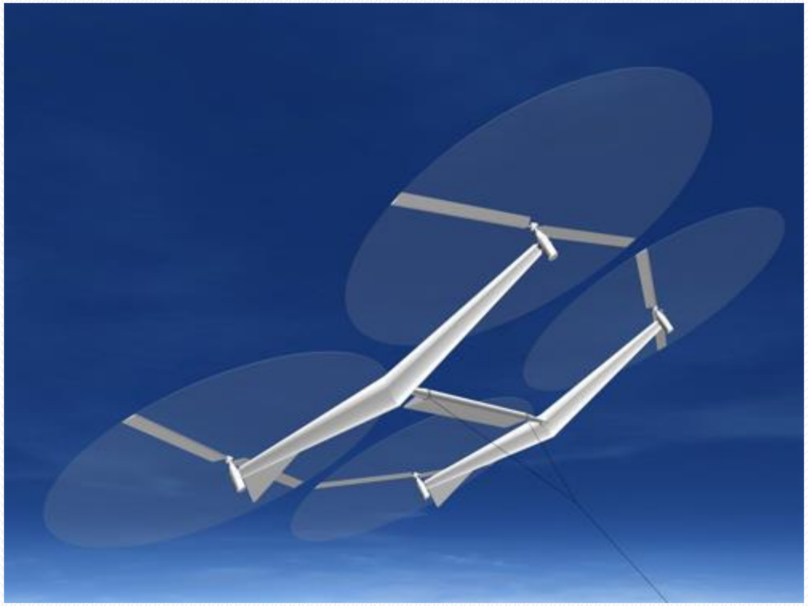


In search for cost-effective offshore foundations



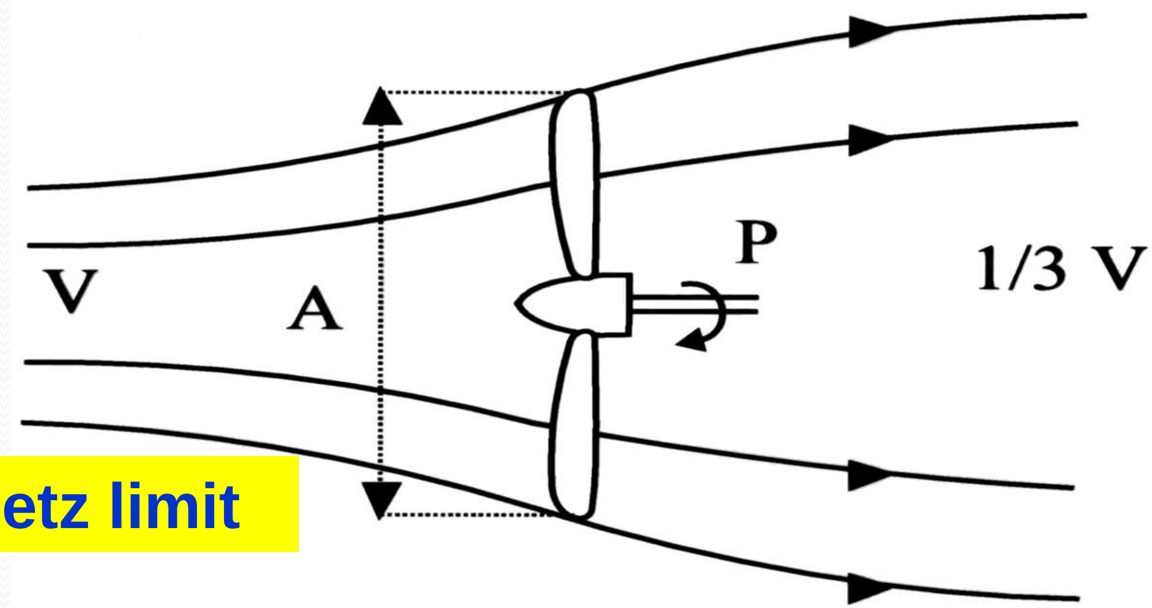
Airborne wind power: at least the foundation is lighter





Wind turbine performance and efficiency

Limit to power extraction from wind



Betz limit

$$P = 1/2\, \rho \,.\, C_p \,.\, V^3 \,.\, A$$

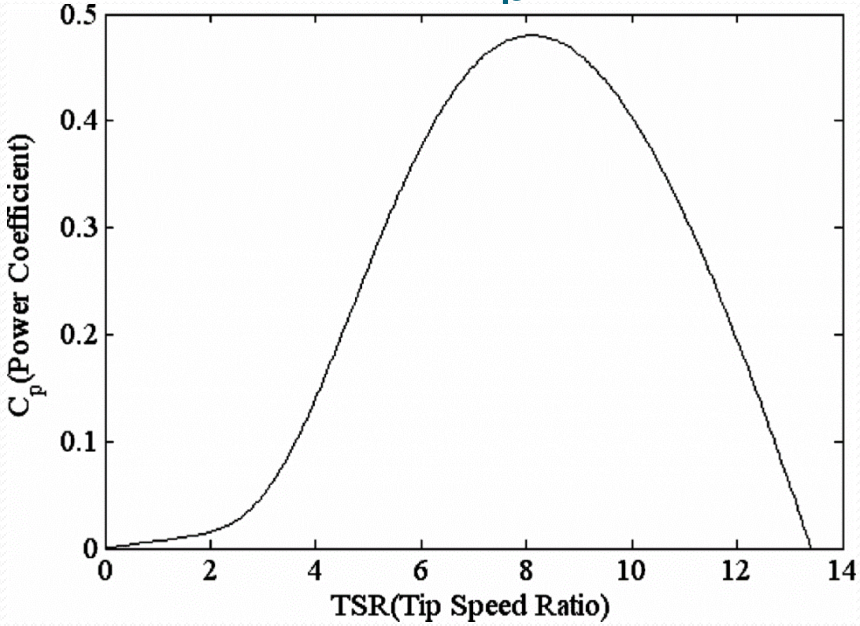
$$C_p \leq 16/27$$

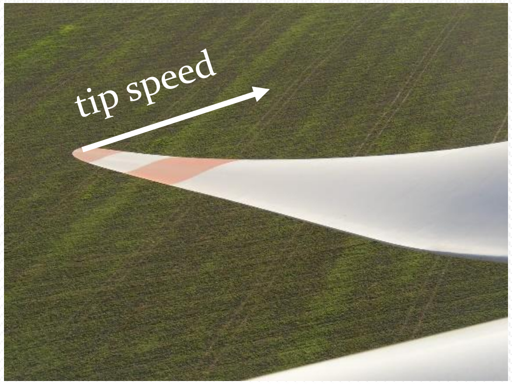
Almost 60% (59,3%)

