University of Stuttgart
Stuttgart Wind Energy (SWE)
@ Institute of Aircraft Design

How to Improve the Integration of Wind Energy

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The Future of Wind Energy 2nd Edition

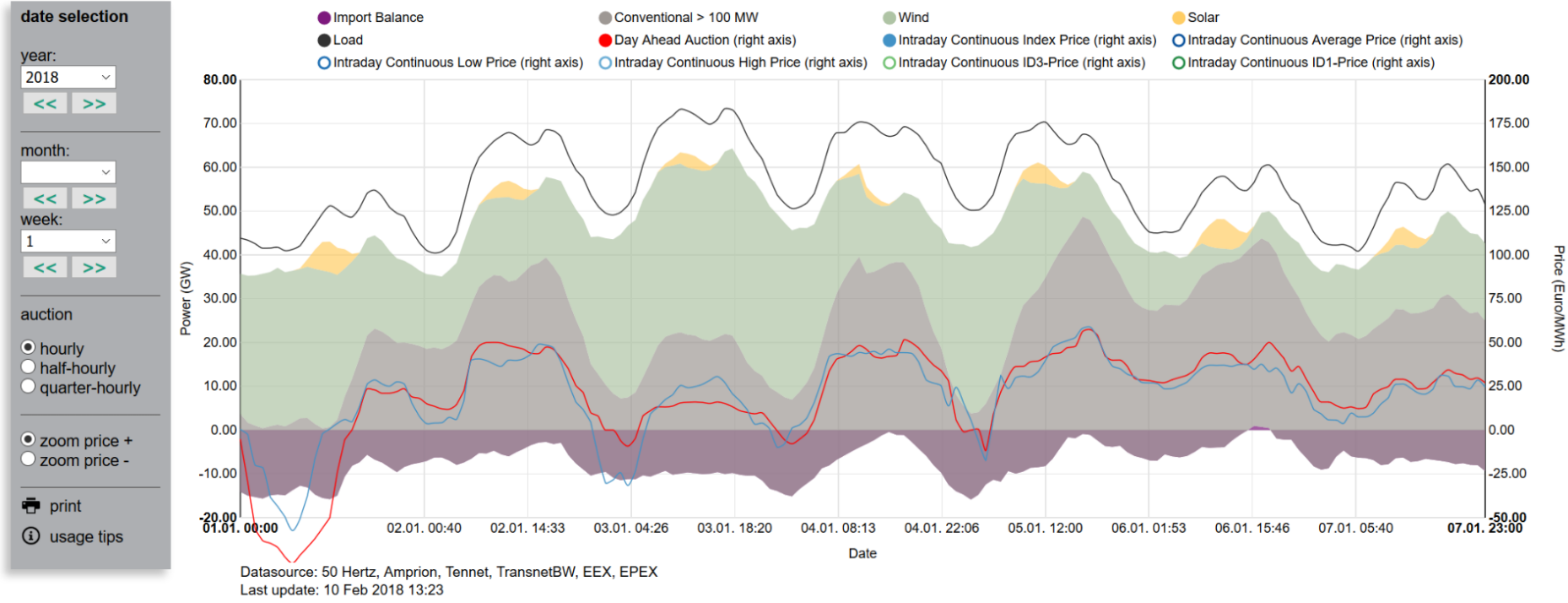
SWE

WindForS
Windenergie
Forschungscluster

Electricity Production and Spot Prices during Week 1 of 2018

Impact of high renewable penetration n the spot prices- negativ electricity price

