Wind Onshore cost development

Philip Vogel; RWE Innogy GmbH

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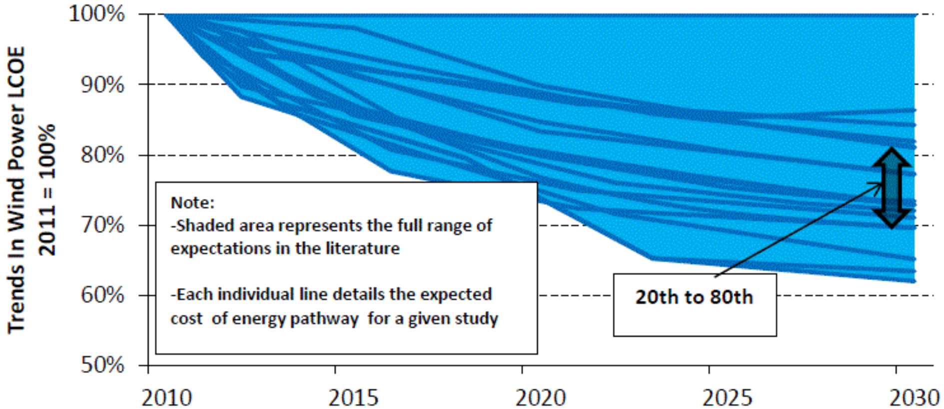
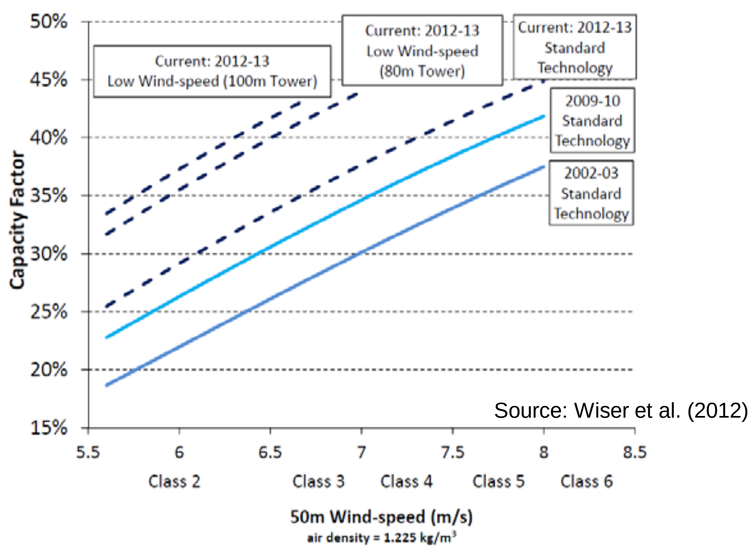
Expected LCOE developments of wind onshore



Source: IEA The past and future cost of wind (2012)



Source: Wiser et al. (2012)

> IEA Meta-study (based on 18 separate studies) foresees significant reduction of Wind Onshore LCOE in the longer run (15-40% until 2030) from 2011 level

> Potentials in cost reduction occur from

- Economies of scale in manufacturing from standardisation and automatisation
- Optimisation of turbine designs and control
- Application of light weighted materials (e.g. carbon fibre)
- Cost reduction due to increased competition in turbine and O&M markets
- Improved power electronics and conversion

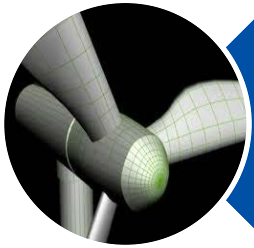
→ Relative reduction of Capex* and o&m-cost, increased reliability and load factors

→ Absolute level of LCOE depends also on average wind speed.

* Certain turbines itself will become cheaper; but in terms of LCOE it might be necessary to increase Capex in wind projects

Europe onshore wind turbine pricing

Prices continue to vary significantly within the same year by vendor, market, and turbine. This is because turbine prices are usually contingent on several factors:



Turbine model is a key determinant

Two megawatt and larger machines as well as new roll-outs and turbines designed for lower-wind-speed sites and higher towers command higher prices. With European orders, it remains common for turbine prices to vary by machine size, illustrating **a nonlinear price premium for higher-output machines**.

Country variations are key to supply agreements

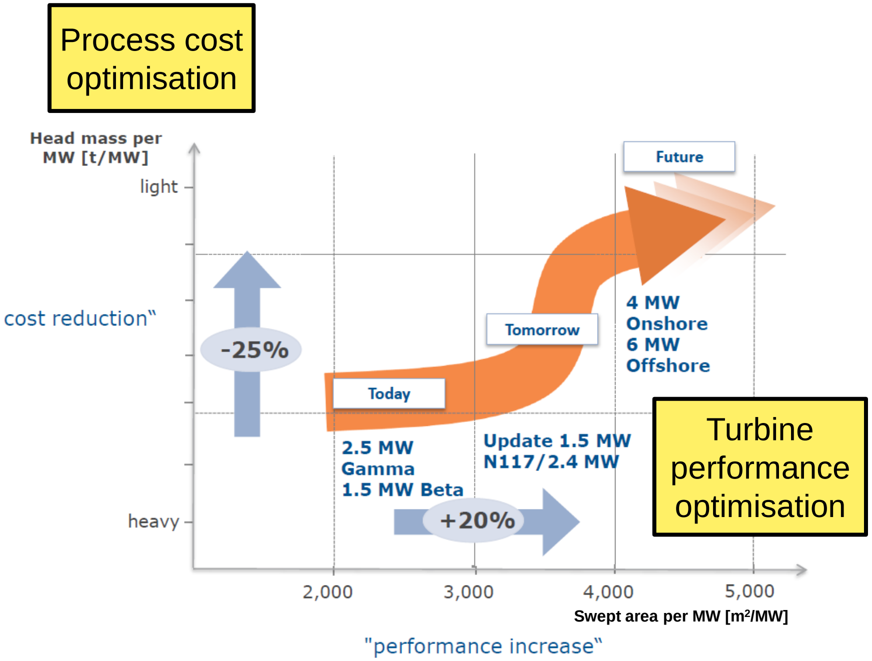
In supplying over 25 countries, all with varying market environments, turbine prices offered by turbine manufacturers vary significantly in Europe. Key levers for this **variation include revenue levels, technology delivered, level of competition and transportation costs.**