Albert Betz, Germany

Wind turbine energetic efficiency : C_p

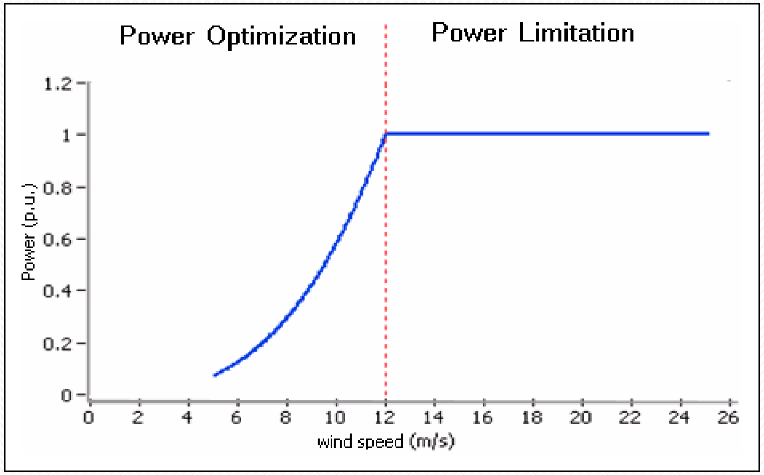
- TSR (tip speed ratio) is blade tip speed divided by wind speed
- there is an optimal (TSR) where efficiency C_p is maximum (lower than 59,3% = Betz limit)
- for optimum efficiency, TSR has to be kept constant in variable wind speed by varying the rotor speed

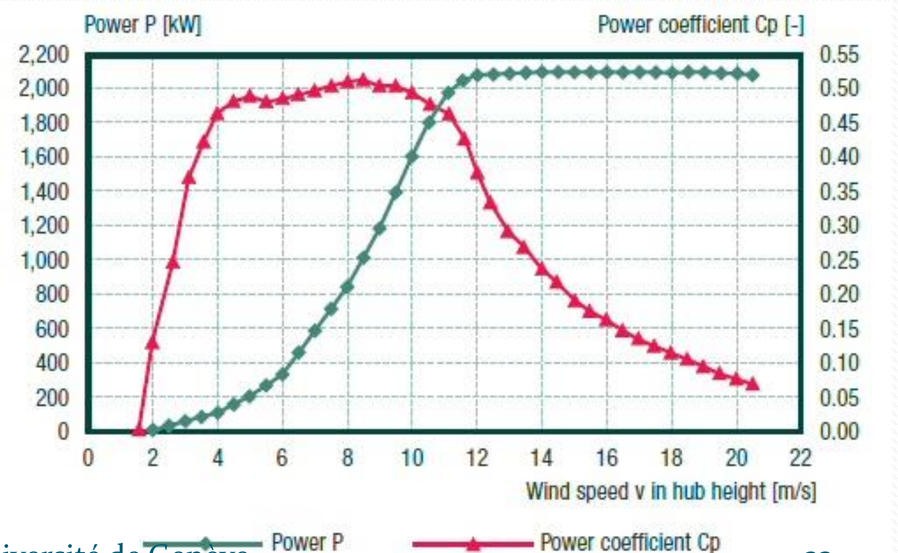




Wind turbine power curve and efficiency

- Power optimisation under v_{rated}, power limitation above v_{rated}
- **Optimisation:** keeping rotor near optimum TSR by varying rotor speed with wind speed
- **Limitation**: blade pitching and rotor speed limitation
- C_P/v curve should be flat (and high) in the band of wind speeds containing most energy
- Power curve must be measured according to international standard IEC 61400-12