Electricity production and spot prices in Germany in week 1 2018

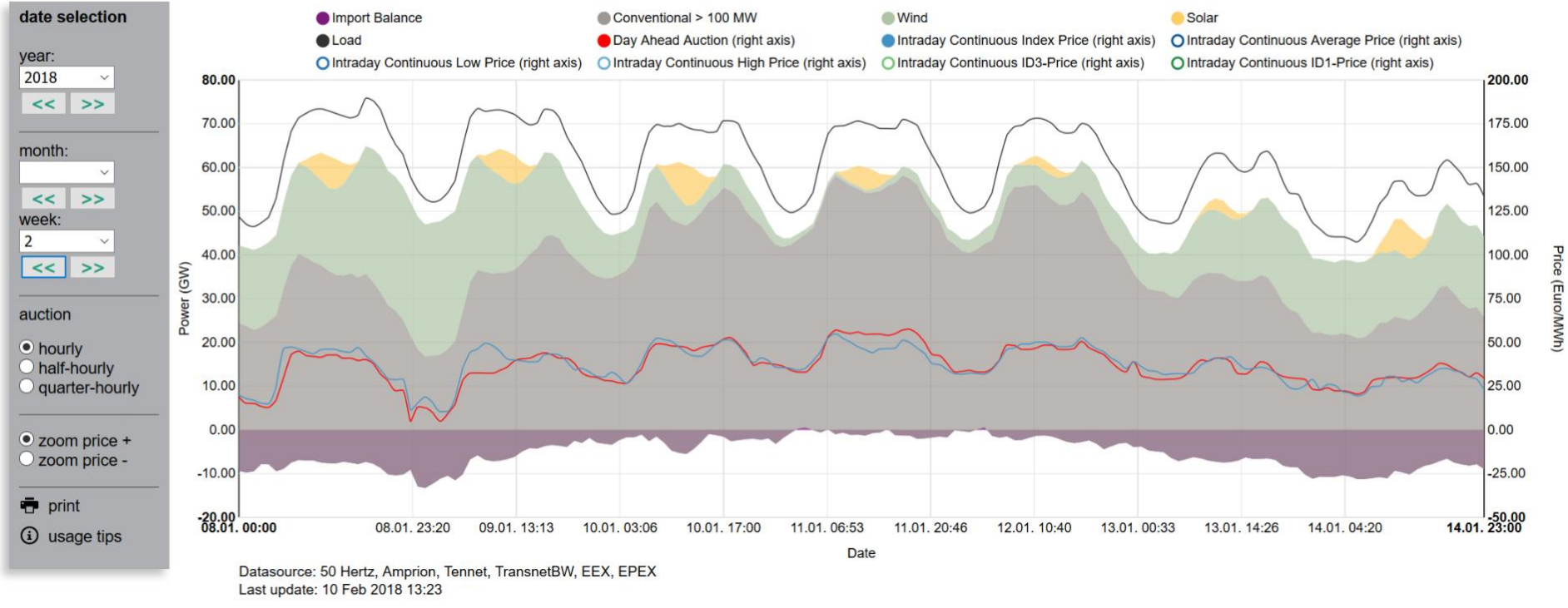


Variability and Cost

Electricity Production and Spot Prices during Week 2 of 2018

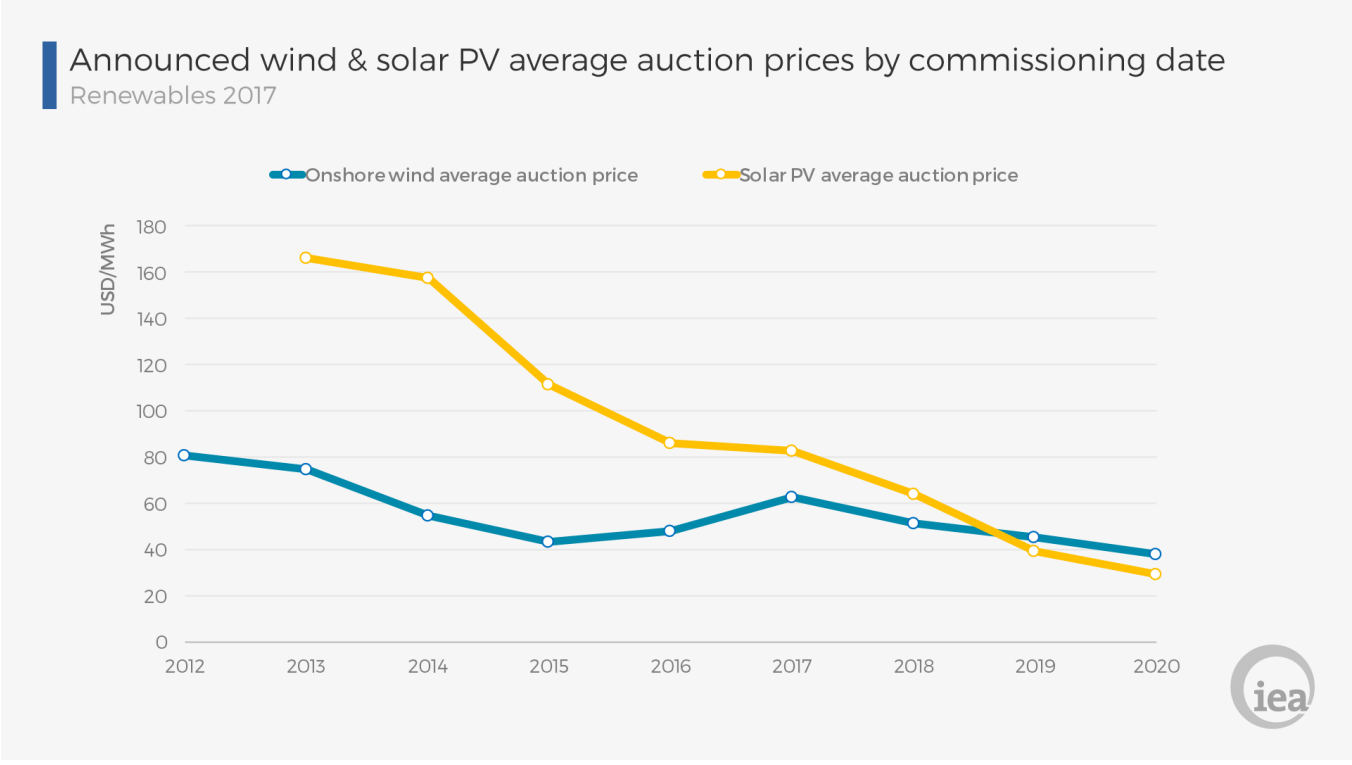
Low contribution of renewable electricity- ramp up of thermal power plants

Electricity production and spot prices in Germany in week 2 2018



Change of System: From Feed-in Tariff to Technology Neutral Auction

Does the change of system lead to an improvement for the integration of solar and wind energy



- In general auction reduces the energy price and increase market efficiency
- Auction prices are not always directly comparable, e.g. length of guaranteed price, grid connection cost , project development costs etc.)
- Long-term effects auction still not clear (zero subsidy bid for offshore wind etc,)

Source: IEA

Redispatch Cost Increases and Grid Expansion Face Opposition

GERMANY

German redispatch costs hit record high

20 June 2018 by Craig Richard

GERMANY: The cost of stabilising the German grid reached a new high of €1.4 billion in 2017 as wind supplied record levels of power, regulator the Bundesnetzagentur (BNA) has announced.

About 10,200GWh of power was curtailed in 2017, the BNA stated (pic credit: Tennet)

This figure is up from €880 million in 2016 and a previous high of €1.1 billion in 2015.

About 10,200GWh was curtailed and approximately 10,238GWh of reserve power was ordered to stabilise the grid, the BNA stated.

Redispatch costs increased in 2017 as Europe experienced a continent-wide cold spell in the first quarter of the year placing a strain on the German grid.

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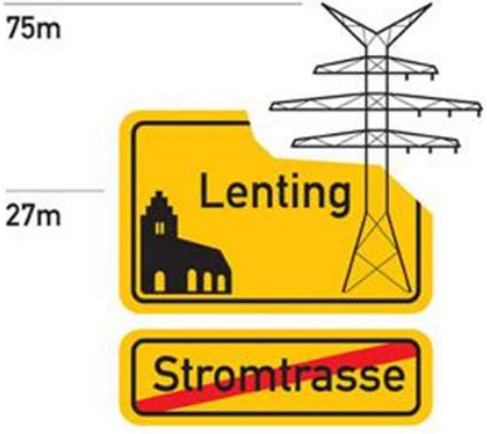
Anglo-Saxon remains found on Rampion cable route

'New opportunities' from renewables for National Grid

Vattenfall commissions co-located 22MW battery

Ørsted developing its

Source: Windpower Monthly, Bürgerinitiative GS



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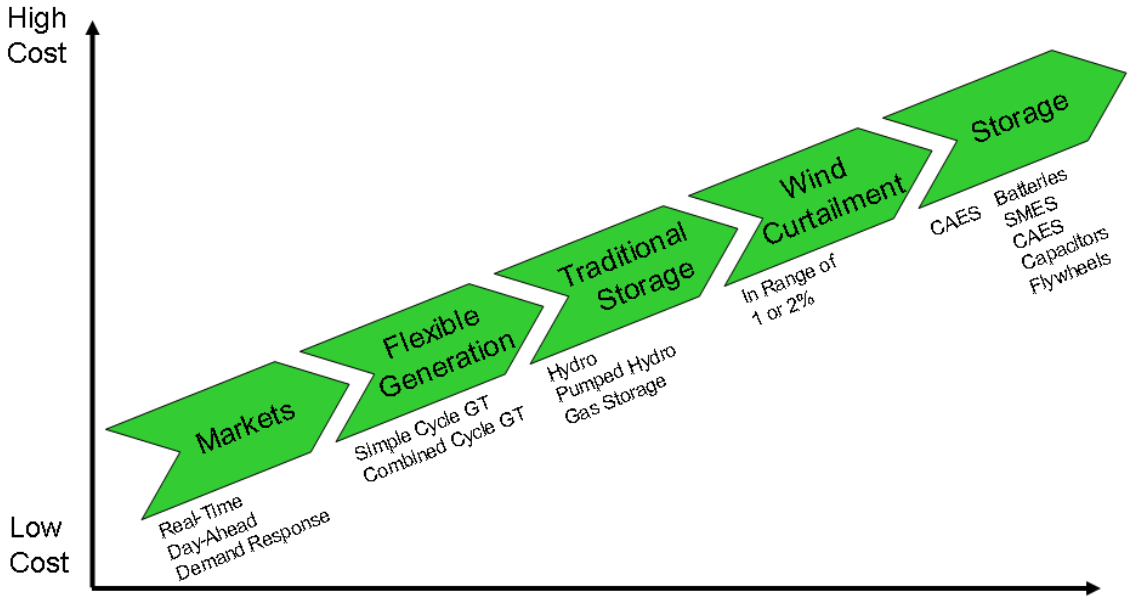
There are Many Ways to Improve the Integration of Wind Energy that cover in a single presentation

- There is no single recipe to integrate the renewable energy. It depends on the characteristic of the power system and local renewable energy resources
- Sector coupling becomes more important as the electrification moves forward in the mobility sector but also in the heating and cooling sectors.
- It is unclear whether electricity can directly replace the fuel as in electrical vehicles or alternative fuels need to be generated through Power to X, e.g. power to liquid as replacement for jet fuels
- Decentralized energy system could be a better solution for developing countries without an adequate grid infrastructure
- Energy efficiency and demand response will be much more cost efficient than storage
- Market design plays an important role in providing incentives for the development of technological solutions to address the integration and balancing issues
- Integration is not just about technical integration but also social integration through acceptance