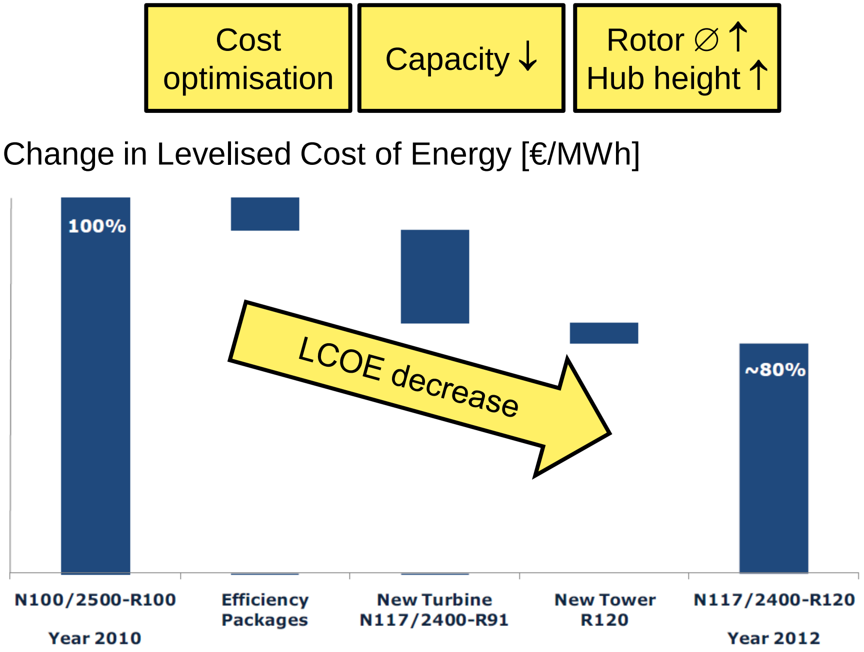
Limited demand results in pressure on prices

With 18 turbine manufacturers delivering to Europe, all of which have production capacity in the region (except Hyundai), lower and more concentrated demand has resulted in vendors reducing prices to capture orders and increase utilization rates of production facilities to avoid or delay downsizing.

Source: IHS cera –Global wind supply chain strategies 2012.

Technology suppliers aim at performance increase plus cost reduction

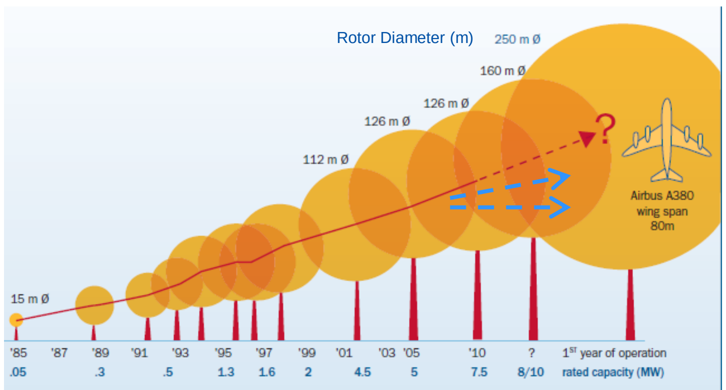


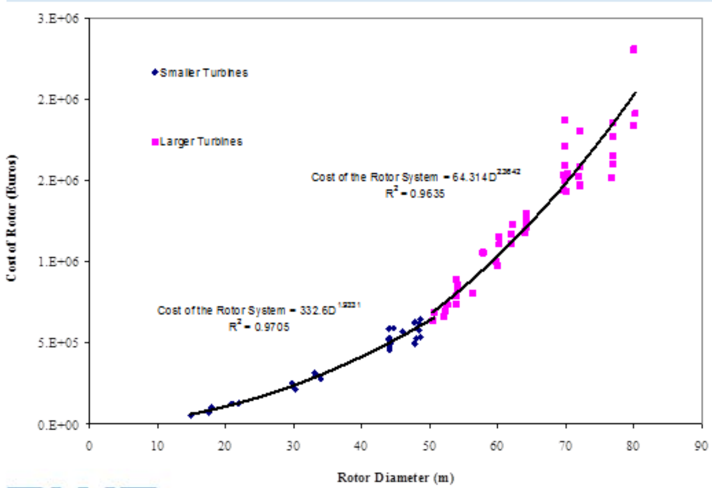


Source: Nordex capital market day presentation 2011

Increasing rotor diameter and hub heights lowers wind generation cost

$$E = 0,5 * \left({}^{D}/_{2}\right)^{2} * \pi * \rho * v^{3} * c_{p}$$





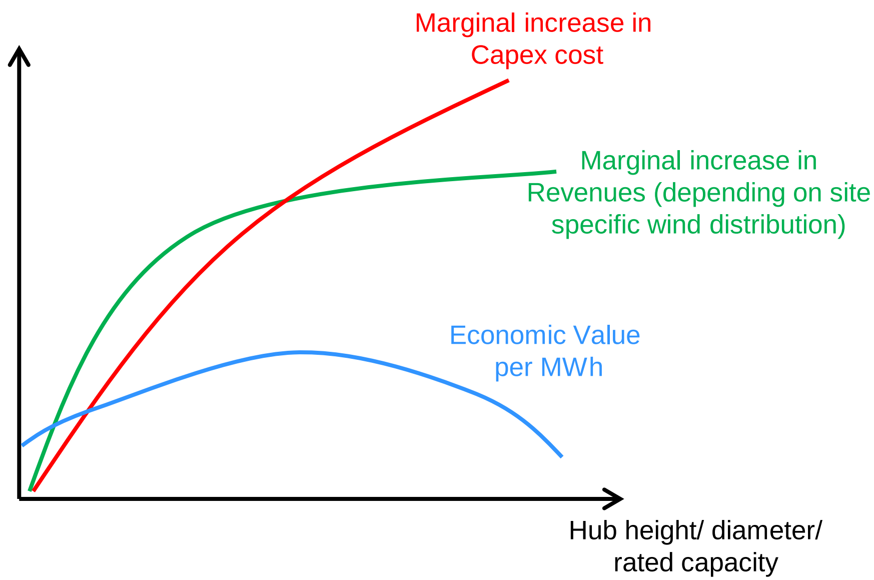
- Captured Energy (E) of the turbine is increasing with the rotor diameter (D) exponentially and with the hub height due to increased average wind speed
- However, also costs of the rotor and turbine are exponentially increased from increased diameter size and hub height (see graph below; source: Narasimalu/Funk)
- Generally diameters/hub heights have increased significantly in recent years, hence revenue increase seems to be higher than cost increase
- Furthermore, suppliers offer wider range of turbines with different combinations of rated capacity/ hub height and rotor diameter, which gives more flexibility in lowering LCOE of generation and optimisation of sites