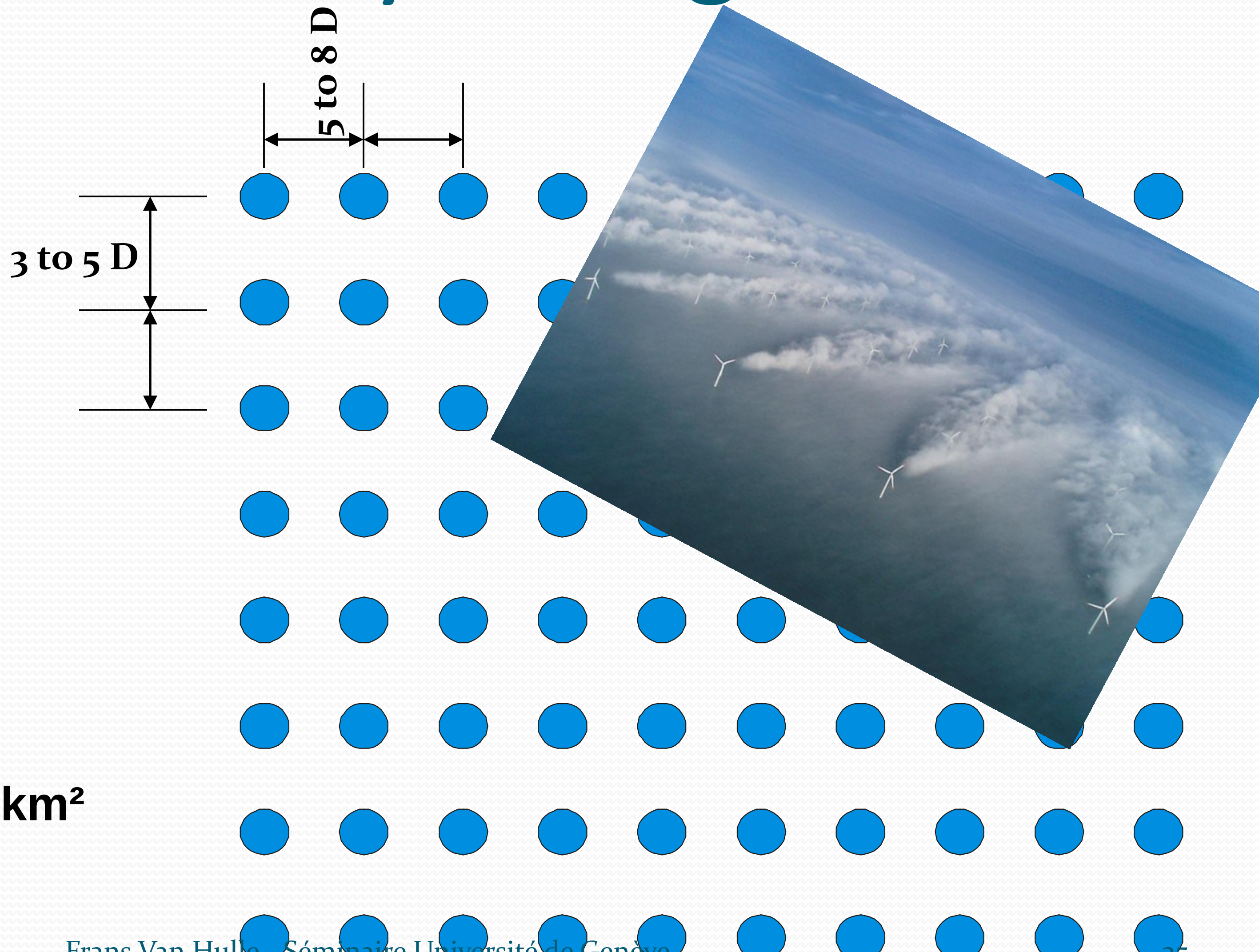




wind farm technology

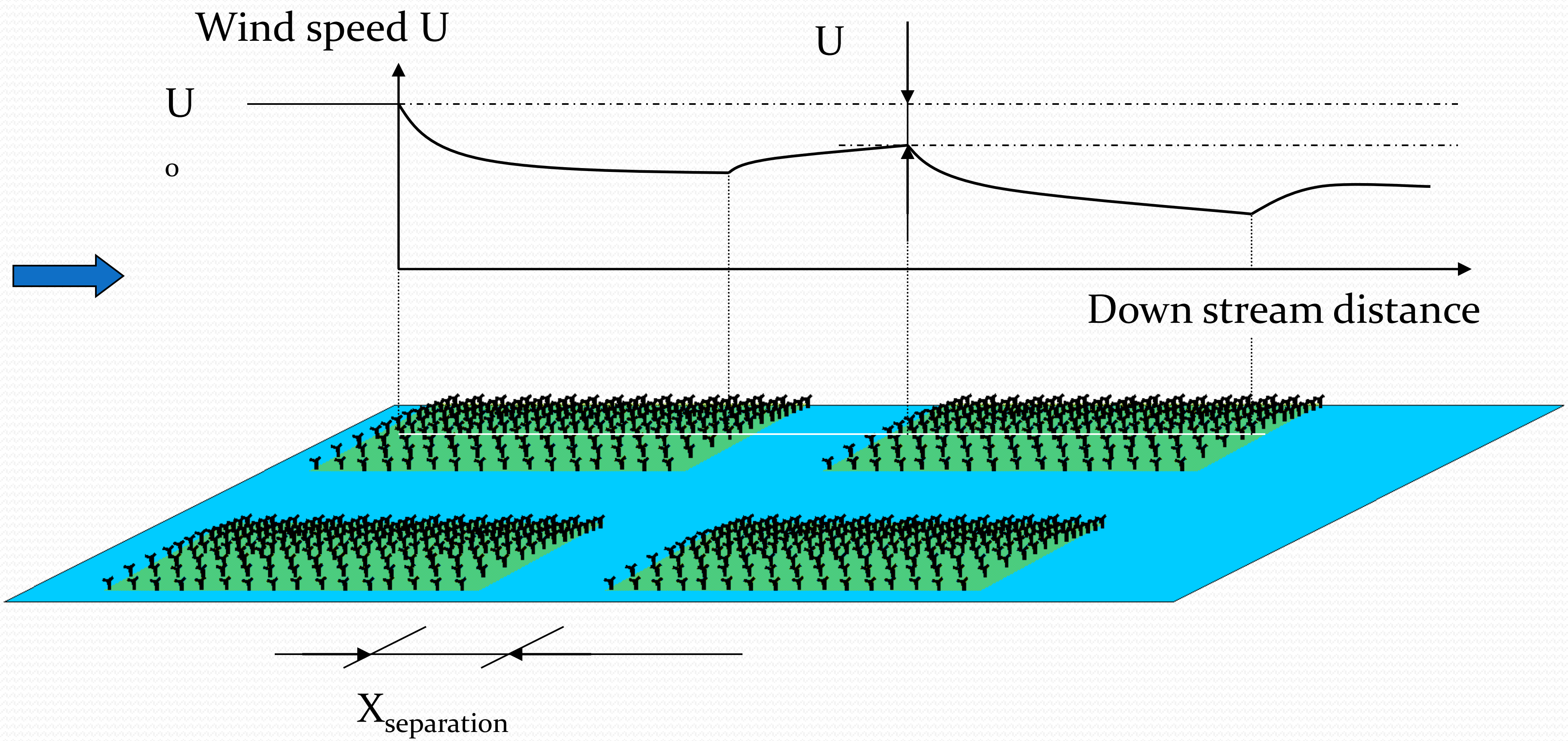
Wind farm array configuration

wind direction



P = 6 to 15 MW/km²

Wind farms need to watch the neighbours



Wind farm cluster design FP7 projects: ClusterDesign and EERA-DTOC

Wind farm lay out optimisation

Line optimisation

- prevailing wind direction
- Respecting distances

Array optimisation

- Grid design
- Controlling the first row to make the 2nd row suffer less

Wind farm design and operation challenges

- Resource evaluation on site: measure and simulate
- Array configuration design: balance all constraints
- Minimising wake losses: dedicated control?
- Technology selection: which supplier?
- Optimising control strategy: grid services?
- Installation: minimising costs / time / impacts
- Operation including
  - Optimal O&M strategies: to maximise availability
  - Operating as power plant, getting maximum income from energy markets and ancillary services

Offshore technology challenges

- Substructures
- Vessels
- Keeping high availability through high reliability
- Condition based O&M

Further technology improvements

- Priorities in the strategic research agenda of the wind power industry:
  - Rotor blade development
  - Structural and mechanical design
  - Electrical plant properties
  - Control on wind turbine and wind farm level
  - Operation and maintenance