To Store or not to Store (The approximate order of the integration costs)

Storage will be the last resort for the grid operator

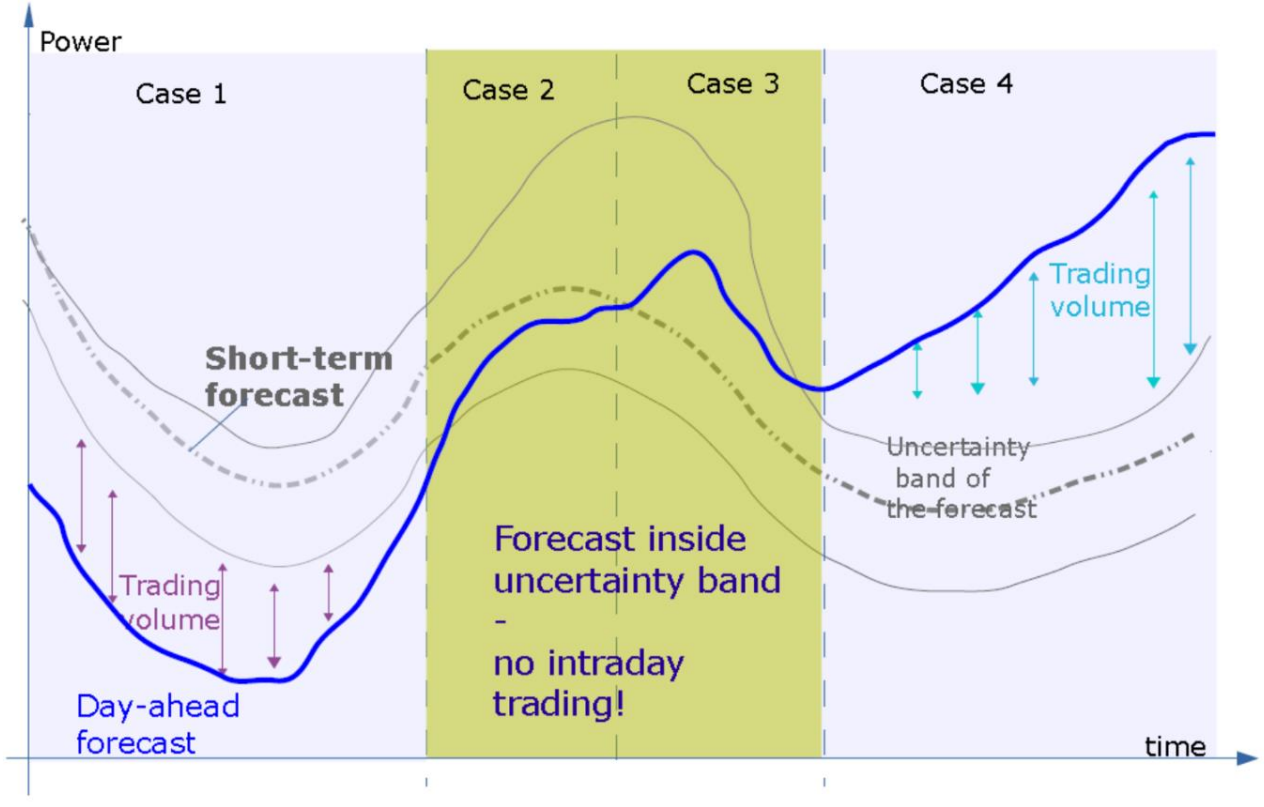


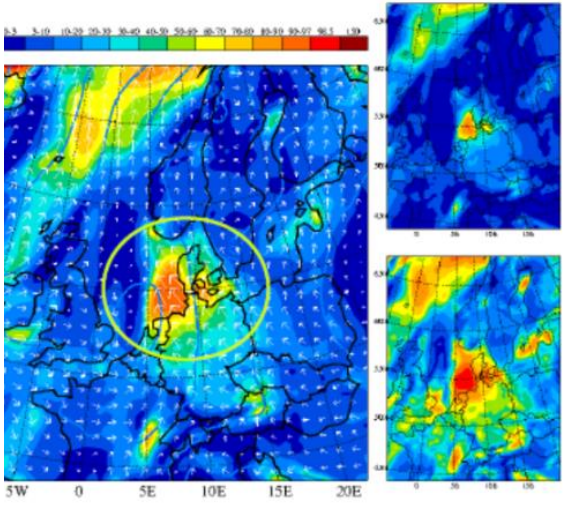
- The need for storage will be further reduced by improved energy forecasting of wind energy (as well as PV)
- The coupling with e-mobility will strongly favor the development of batteries as the preferred solution for short-term storage.
- Hydrogen is in the long run, a possible solution for the energy and mobility sectors

Source: UWIG

Forecast as Tool to Reduce Imbalance and Waste in The Power System

- Use of probabilisitic forecasting to increase to increase intra-day trading can reduce the peak reserve, reduce the volatility of balancing cost and increase volume in the market





Short-term Forecasting to Reduce Spinning Reserve

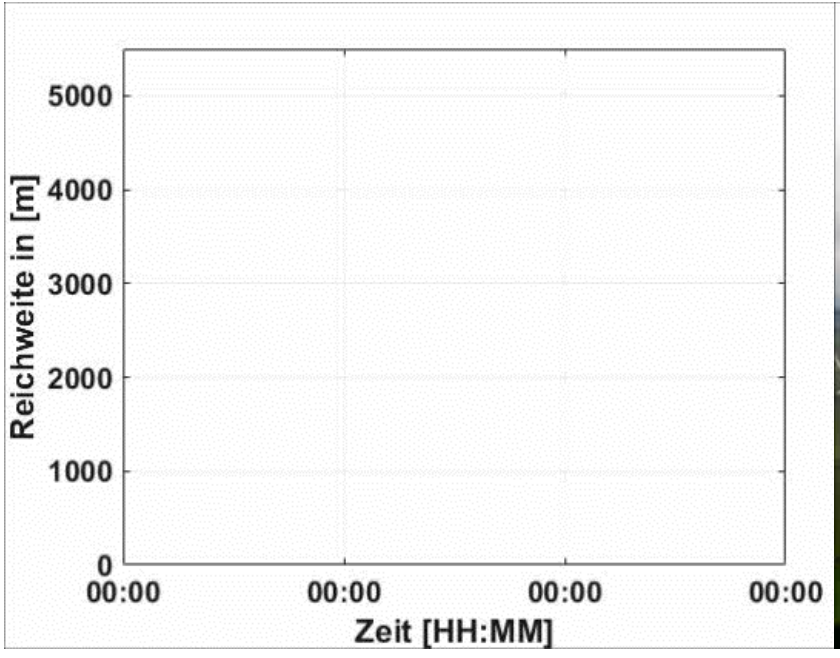
Lidar Based Short-term Forecasting - Stream Line XR

Lidar

- Maximum range: 10 km
- Pulse length: 410ns
- Measurement volume: ~80m
- Number of range gates: 167
- Trajectories: staring, DBS, VAD, RHI, custom (also depending on wind direction)