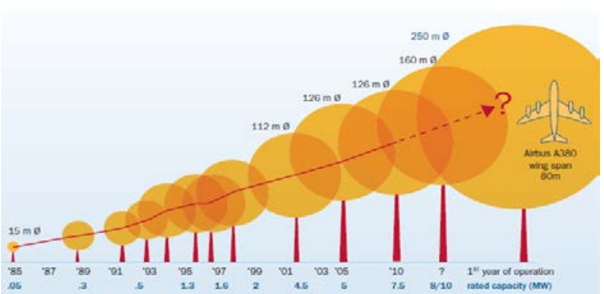
E *= Captured Energy* ***v*** *=velocity of wind*

D *= rotor diameter* ***cp*** *= efficiency of turbine (as function of* ***v****)*

Π *= pi* ***ρ*** *= air density*

Optimal siting – Optimizing Capex cost vs. revenues by technology selection





> Generally it is tried to optimize the ratio between capex cost and discounted revenues

> Optimal turbine for a site is given where marginal increase of capex equals marginal increase of revenues

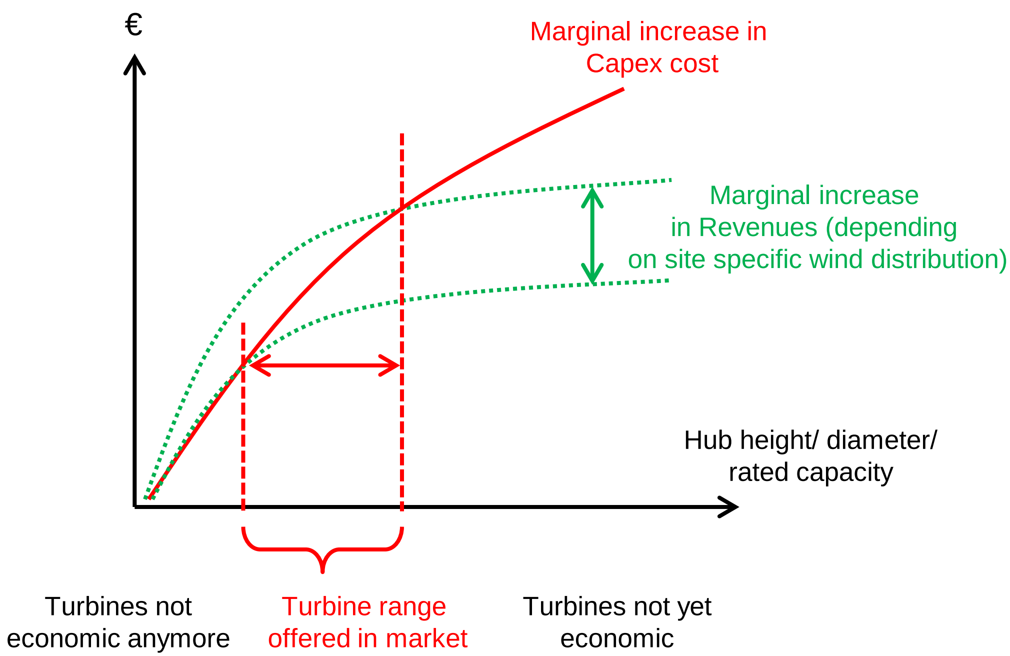
> This maximizes economic value per MWh or LCOE for a certain site

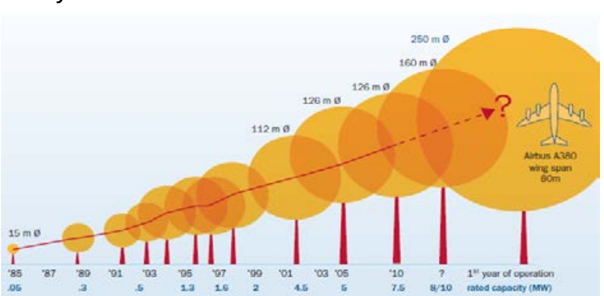
> Taking different local characteristics into account different turbines are selected for different wind sites

> Major issues are:

- Wind speed average and distribution
- Maximum load on turbine
- Subsidy scheme for revenues
- Regulation, e.g. constraints on hub heights, noise emission (see next slide)

Differences in wind sites lead to a range of turbines offered to the market





- > Different turbines are optimal for different sites. This explains wide range of turbines offered to the market and used by Operators
- > Very large turbines are too expensive and capex cost out-level increase in revenues (so far). Hence, they are often not used (yet)
- > Very small turbines are not state of the art and there exist functioning alternatives with better revenue/ capex ratio
- > However, in older wind farms older technologies are often still in place – often with higher fixed subsidies, which explain continuation of operation

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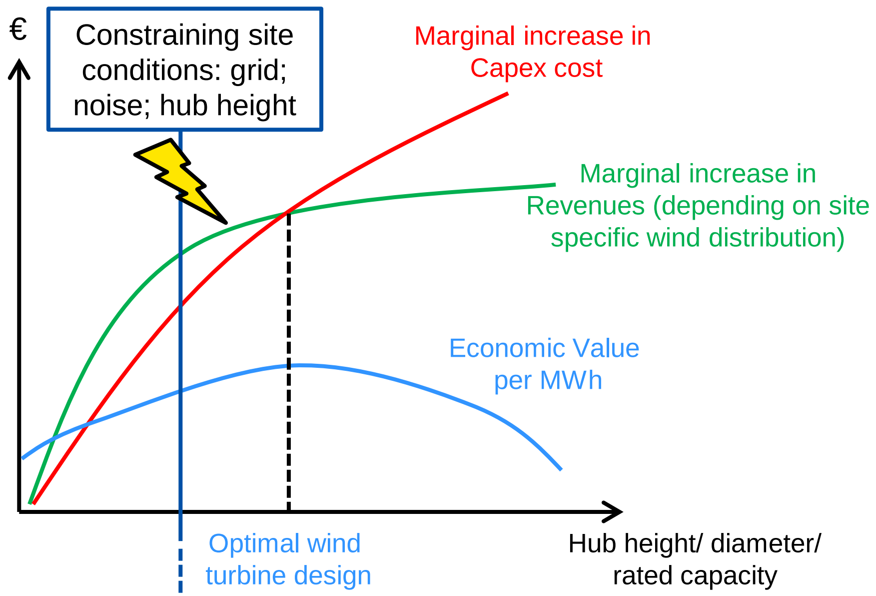
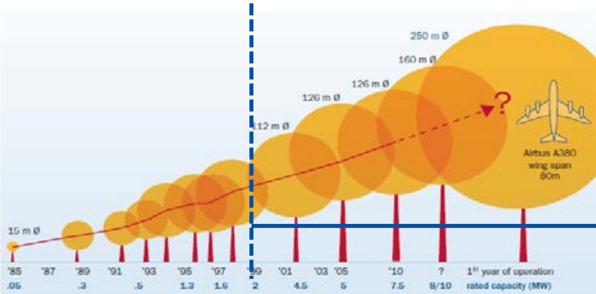
Optimal siting – Optimizing capex vs. revenues by technology selection with constraints and subsequent tender





