Introduction to wind energy

Energy Centre summer school in Energy Economics
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Outline

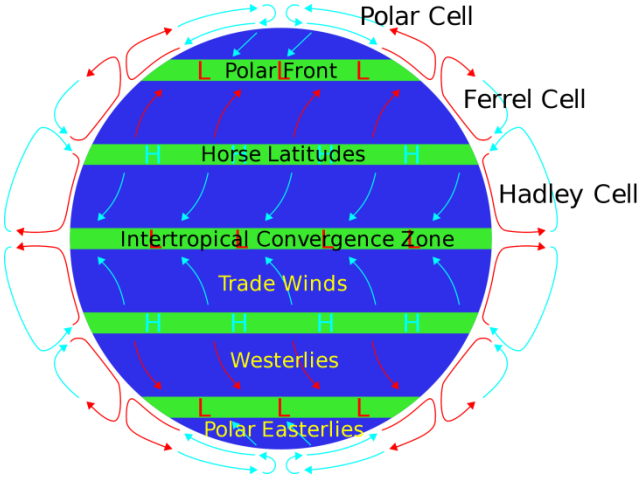
The resource

The technology

Wind energy in the world

Research at the Energy Centre

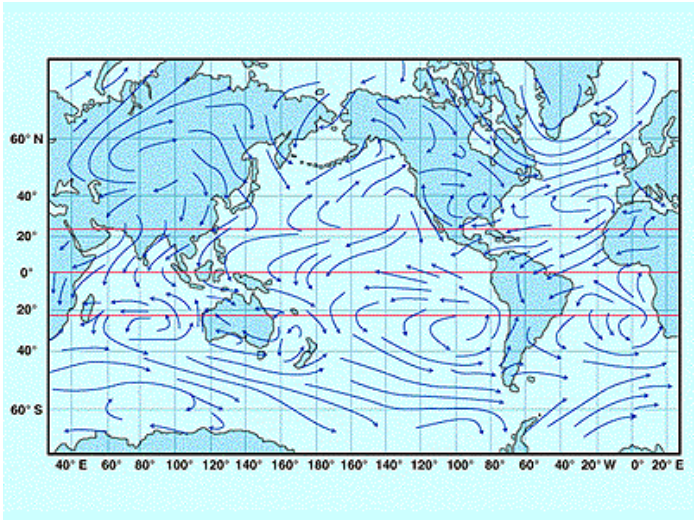
Source of wind



Wind is caused by the uneven heating of the Earth's surface by solar radiation.
Depends on:

- Latitude
- Season (summer, winter)
- Time of day (day, night)
- Type of surface (sea, land)

Earth's rotation -> Corriolis acceleration -> curvature of wind streamlines



Large-scale modifications to the global wind patterns caused by continents and large islands.

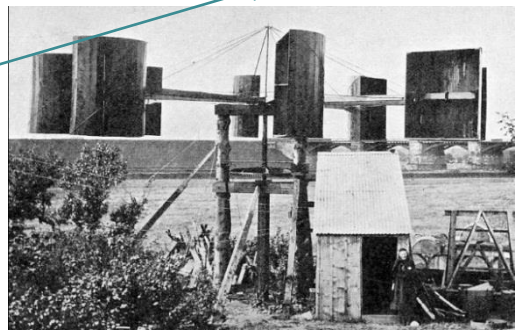
Historical milestones

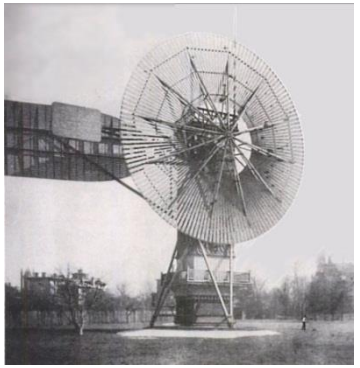
Middle Ages

- Iran/Afghanistan (7th/9th century): grinding corn and pumping water
- Middle East, Central Asia, China, India, Sicily (by 1000 AD): seawater pumping for making salt
- North-western Europe (1180s on): grinding flour

19th century

- Denmark: 2500 windmills for pumps, mills
- American mid-west: ca 6 million small windmills for irrigation
- Scotland, 1887: Prof James Blyth built the first windmill for production on electricity, used for providing lighting in his holiday cottage
- Ohio, 1888: Charles F. Brush's 17m rotor diameter wind turbine, 12 kW, used to charge batteries or operate up to 100 (inefficient!) light bulbs