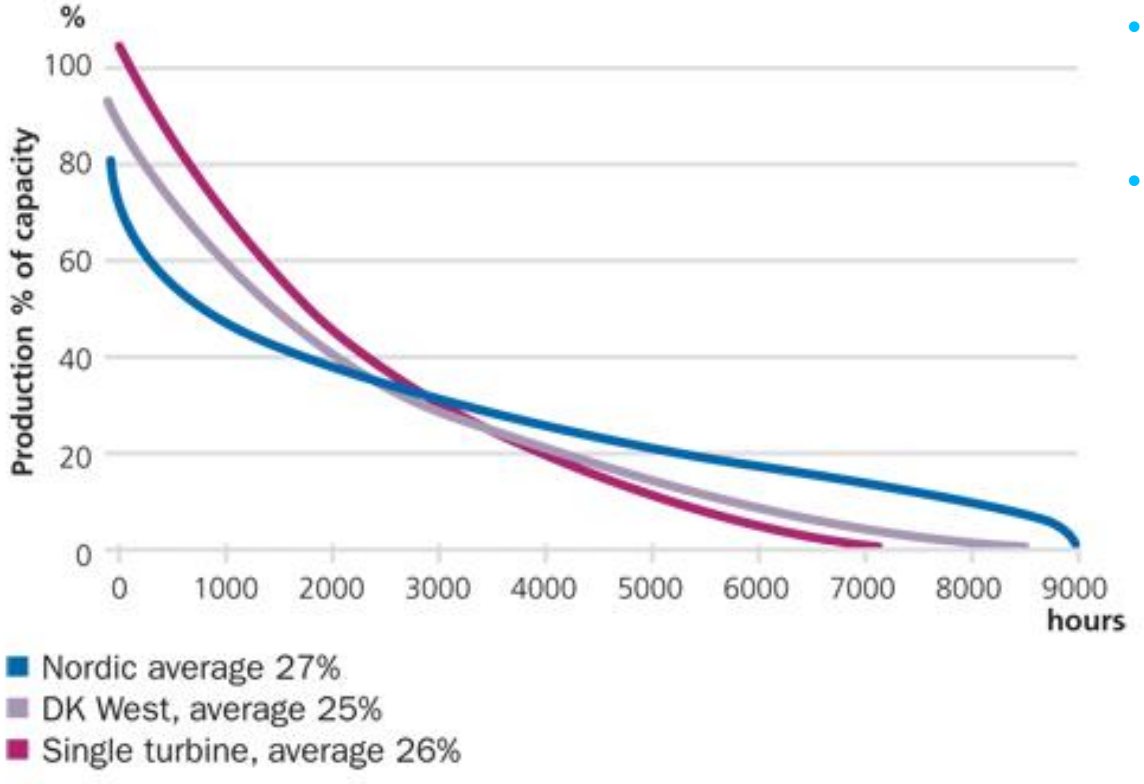
Influence of Environmental Conditions

Atmospheric humidity on the range of measurement



Power Duration Curve

The effect of geographical spreading and capacity factor

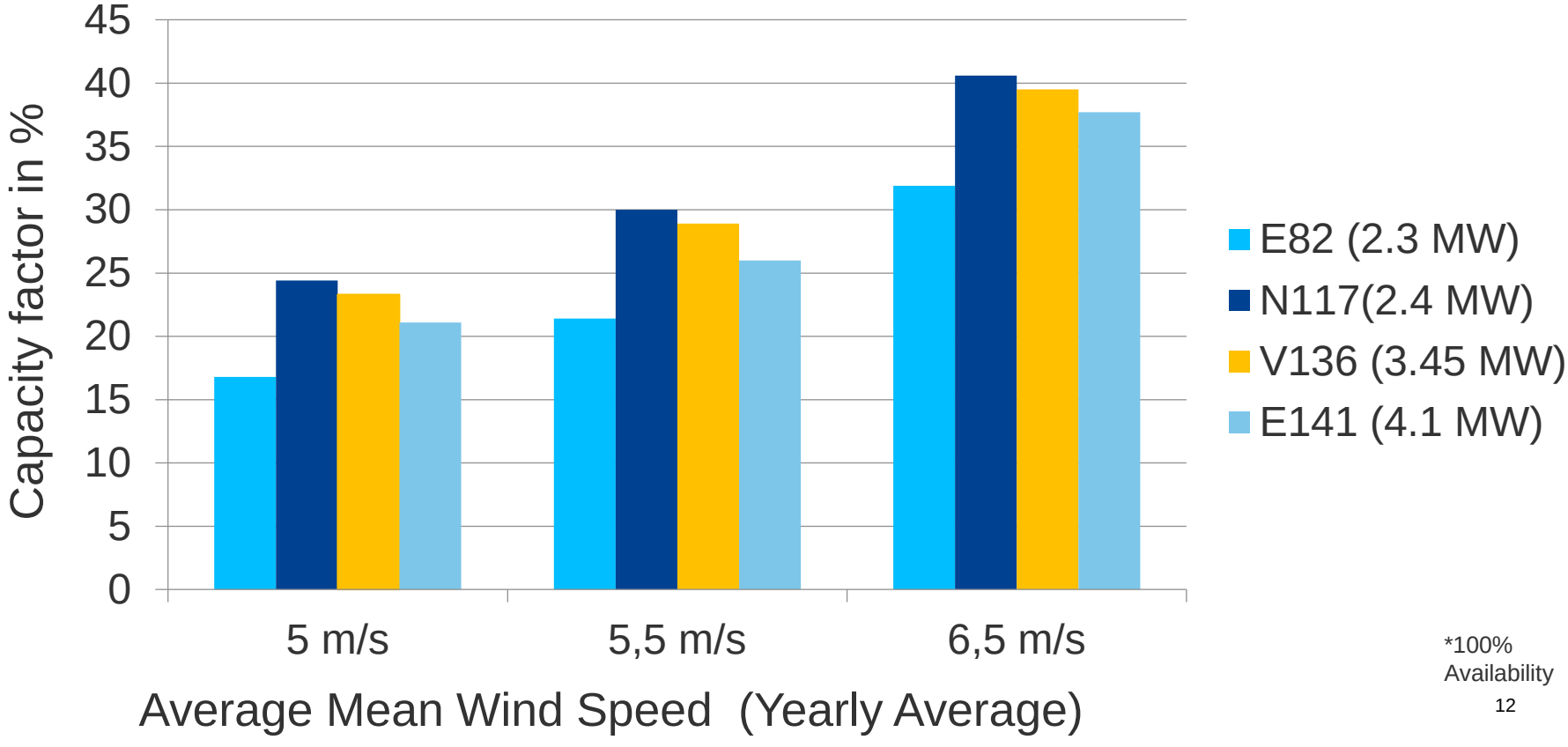


- Geographical spreading will make the power duration curve flatter
- Higher capacity factor will make the power duration curve flatter, meaning more constant production of electricity

Source: EWEA

Capacity Factors with the New Generation of Wind Turbine

Capacity factors (in Percent)* for Different Onshore Wind Turbines



*100% Availability

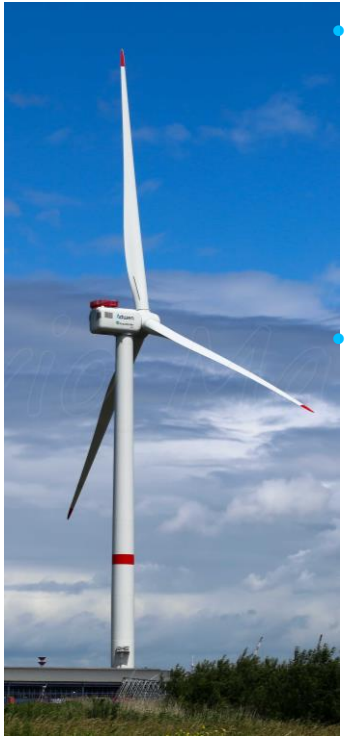
Taller Tower mean Higher Capacity Factor