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SIEMENS
Vestas

Identification of optimal possible turbine design for site

Screening of target suppliers for suitable turbines

> Development is trying to optimize ratio of capex and NPV of future returns in order to maximize economic value of a project

> Furthermore, constraining site parameters need to be taken into account, which limit the potential for economic optimisation
- Grid connection points
- Regulation of noise
- Regulation of hubheight
- Environmental regulation etc.

> **Constraints usually increase the LCOE of a project and limit potential for optimisation**

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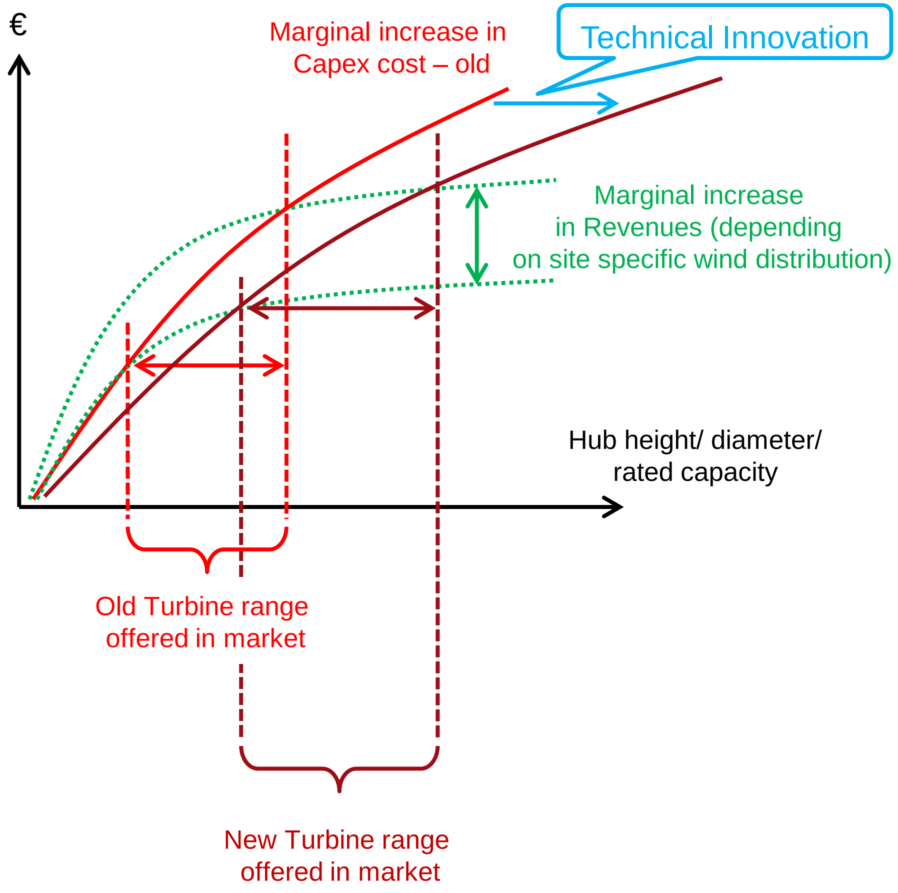
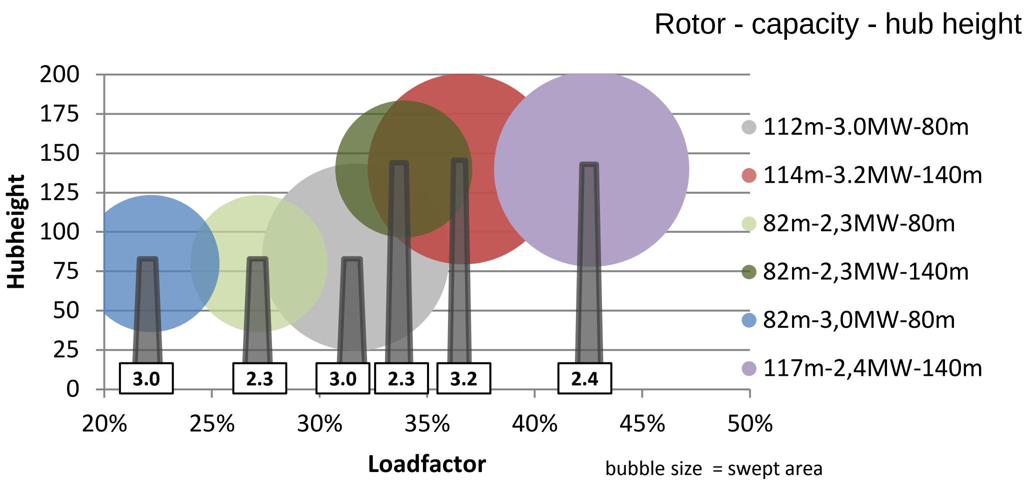
Offered range of turbines is changing with technical progress in the industry



- During the last years, offered turbines have changed significantly and new prototypes were getting onto the market frequently (until now)