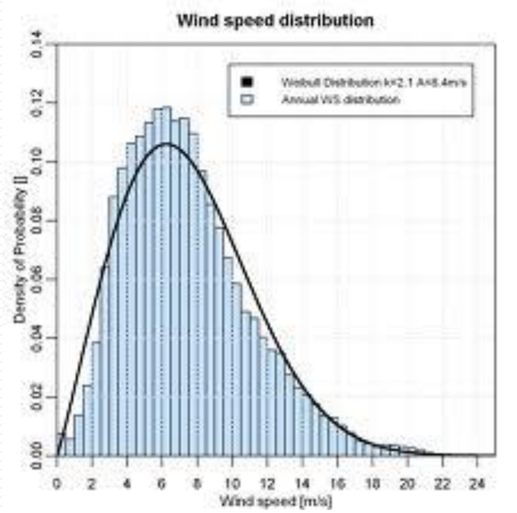
Forecasting energy from wind

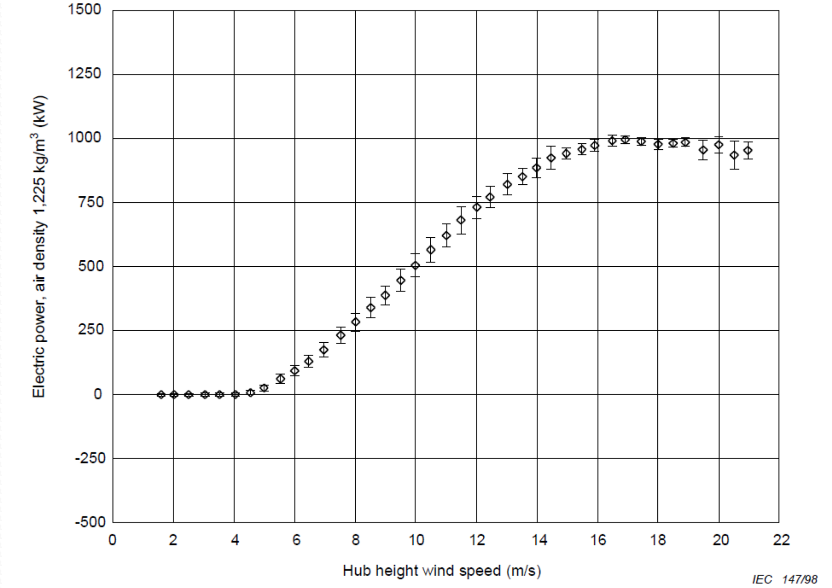
Accurate energy output estimation

- Predicting long-term energy output (mostly AEO = annual energy output) with **low uncertainty** is very important for successful wind project
- Projected energy output (AEO) is **extremely** project/location specific (unlike e.g. solar PV)
- Technology factors:
  - Rotor size is determining the AEO, not the rated power – **the measured power curve counts**!
  - Wind farm configuration (wake losses)
  - Wind farm reliability, determining the technical availability

annual energy output forecast: necessary steps

- **Wind study:** long term wind regime (distributions) at the projected wind turbine locations
  - short term (eg 1 year) measurements
  - Correlation with long term (>10 years) measurements
  - Validated software tools for horizontal and vertical extrapolation to wind turbine positions (terrain effects)
- **wind turbine power curve** (backed up by measurements according to IEC 61400-12)
- Estimates of **losses due to wake effects** (interaction between wind turbines)
- Combine wind and power curve and estimate the uncertainties



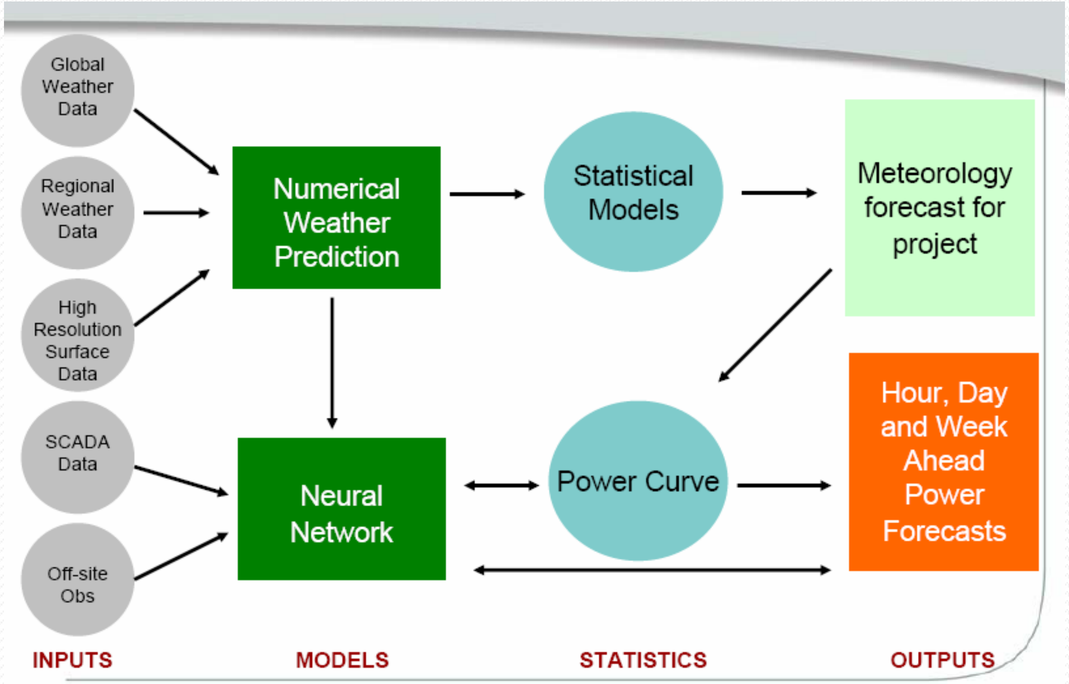


Actual energy output of wind projects

- Full load hours (capacity factors) :
  - Onshore : 2500 – 3000 h (CF 20-30%)
  - Offshore : 3500 – 4500 h (CF 40-50%)
- Tendency for higher capacity factors in recent years due to increased rotor sizes (for same rated capacity)
- Specific energy output increases of projects expected?
  - No spectacular WT efficiency improvements foreseen
  - Higher share of offshore will increase the average capacity factor of installed wind power
  - Basic principle remains: E proportional to v^3
    - Extreme sensitivity of output with local average wind speed
- Specific project data difficult to obtain (confidentiality) – exception: Germany - Denmark

Short term forecast: power to grid

- To assist system operator (e.g. participation in balancing)
- To increase economic benefits of wind energy projects



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Expected cost developments

Costs of wind energy: LCOE

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

- Strong dependency on energy output E (capacity factor etc.)!