-There are many concepts for large hub height towers
-Concrete versus steel or hybrid
-Segmented steel tower (LDST), lattice tower, steel shale (BSS), Hexacrete tower
-Hub height up to 180 meters
-Challenges transportation, logistics and manufacturing

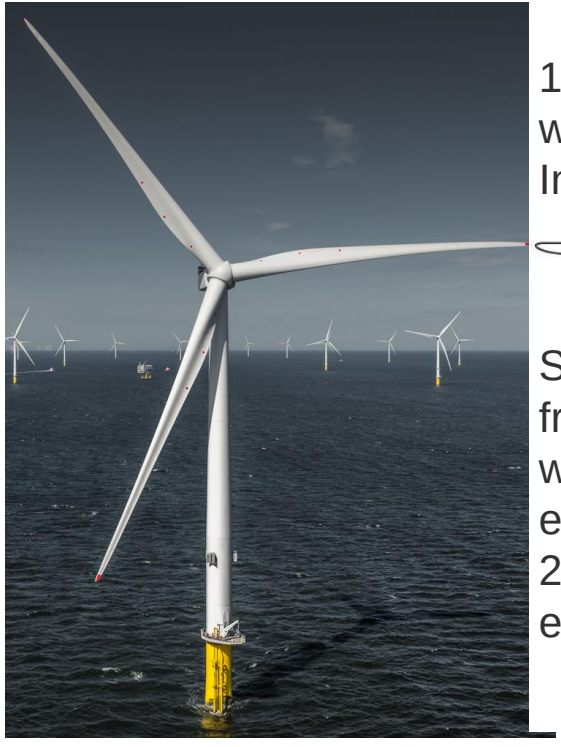
Quelle: GE, Siemens AG

Going Offshore (high capacity factor)

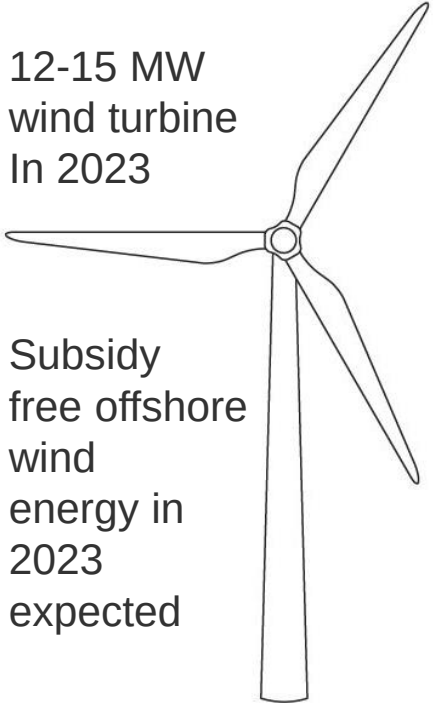
The largest and the most powerful wind turbines with more constant wind resources



- World largest wind turbine with 180 meter rotor diameter 8 MW rated power produced by Adwen (Siemens-Gamesa)
- World most powerful wind turbine with 164 meter rotor diameter, 9.5 MW rated power produced by MHI Vestas



12-15 MW wind turbine In 2023



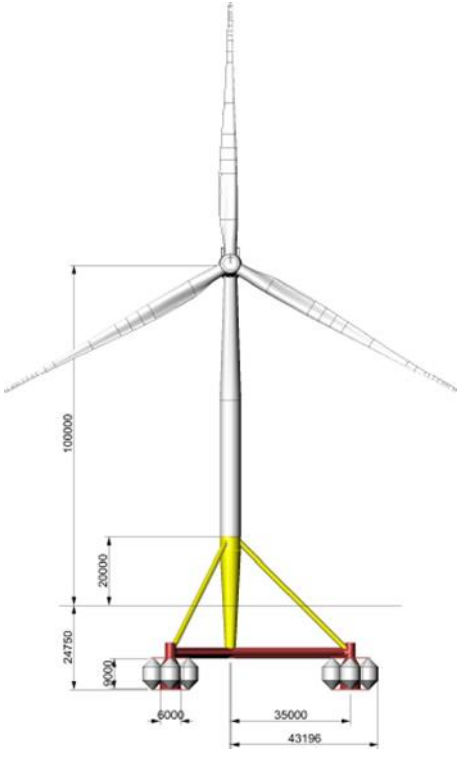
Subsidy free offshore wind energy in 2023 expected

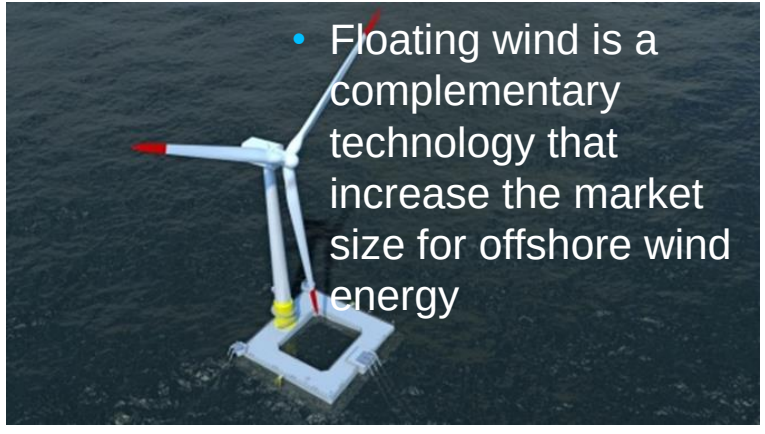
Source: Matysik, MHI Vestas

Floating Wind Energy – Even Higher Capacity Factor?

Closer to the centers of energy consumption – lower transmission costs

Research->Demonstrate->Learn to reduce cost->Research->Demonstrate, Small Wind Farm->Learn to reduce cost->Research->Larger Wind Farm ->Learn to Reduce More Cost





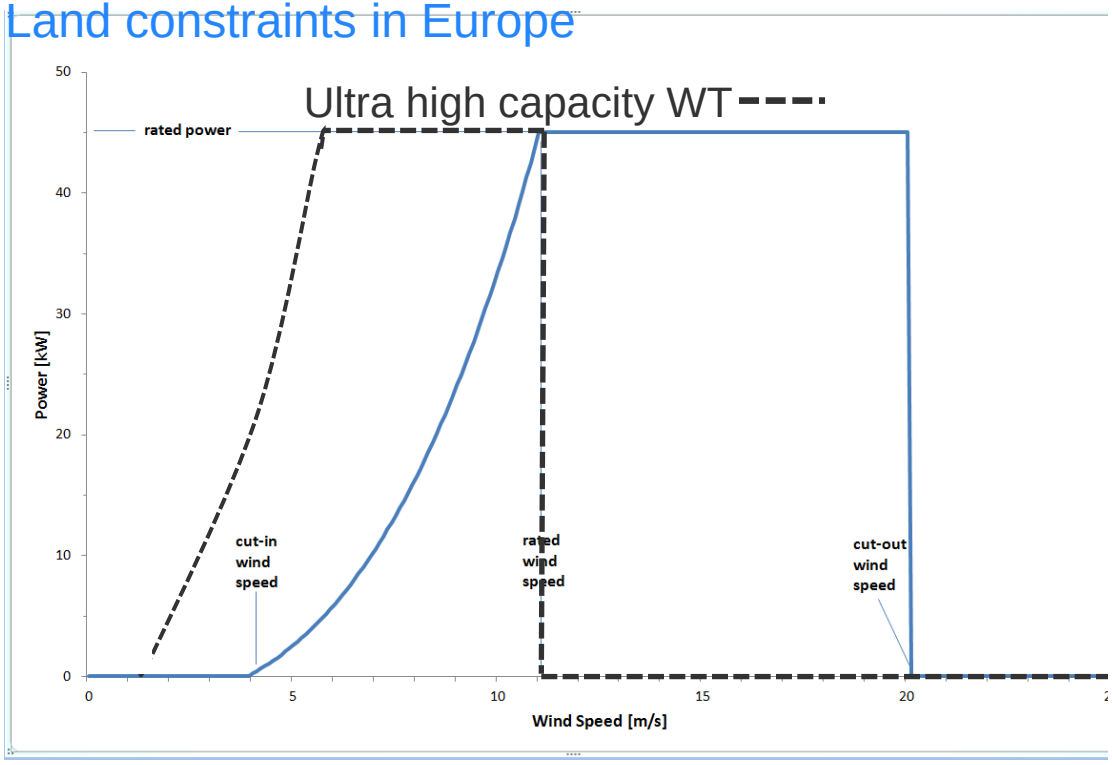
Source: Henrik Stiesdal, Gicon, Statoil, Principle Power, Ideol