Example for turbine design – performance increase



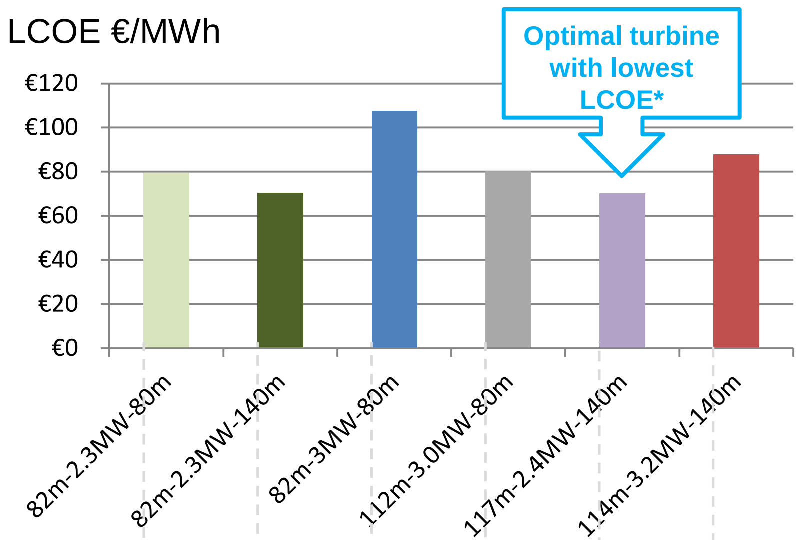
Assumptions on wind	value	dimension
Weibull-A-Parameter	7	m/sec
Weibull-k-Parameter	3	-
average wind speed 80 m	6.3	m/sec
air density	1.225	kg/m³
average wind speed 140 m	7.2	m/sec
Efficiency of wind turbines Cp	manufacturer data depending on wind speed	%

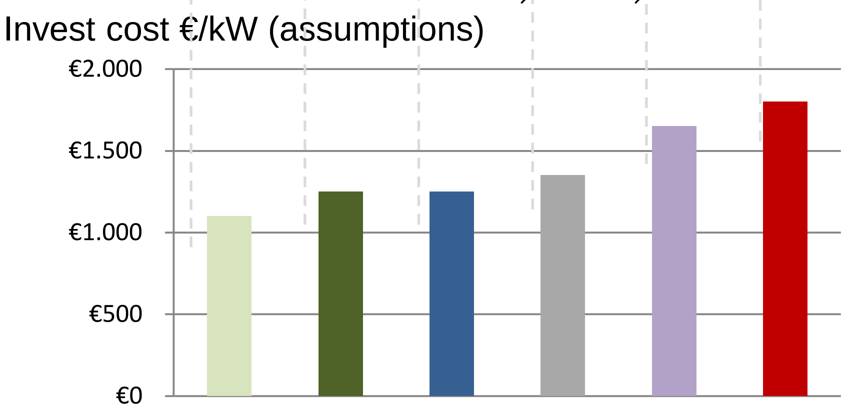
> Using a simplified example for available turbines at different hub heights/ rotor diameter and rated capacity on the same site shows significant differences of load factors (or full load hours)

> Local inefficiencies are not considered here, which might reduce the output of a turbine significantly, e.g. turbulence and wake effects

> This alone is no indication for improved economics in low wind areas

Capex increase but LCOE decrease



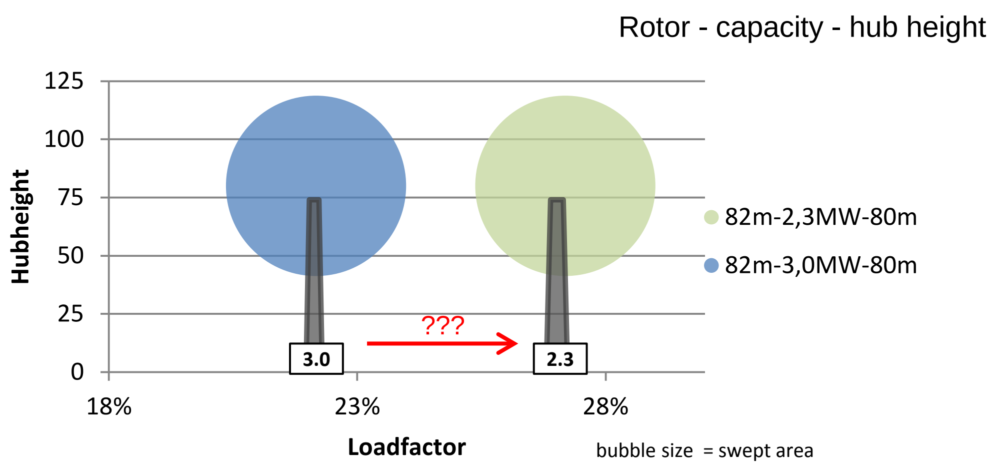


- Optimal turbine for example is with high hub height, large rotor diameter and smaller rated capacity (pink data)
- Lowest LCOE are associated with higher Capex cost, which are more than outlevelled by increase in returns
- This does not necessarily hold true for all wind sites
- Results indicate that newer turbines at low wind sites (~6,5m/sec) could become even cheaper than conventional generation

Further economic parameters		
Opex cost	38.7	€/KW
Availability	97	%
Inefficiencies via turbulence, wake effect etc.	10	%
Lifetime	20	a
Assumed Interest rate	7	%

* This might look different for other wind sites/ distributions; it also is driven by assumptions on CAPEX/ which might differ significantly.

Backup: Smaller turbine – less energy but larger load factor



$$\frac{\Delta\, MWh}{\Delta MW} = \frac{\frac{(5826-5478)}{5826}}{\frac{(3-2,3)}{3}} = \frac{6\%}{23\%}$$

→ Increase in energy

→ Increase in capacity

Larger turbine leads to relative decrease of Output – despite increasing output

	Energy [MWh]	Fullload hours [MWh/MW]	Load factor [Flh/8760]	Specific Capex [€/kW]	LCOE [€/MWh]
82m-3,0MW-80m	5826	1942	22,17%	1.250	108
82m-2,3MW-80m	5478	2382	27,19%	1.100	80

- Building a turbine with lower rated capacity but same design, results in decrease of **produced energy as absolute measure**, because in high wind situations less is produced
- However, the load factor/ fullloadhours are a relative measure and **energy produced is only part of the enumerator**. At the same time **rated capacity is the denominator**
- If the reduction of the denominator is larger than the decrease of the enumerator, **the fulload hours/load factor as relative measure** is increasing – which might not seem intuitive on first thought
- Turbines are not optimal if they maximize MWh, they are optimal if they minimize the specific cost of generating one MWh at a site (→ optimal siting)
- Smaller generators are cheaper and if load factor is increasing by reducing rated capacity, LCOE are also decreasing