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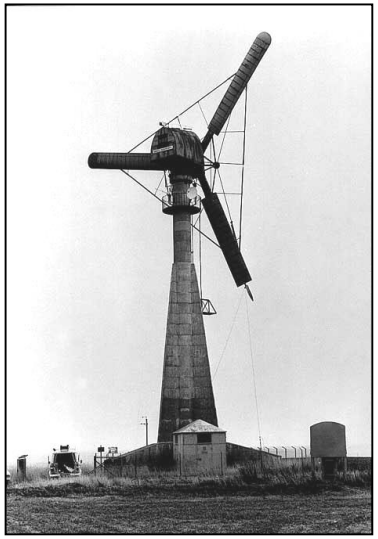
Historical milestones

20th century

- 1900-1973: wind generators widespread, but competed against fossil fuel plants and centrally generated electricity
  - USSR, 1931: 100kW, 30m diameter (d)
  - UK, early 1950s: 100kW, 24m (d)
  - Denmark, 1956: 200kW, 24m (d)
  - France, 1963: 1.1MW, 35m (d)
- 1973-onwards: oil price crisis spurred investigation of non-petroleum energy sources
  - USA, 1987: 2.5MW, 97.5m (d)
  - USA, 1981: 3MW horizontal axis, hydraulic transmission instead of yaw drive
  - Canada, 1984: 4MW Darrieus wind turbine
  - Large turbines constructed with 1, 2 or 3 blades (prototypes)
  - Smaller, often simpler turbines available for commercial sale
  - **'Danish' wind turbine concept proved to be the successful one!**



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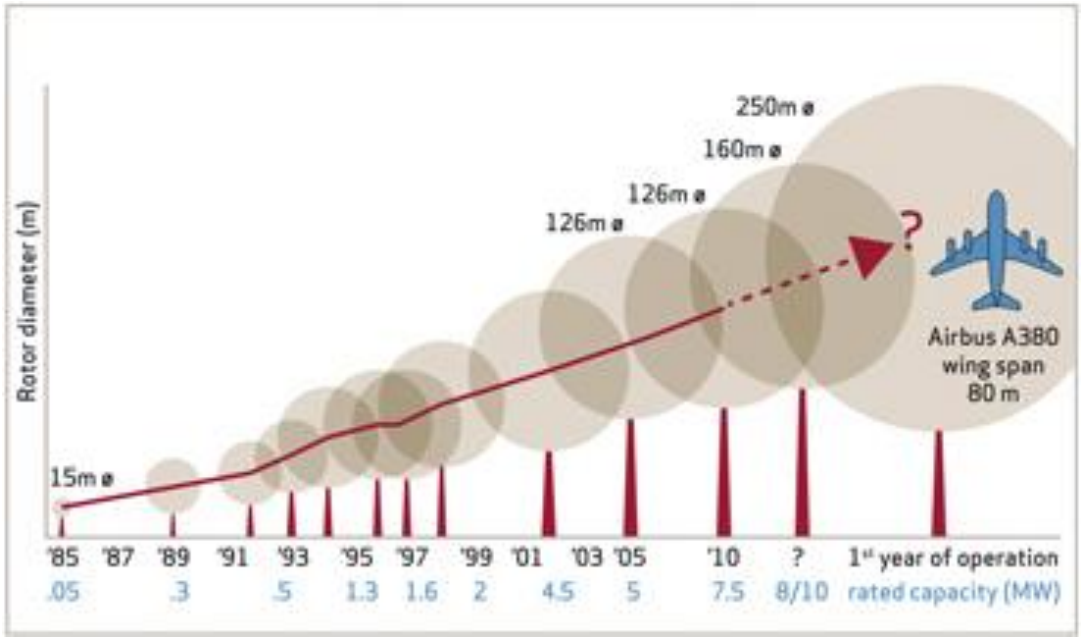
Modern wind turbines