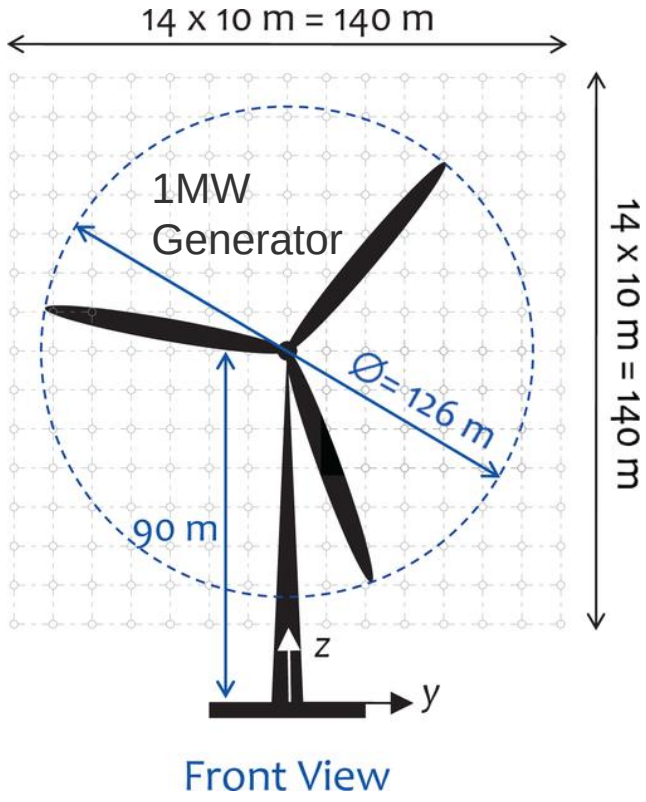
Ultra High Capacity Wind Turbine

The value wind energy is higher at low supply time, that is at low wind speed

Required new turbine design philosophy and market incentives

Land constraints in Europe

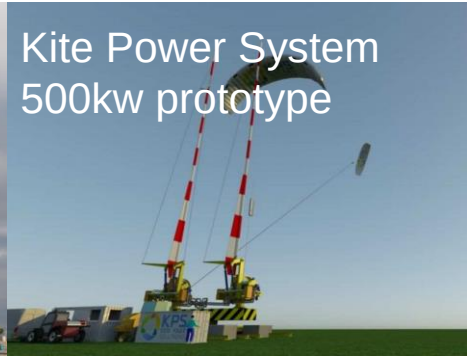


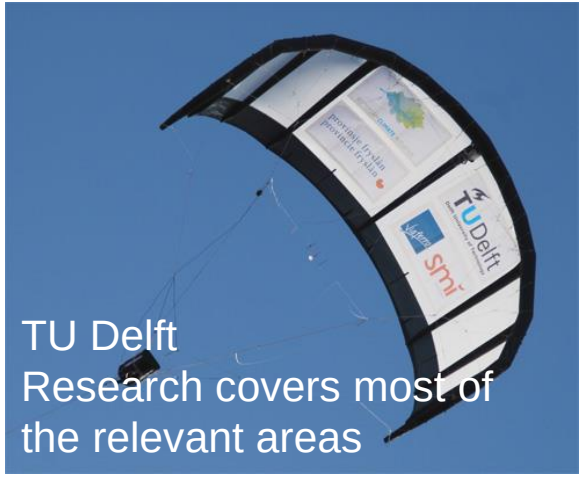


Can this be the future of wind energy? High Capacity Factor

Ampyx Power 250kw prototype


Google X 600kw prototype


Kite Power System 500kw prototype



TU Delft
Research covers most of the relevant areas

ERC HIGHWIND

System and Control

KU LEUVEN


Freiburg University
Control and Optimization

Source: Ampyx Power, Google X, KPS, TU Delft, KU Leuven, Universität Freibug

Load Management Using Advance Sensors

- Intelligent load management system enables trading between loads and power

scanning lidar on the CART2

Windcube V1

mirror with 2 DOF

CART2
D=42 m
P=600 kW

commercial lidar on the CART3

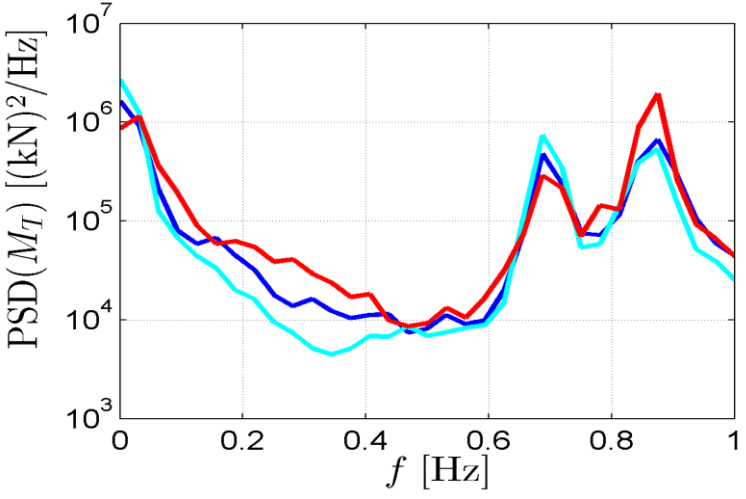
met mast

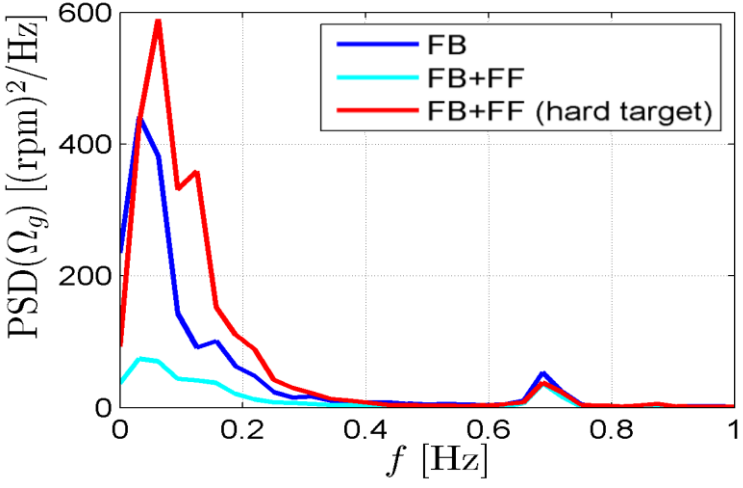
control engineers

National Wind Technology Center
Boulder, Colorado, USA
from March to August 2012

Lidar Assisted Collective Pitch Control
First Field Testing Results – CART2 Feedforward

data divided in blocks of 32 s





- similar wind distribution
- reduction in standard deviation of the generator speed of 30% at low frequencies
- but increase of 30% before solving the hard target problem
- similar behavior for the tower base bending moment and other loads

Increase Power Production – Increase Capacity Factor through Wind Farm Control

Focus shifts from wind turbine to wind farm control, increase power output (active wake control), optimize power output and life time

Increase power output at partial load range.