Illustrating the tendency (but do not generalise the numbers)

Breakdown of investment costs

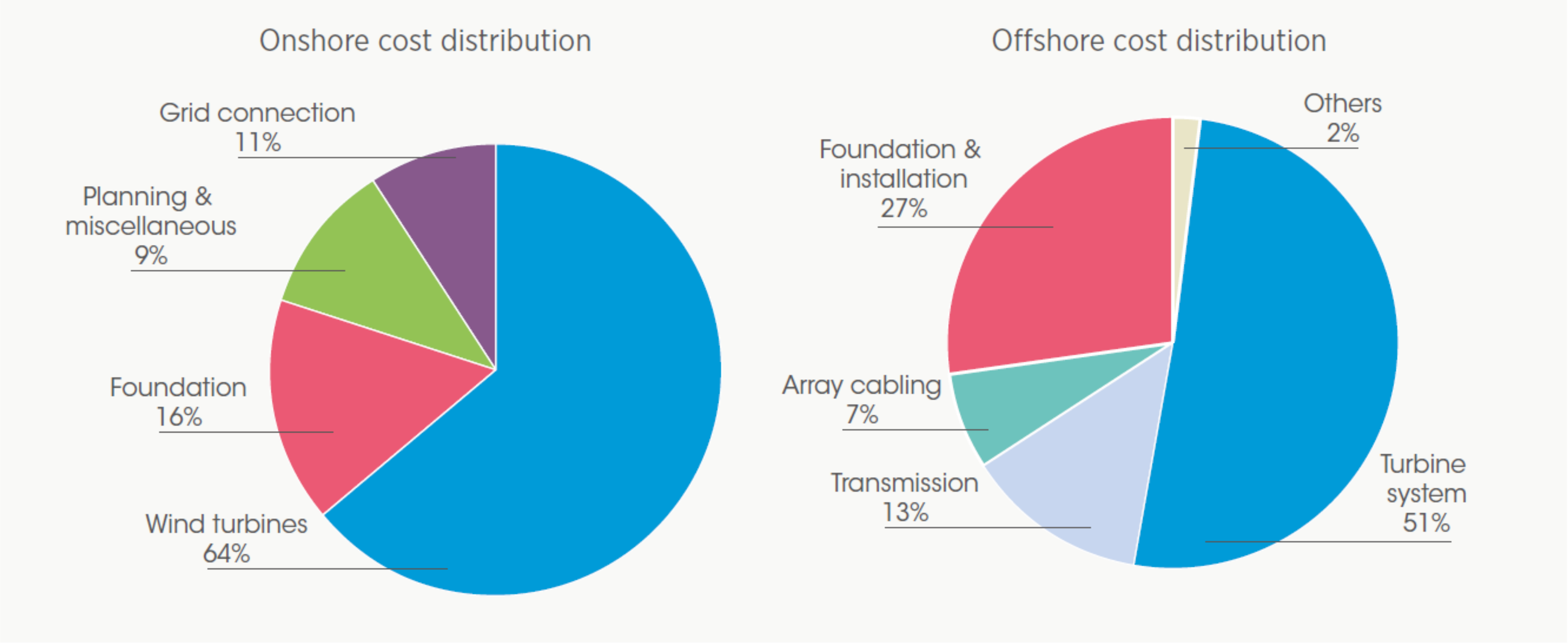
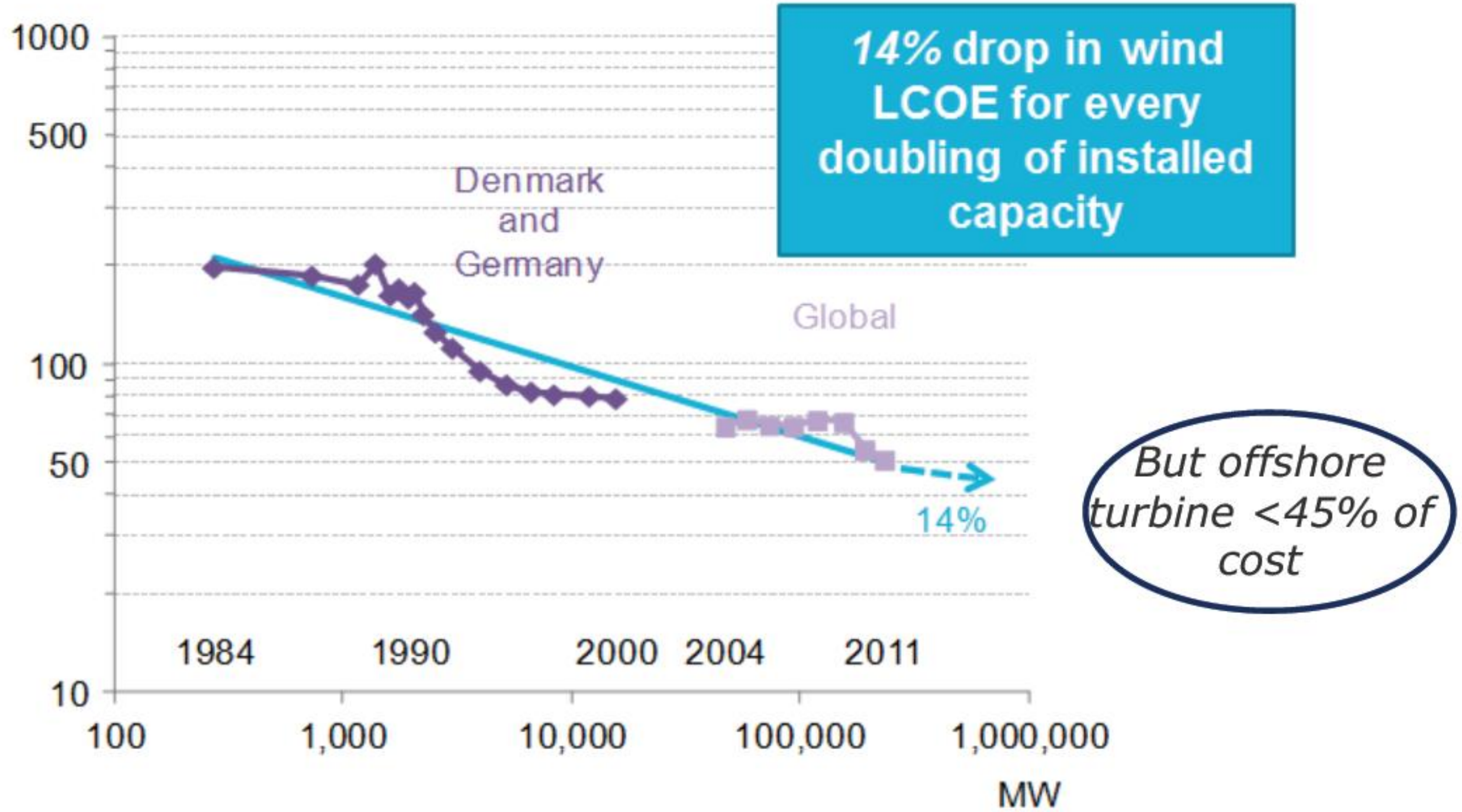