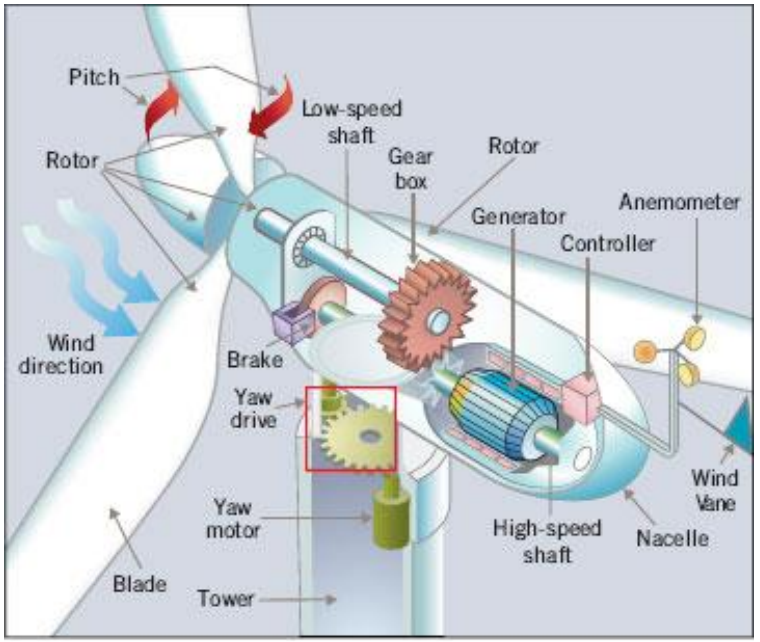
Danish concept:

- 3-bladed, stall-regulated rotor, fixed speed became dominant model in 1980s, less than 200kW rated power

More recent developments:

- 2-3MW(3-8MW)/97-117m(112-164m) diameter onshore (offshore)
- Rotor speed: Fixed speed / Variable speed
- Blade control: Full-span control of the blades (pitch regulated)
- Advanced materials: blades lighter -> can be made longer
- Drive train: Direct-drive concept vs. gearbox+high speed generator





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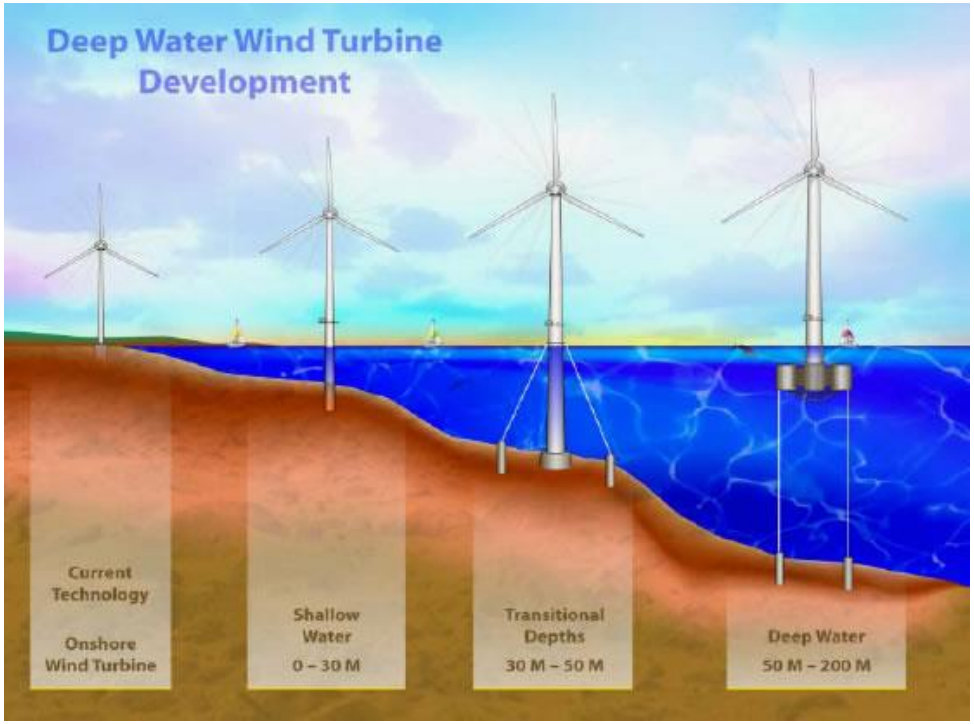
Offshore technologies

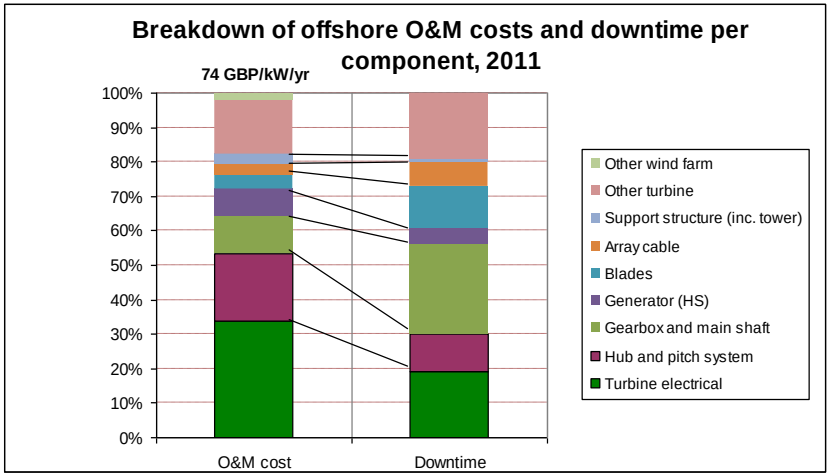
Main issues for offshore wind power

- Going deeper, farther from coast – foundations & interconnections
- Reliability – high cost of maintenance!
- Need for mainstreaming installation processes (currently few specialised vessels)