Load increase due to yaw misalignment

Partial wake situations can be more damaging

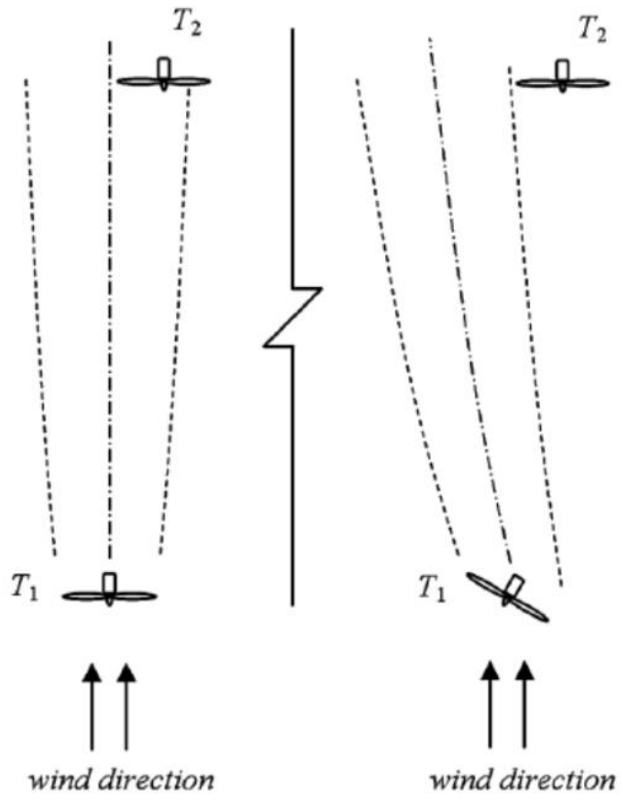
Wake control depends on the atmospheric conditions

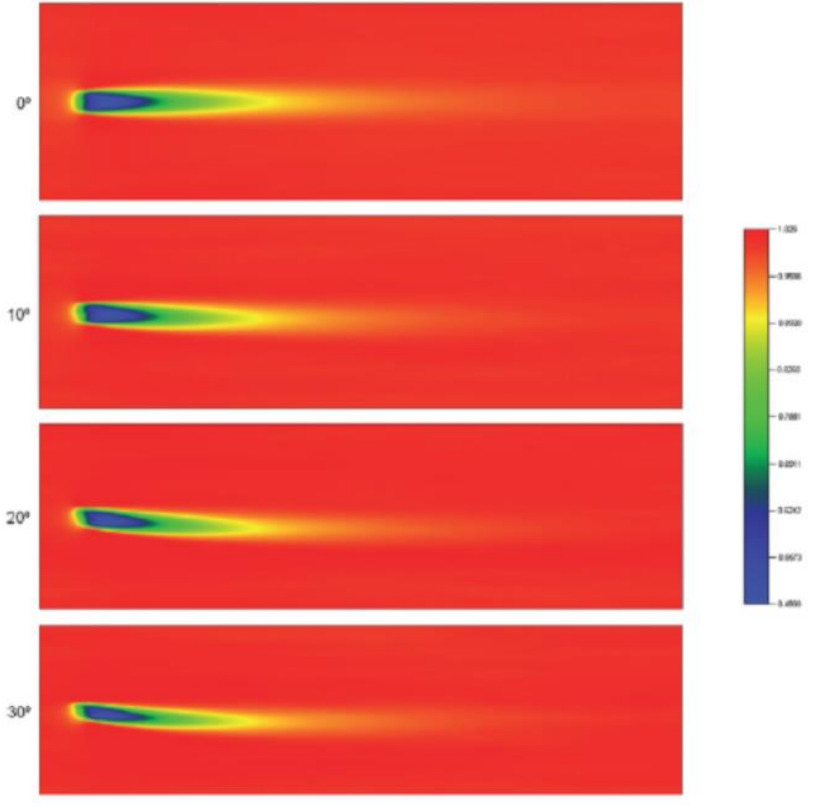
Source: Dong Energy

Wind Farm Control : Wake developments in different atmospheric conditions

Source: Dong Energy

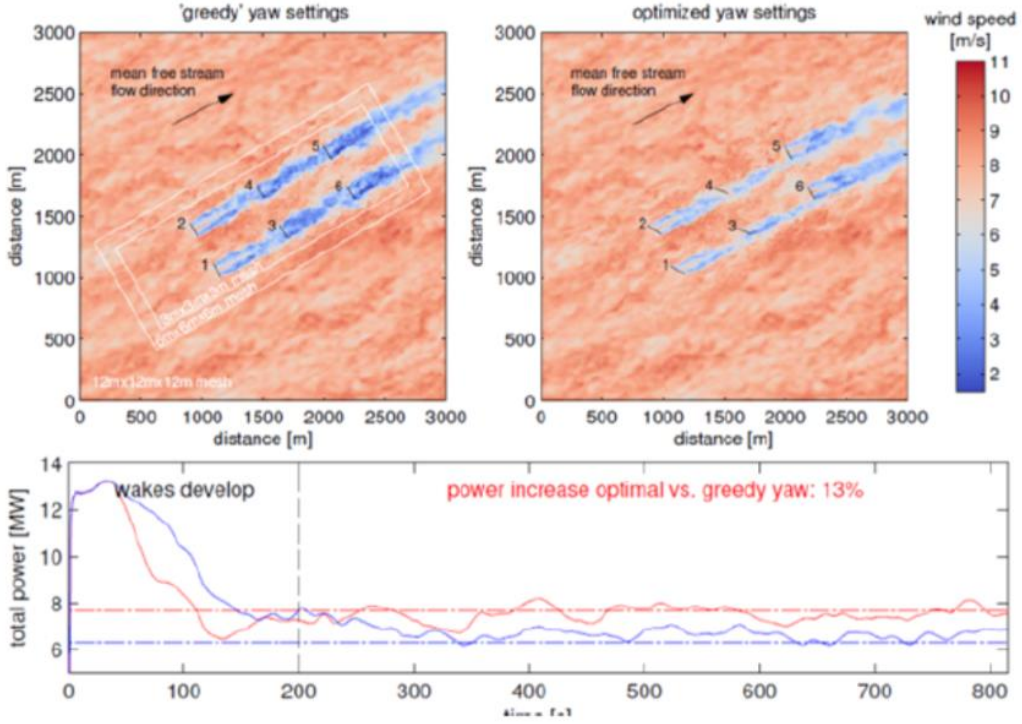
Optimization-based wind farm control - wake steering