FIGURE 6.2: CAPITAL COST BREAKDOWNS FOR TYPICAL ONSHORE AND OFFSHORE WIND SYSTEMS

Source: Blanco, 2009.

LCOE development onshore (EUR/MWh)



Source: Bloomberg New Energy Finance

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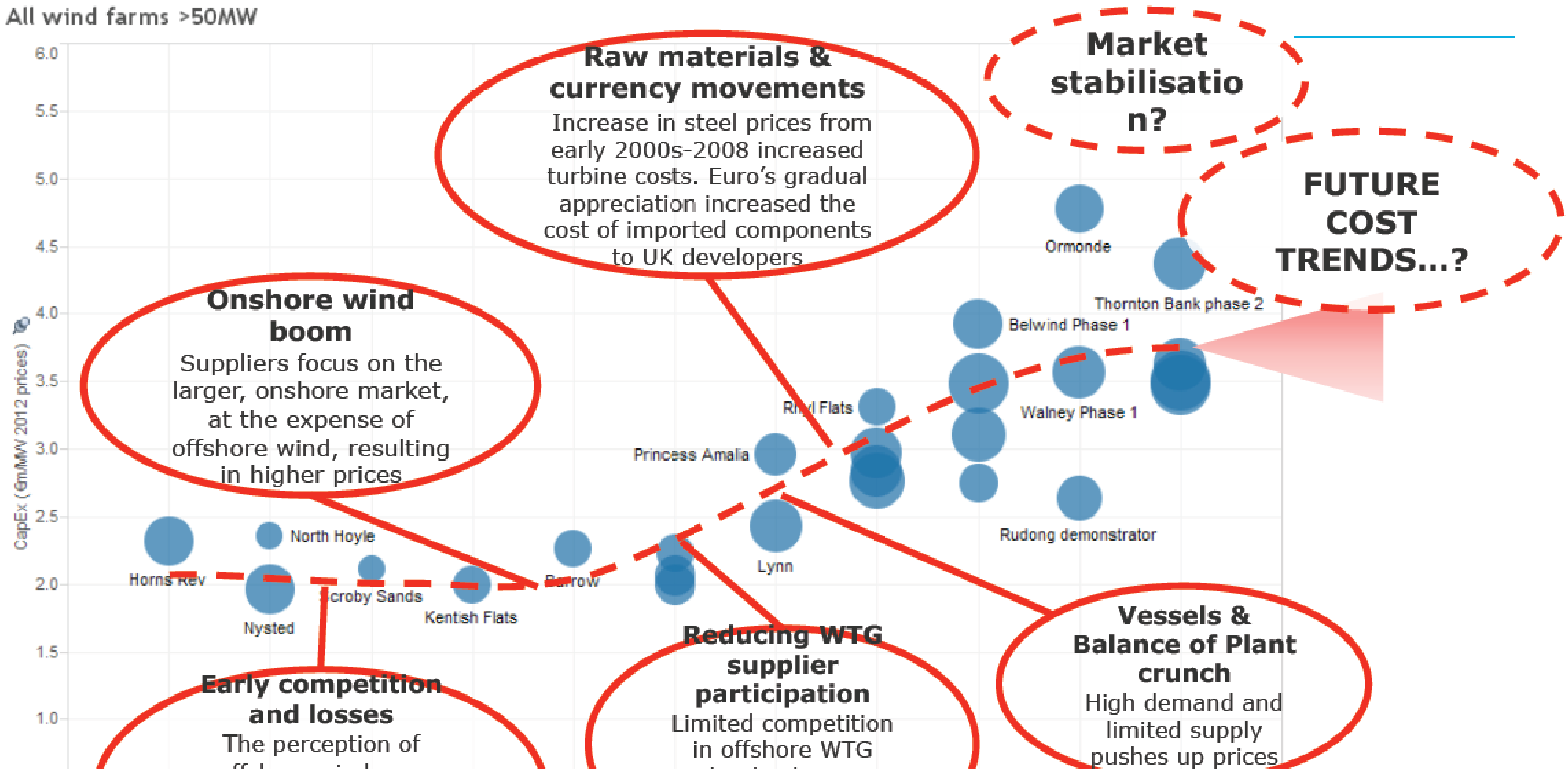
Historical offshore wind capex trend