Existing foundation types



Emerging foundation solutions



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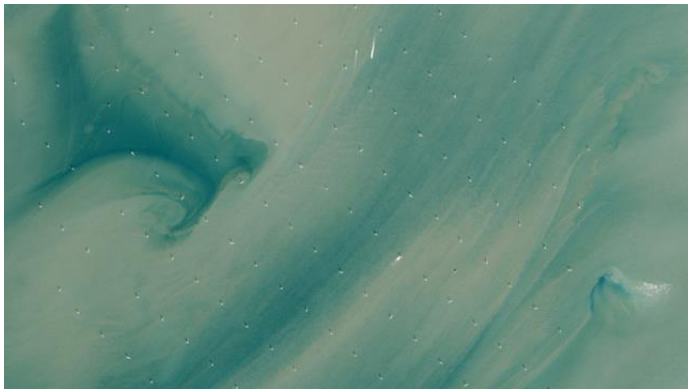
Large wind farms

The Gansu Wind Farm Project (6000 MW).
The project is one of six national wind power megaprojects approved by the Chinese government. It is expected to grow to 20,000 MW by 2020 (below)

The London Array (630 MW)
World's largest offshore wind farm, 20km off the coast of Kent and Essex, England (right, both)



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Power output

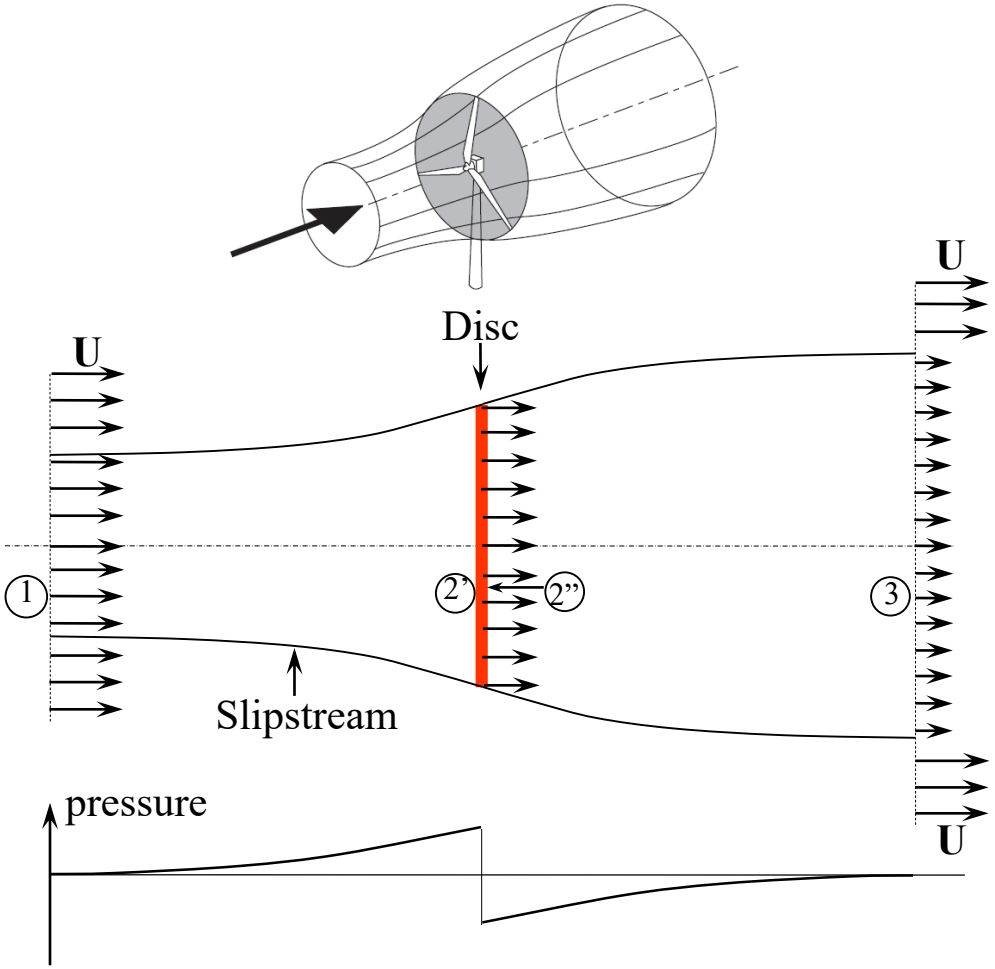
Available power (from wind kinetic energy)