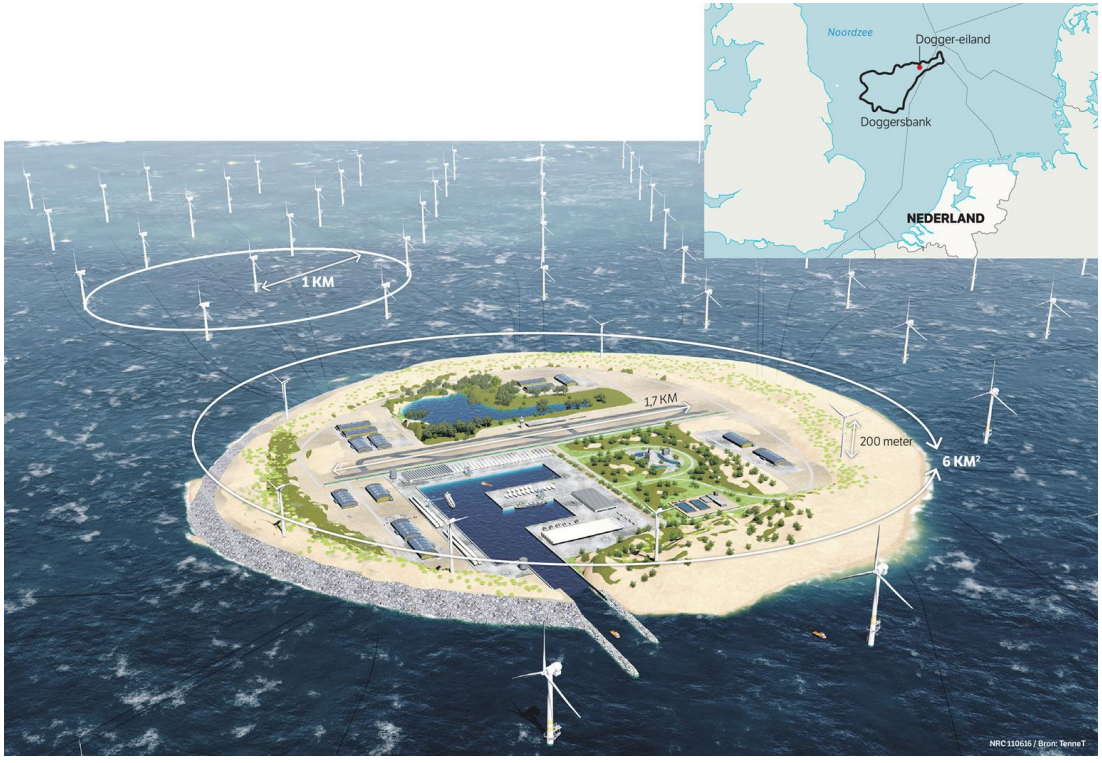
Á. Jiménez, A. Crespo, and E. Migoya (2010). "Application of a LES technique to characterize the wake deflection of a wind turbine in yaw". In: *Wind Energy*

Optimization-based wind farm control - wake steering



P. M. O. Gebraad et al. (2014). "Wind plant power optimization through yaw control using a parametric model for wake effects - a CFD simulation study". In: *Wind Energy*

Large Offshore Wind Farm Cluster



A joint permanent basis for builders of wind farms and infrastructure

Joint storage of components (e.g. turbines, rotor blades, pylons, HV equipment)

Strong reduction in transport costs: landing strip for airplanes and permanent residency opportunities for staff

Joint maintenance facilities

Joint port facilities

Capacity for connecting 30 GW of offshore Wind farms

DC Interconnection for the electricity markets in 6 countries

Source: Tennet

Development of Wind Energy with Pump Storage

- 4x3.4 MW wind turbine
- 16 MW hydro turbine

- 70 MWh storage capacity
- 175 meter hub height

Source: Naturstromspeicher

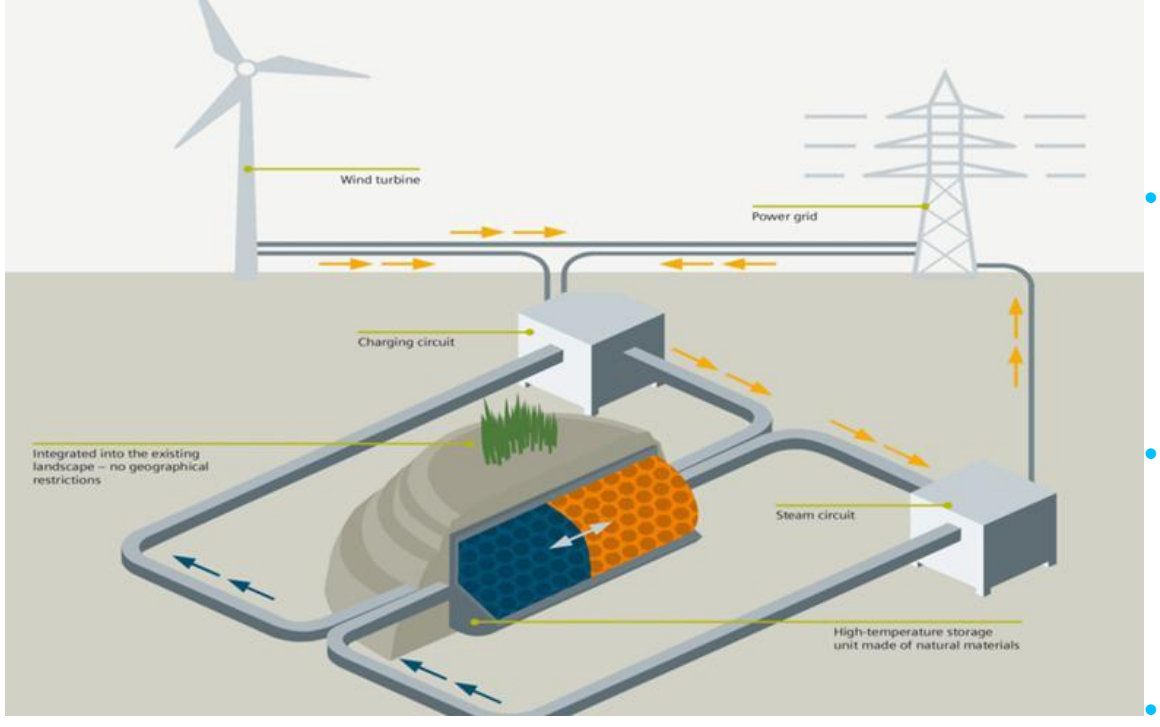
Development of Wind Energy with Storage

The most obvious option- Battery, mainly Lithium based. Redox Flow Prototypes

- Wind turbine with PV and storage for island grid (with diesel generator as backup)
- Wind turbine with batteries for grid support (frequency control)

Source: SiemensGamesa, Acciona

Development of Wind Energy with Thermal Storage



- a fan uses an electrically-heated air flow to heat the stone up to 600 degrees
- During discharge the rock will heat the air and transfer the heat to a steam boiler to run a steam turbine
- Prototype with 36 MWh of storage (2000 cubic meters of rocks) connected to a steam turbine of 1.5 MW
- Efficiency of 25% expected for the prototype. 50% is expected for the commercial product.

Source: Siemens

Where the wind energy is going in order to improve integration

Here my personal opinion

- In term of LCOE wind energy is already already competitive in some part of the world without subsidies. The cost reduction for onshore wind turbines will be slower than for offshore/floating because it is becoming a more mature technology.
- Wind turbine/wind farm operation needs to become more intelligent to adapt to the demand and market signals, actively managing the loads and power using for example wake steering, remote sensing, or machine learning
- Forecasting techniques need to be further improved, the uncertainty need to be reduced. At the same time the energy market need to provide incentive to use the forecasting techniques to reduce integration costs.
- For Europe and other countries with high population density, one should not underestimate the acceptance issue for wind energy. The noise issue and the change in the landscape will always be a topic for the inhabitants around the wind park as the turbine becomes bigger. People want to be in control of the changes. Acceptance oriented turbine design?

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Thank you!

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