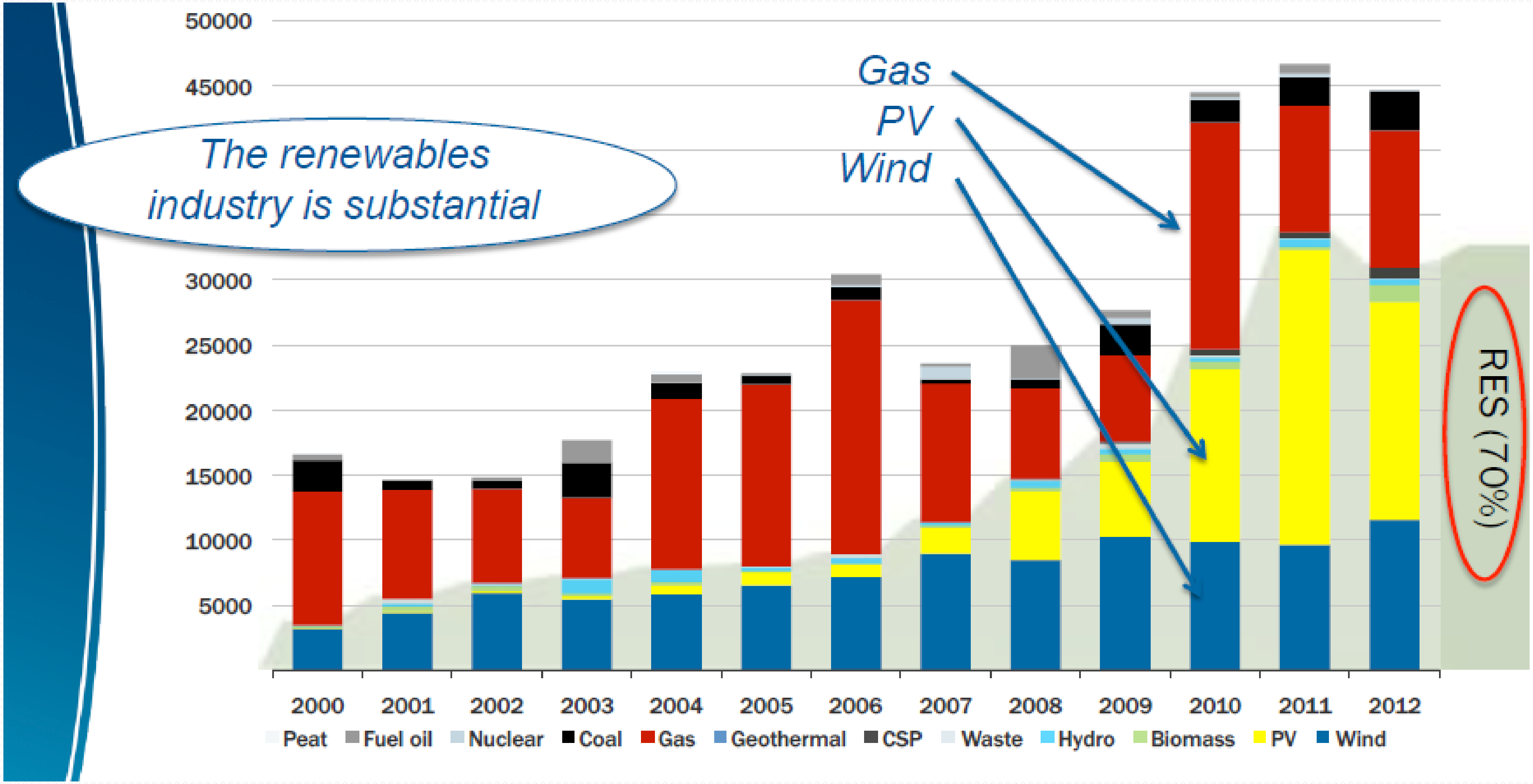
Cost and confidence

- Cost reduction comes through volume
- Volume requires confidence
- Confidence needs consistent policies

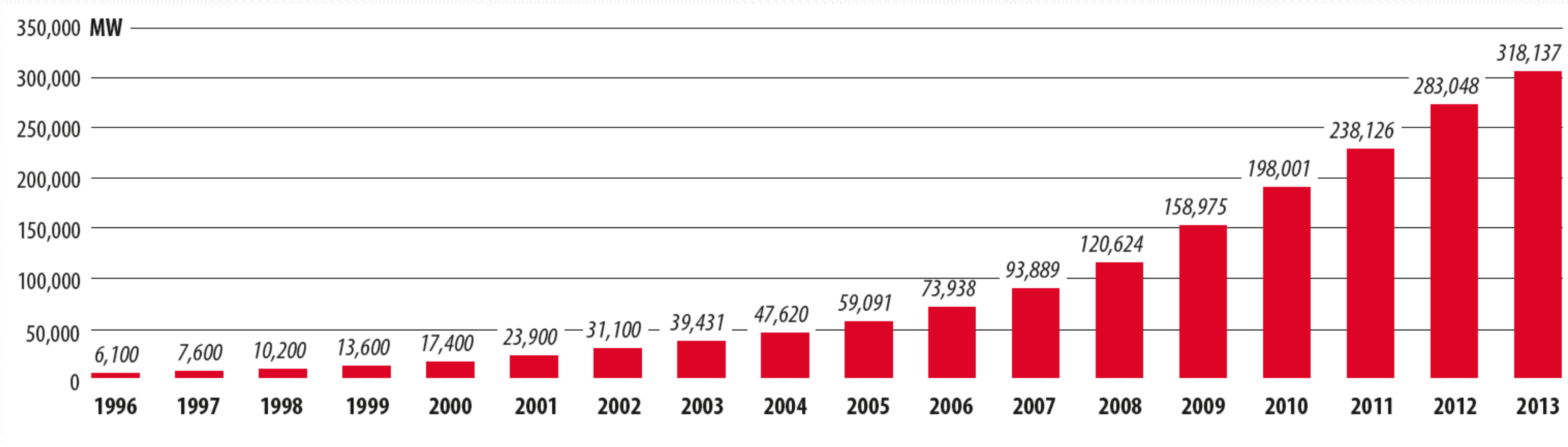
Andrew Garrad DNV GL


Finally some numbers to show significance of wind
as a powerful source today and more so tomorrow