$$P_{\text{avail}} = (\rho AU)\frac{U^2}{2} = \frac{1}{2}\rho AU^3$$

Power output of wind turbine

$$P = \frac{1}{2}C_p\rho AU^3 \qquad C_P = \frac{P_{\text{absorbed}}}{P_{\text{avail}}}$$

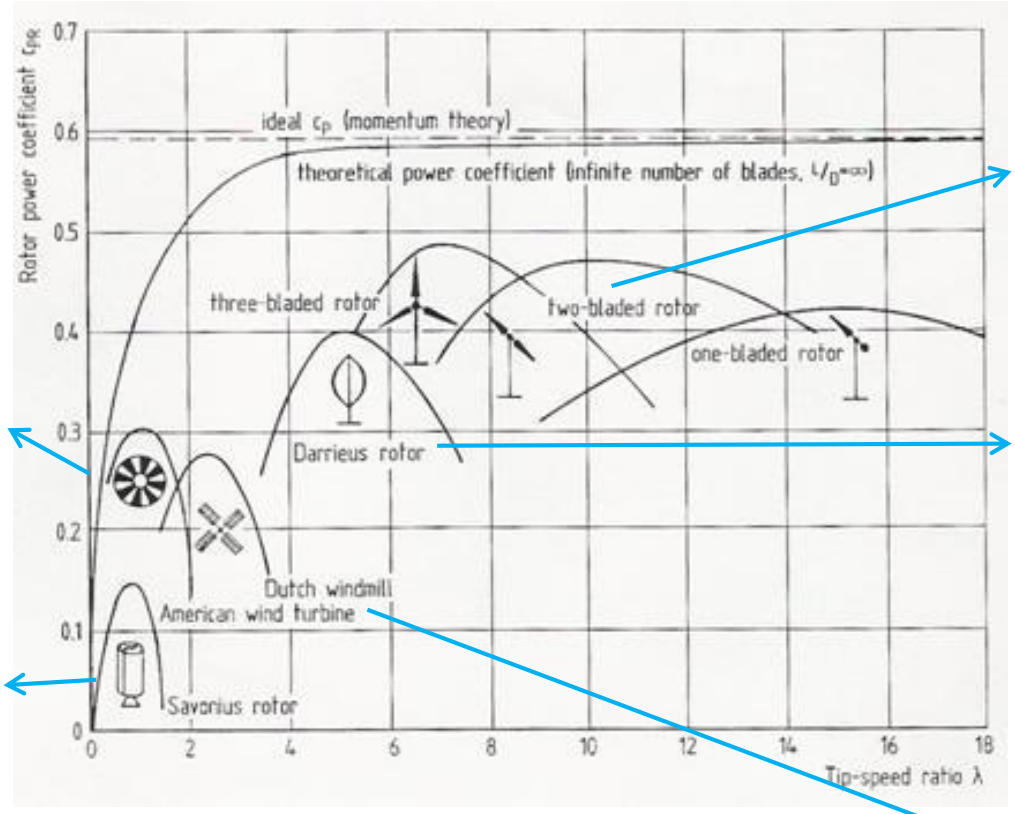
P : power output
C_p: power coefficient
ρ : density of air (1.225 kg/m3)
A : rotor swept area
U : wind speed



Theoretical maximum lin (Albert Betz, 1926)

$$C_{P,\max} = \frac{16}{27} = 0.593$$

Power coefficient



Blade-tip-speed ratio: $\lambda = \dfrac{\text{blade tip speed}}{\text{wind speed}}$