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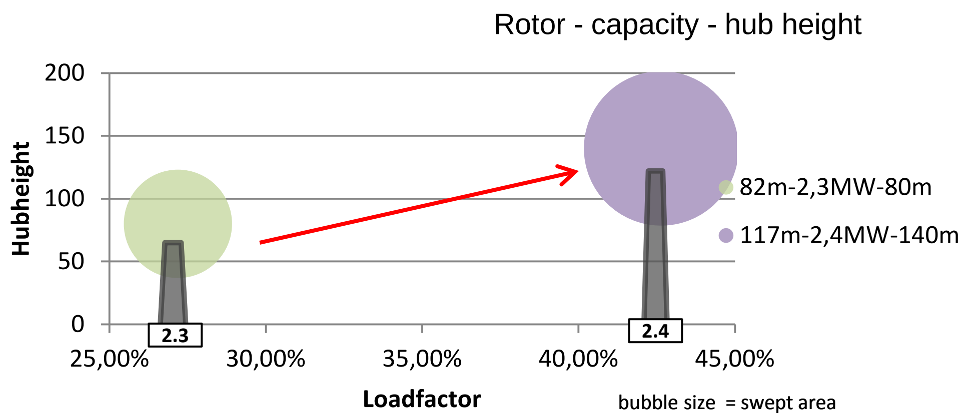
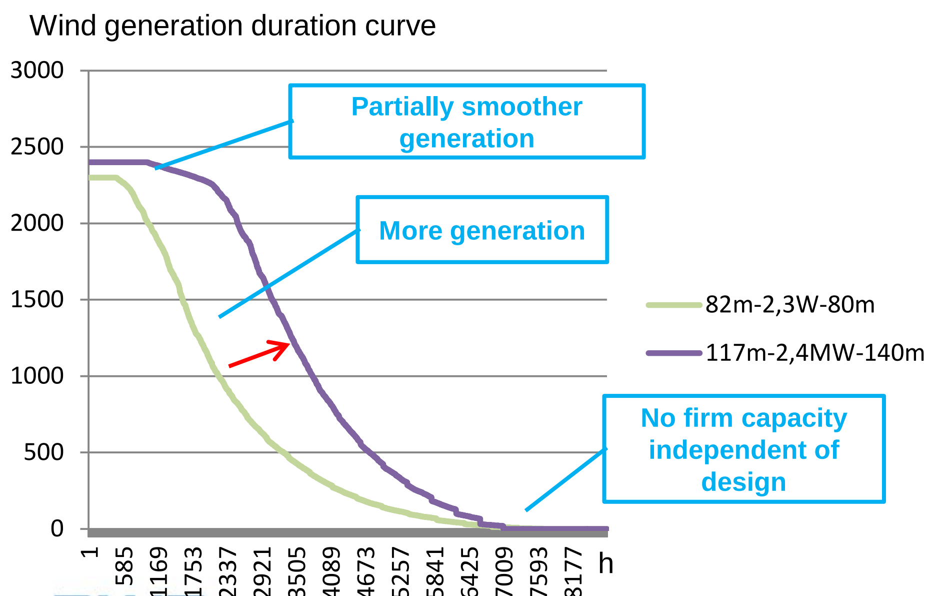
Backup: Turbine design affects generation profile





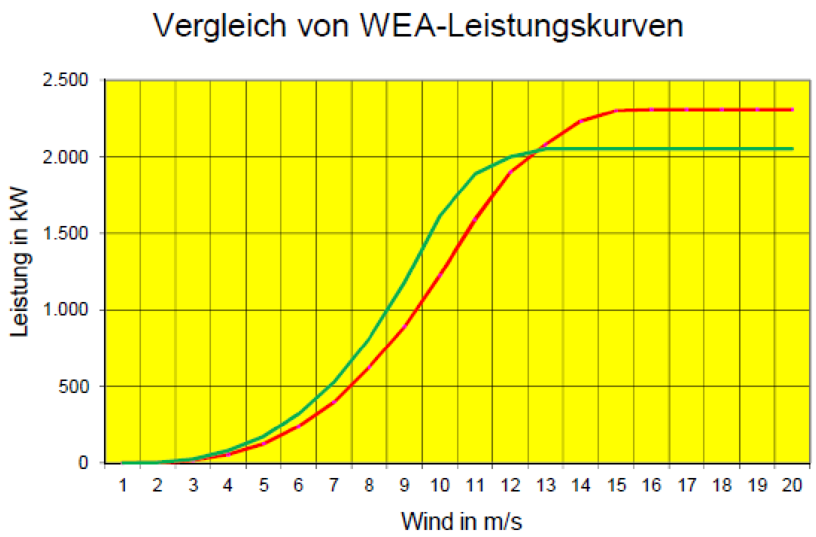
> Improving hub height increases wind speed and rotor diameter increases captured wind energy - in total increasing energy generation

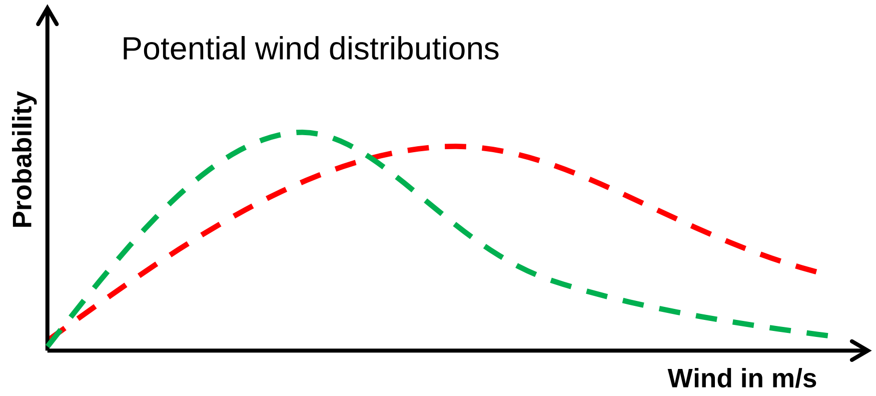
> Meanwhile there are always periods with no or almost no wind, hence improved design is not increasing the capacity credit/ secured capacity of wind power

> In this example production is smoother in windy situations and incremental changes in wind generation are lowered sometimes (at least in this example)

> By increasing hub height and rotor and capacity, the production duration curves are not fully comparable, because average wind is increasing etc.