Renewables are significant form of generation in EU

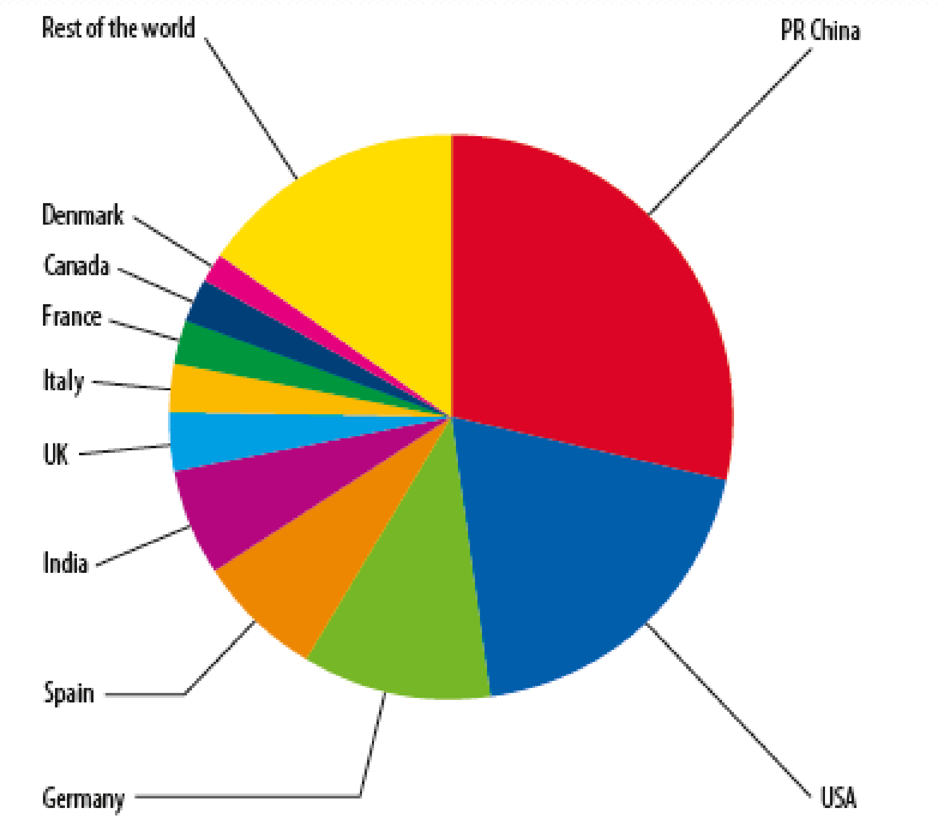


Global installed wind capacity

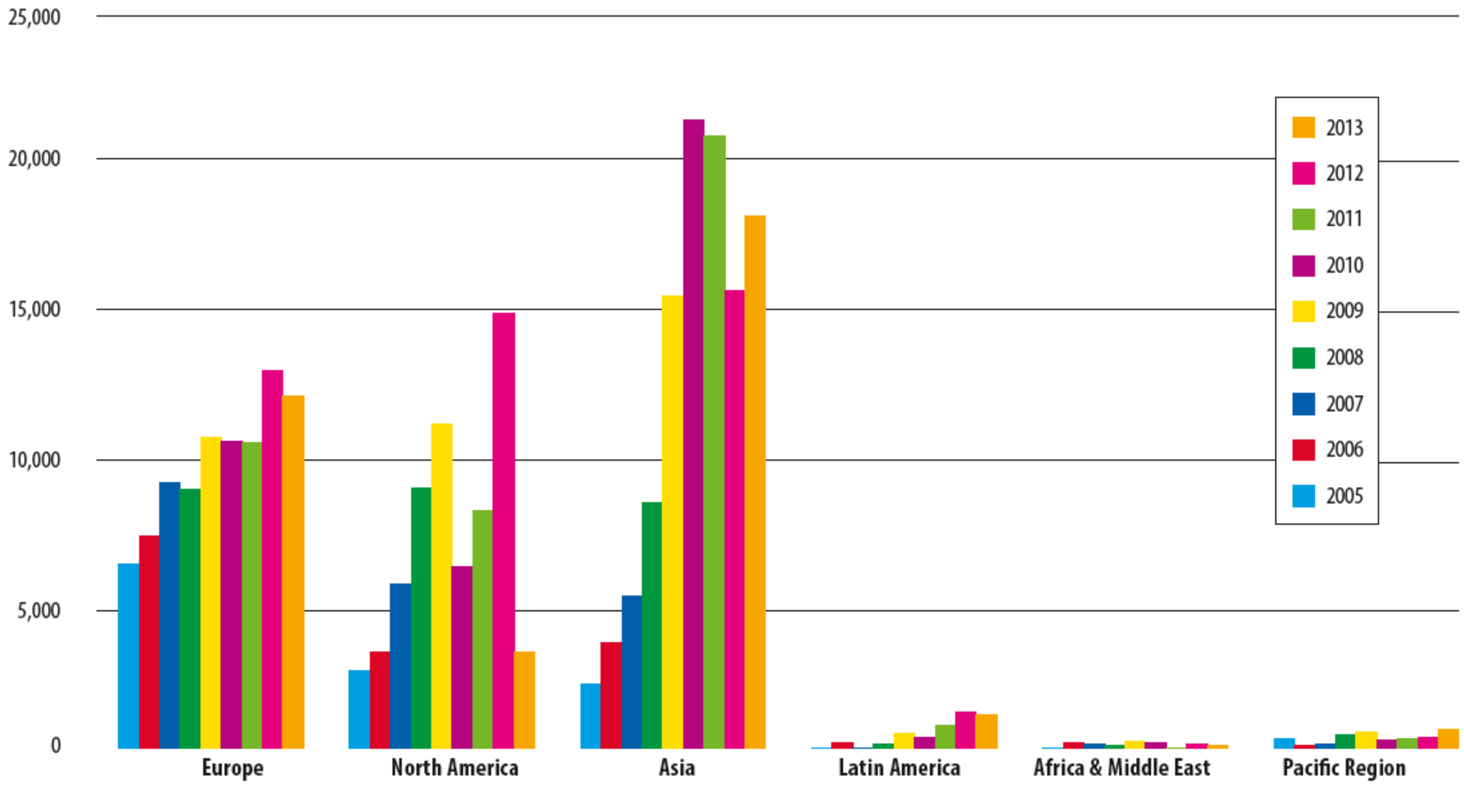


GWEC
GLOBAL WIND ENERGY COUNCIL

Top ten countries 2014: cumulative installed wind power capacity



Annual installed per region



Wrapping up

- Advanced control possibilities enable wind farms to participate as full partner in the mix and get more revenues – both from energy market and Ancillary Services market
- Technology ready onshore – and for bottom mounted offshore. Floating offshore gets fast increasing interest but learning effects on costs did not even start.
- Onshore cost levels (LCOE) comparable to non-renewable generation, cost reduction mainly through volume
- Offshore cost levels (LCOE) trends much more difficult to predict.
- Wind power becomes mainstream generation challenging the future development of the electricity system – for the better because climate friendly.

Thank you for your attention

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