Modern wind turbines: $\lambda \cong 7$

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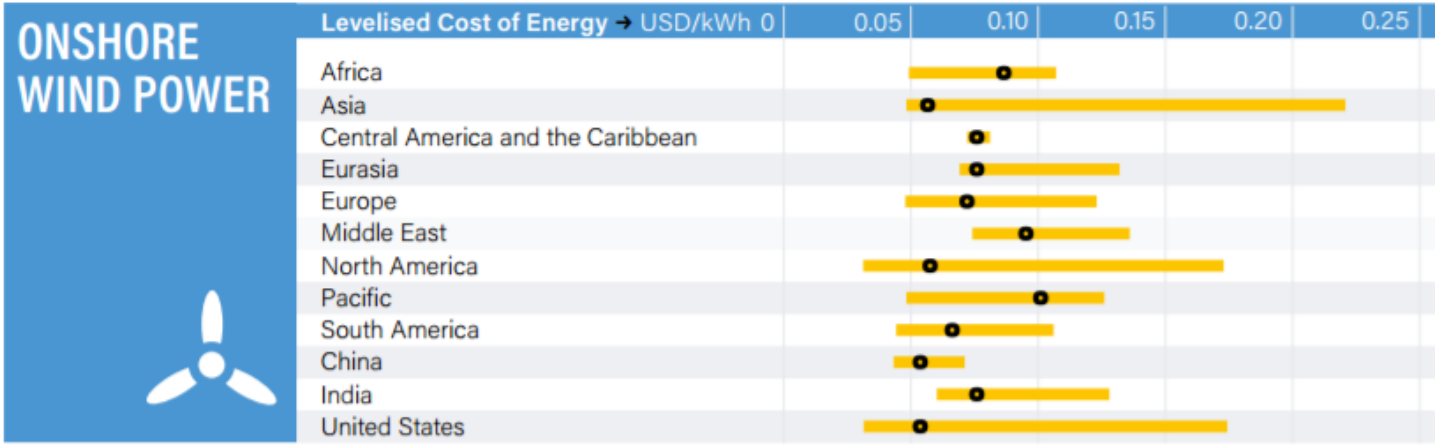
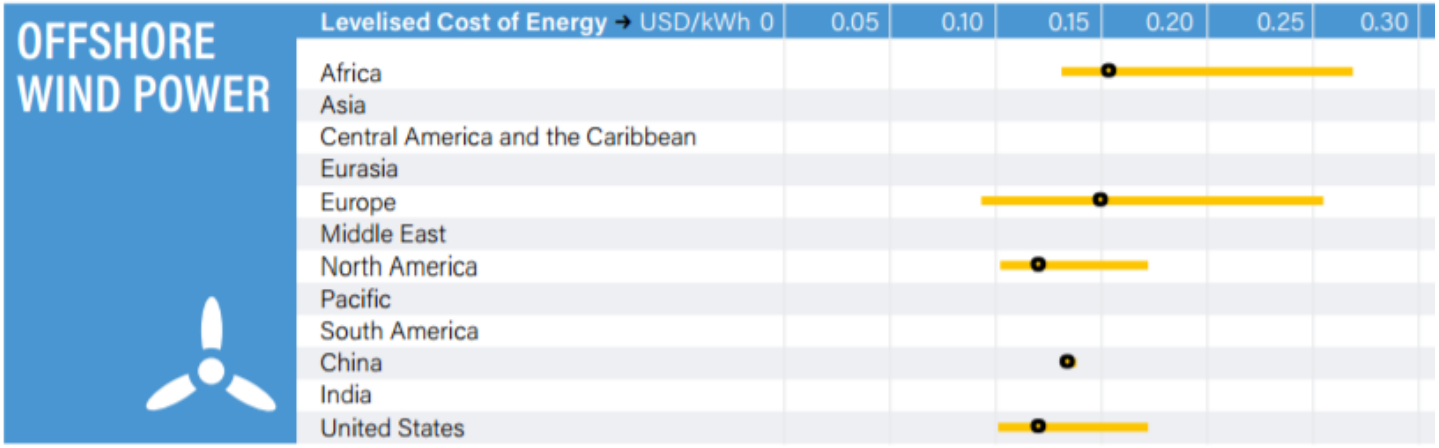
LCOE by region