Optimal siting – Different technology designs for different wind speed sites



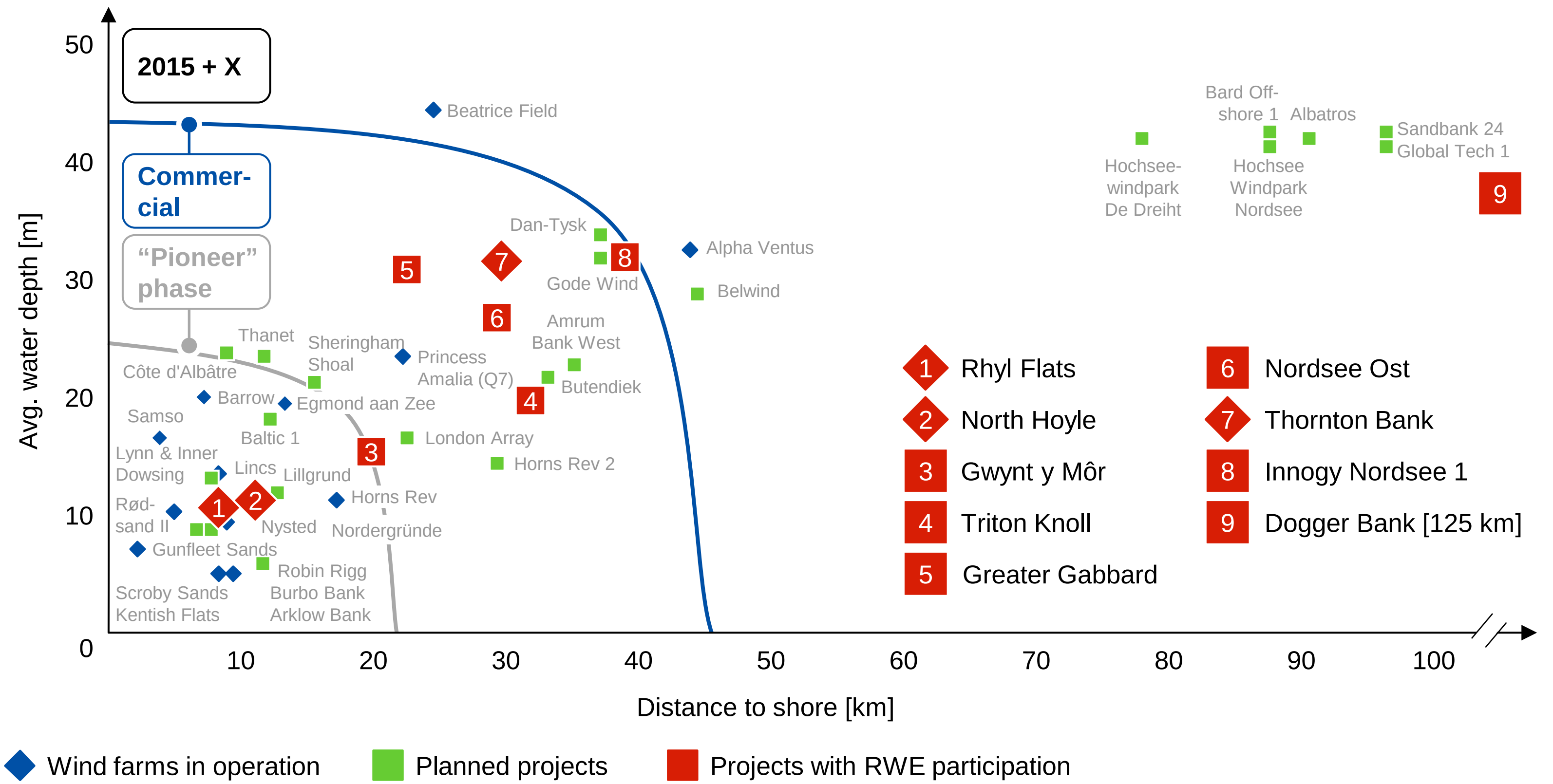


- Some turbines are extra designed for sites with lower wind speeds
- They offer higher efficiency during periods of lower wind speeds
- Despite, lower maximum rated capacity (kW) the green curve might yield higher energy returns (kWh) than the red curve if the green wind probability density is considered
- There is no turbine that fits to all sites, local measurement on wind distribution is necessary
- Optimisation is done site specific during development of projects
- No manufacturer offers turbines suitable for all wind sites, hence several suppliers are needed for developing a wider range of wind projects