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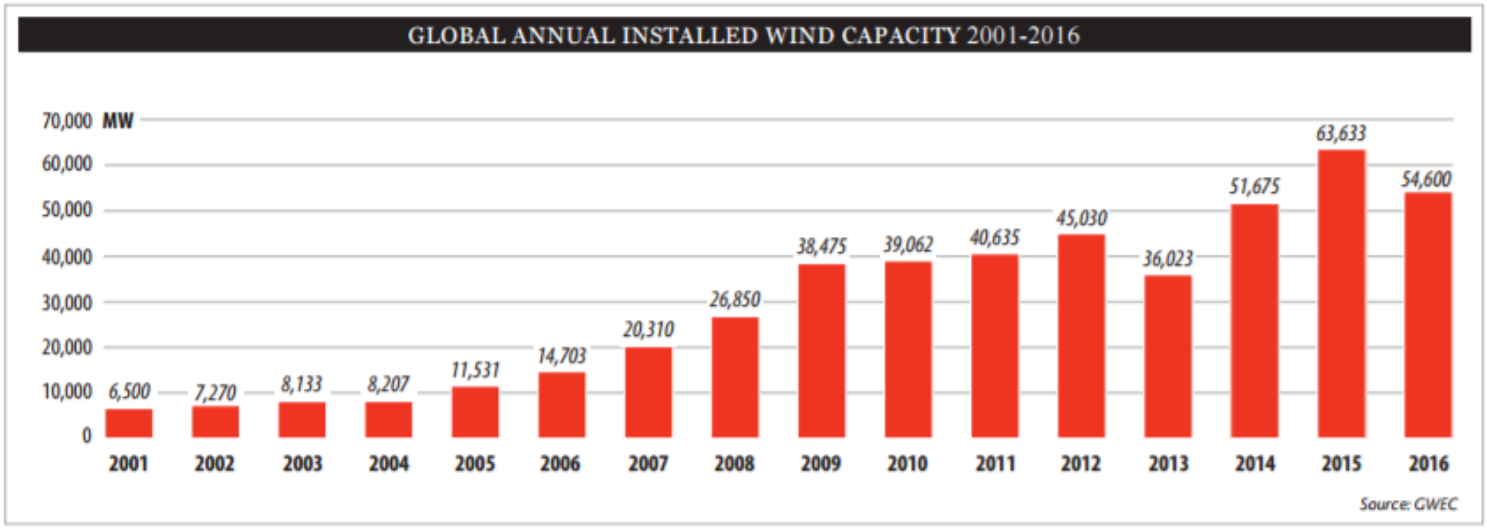
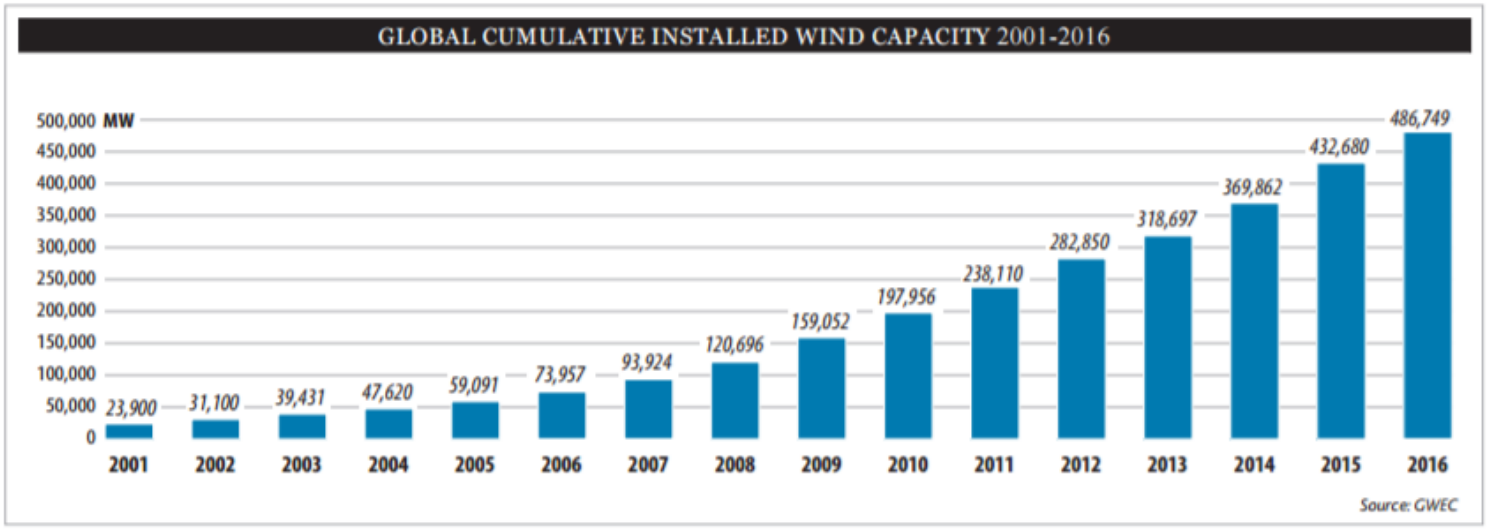
Wind energy in the world