Annex: Offshore

New projects will be in deeper water and further from shore

Distance to shore and water depths pose additional challenges



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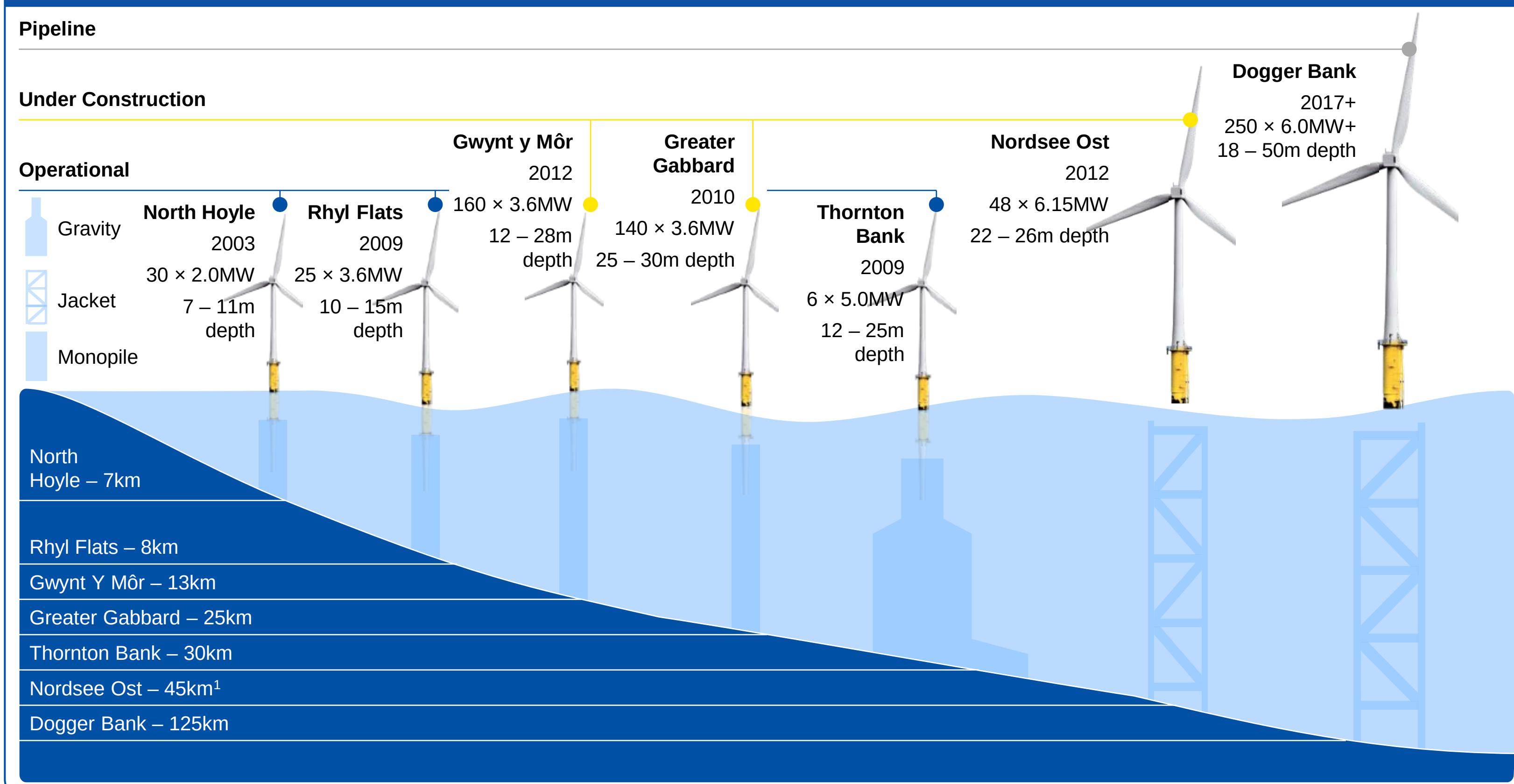
Bigger, deeper, further offshore – an inevitable path forward

RWE Innogy's stepwise approach to reduce execution risk



Cost reductions to be expected for: foundations

Serial production of foundations leads to reduced prices and faster production

Optimised designs for various foundations types (monopiles, jackets, gravity foundations etc.) reduce prices (e.g. due to lesser steel requirements)

Alignment of German industry regulations with international regulations would lead to significant reductions of foundation costs (e.g. due to less strict requirements regarding steel thicknesses[1])

[1] Comparing weights and thus costs of 48 jacket foundations at Nordsee Ost (built according to German regulations) and at Thornton Bank (built according to international regulations) shows the effect. Given similar average water depths (Nordsee Ost: 23m, Thornton Bank: 18m) and comparable soil conditions the average weight of a Thornton Bank jacket is only 500t whereas the average weight of a Nordsee Ost jacket is 600t and thus 20% above the weight of the jacket built according to international regulations.

Cost reductions to be expected for: O&M

Increased in-house activities regarding O&M for offshore wind farms will partly or fully replace costly O&M contacts with turbine manufacturers

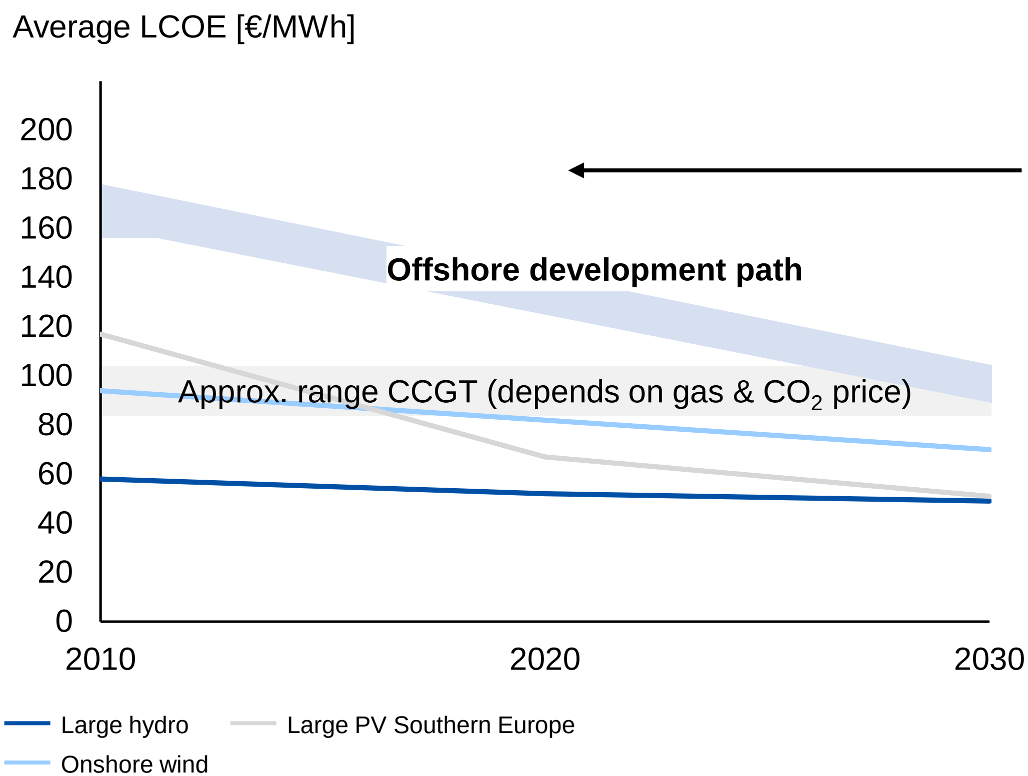
Geographical clusters for offshore wind farms (e.g. off the coast of North Wales: North Hoyle, Rhyl Flats, Gwynt y Môr) create synergies for O&M activities

Increased reliability of components (turbines, foundations, substations etc.) reduces numbers of arduous and expensive offshore service activities

Increased rated power of turbines means a reduced number of turbines to be maintained without reducing the capacity of the wind farm

Cost reductions with 2020 target level of €120/MWh in mind

UK industry task force has shown development paths to achieve a LCOE[1] level of €120/MWh by 2020 – reduction in the range of 30% required



Main cost reduction drivers

- Cost reduction **turbines**
- Design & cost improvements **foundations**
- Advanced **O&M solutions** and increased reliability

[1] LCOE: Levelised cost of energy including development and capital expenditure | Data source: Desertec Initiative 2011; RWE 2012