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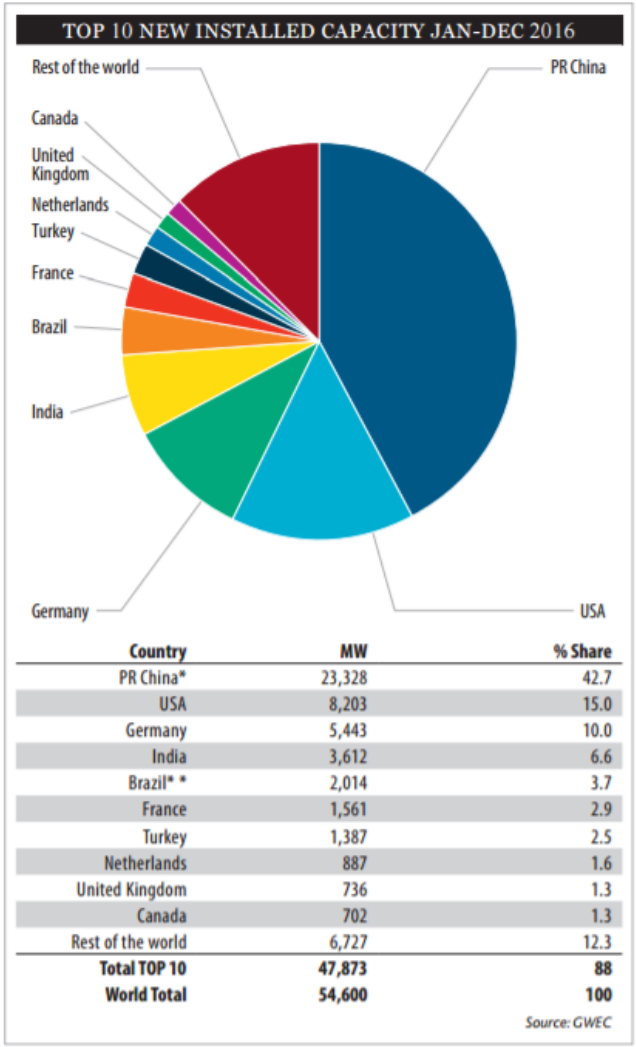
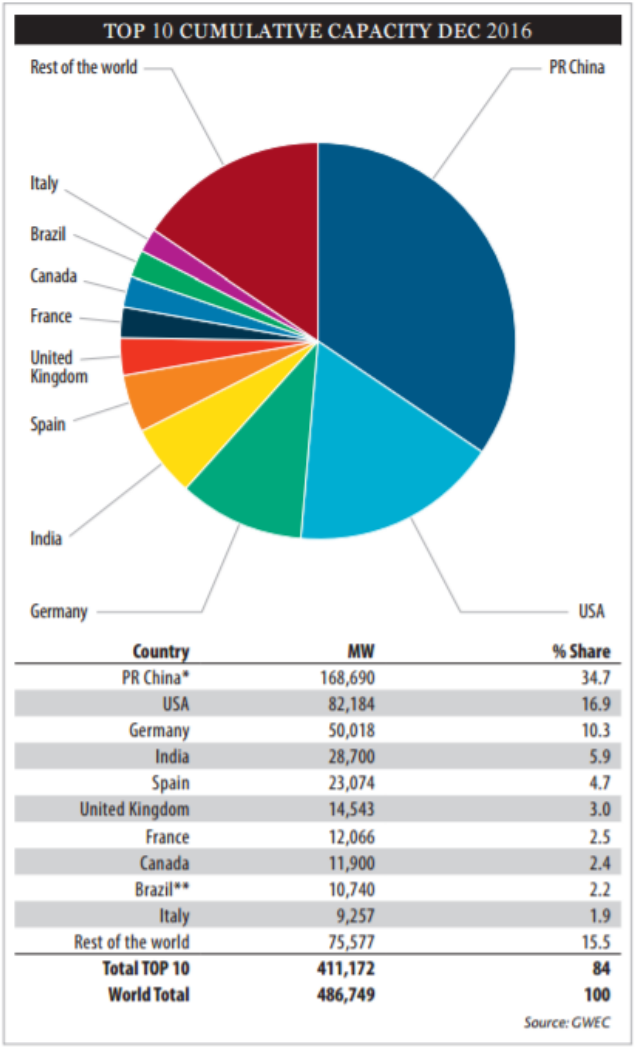
Where in the world?



Country	MW	% Share
PR China*	23,328	42.7
USA	8,203	15.0
Germany	5,443	10.0
India	3,612	6.6
Brazil* *	2,014	3.7
France	1,561	2.9
Turkey	1,387	2.5
Netherlands	887	1.6
United Kingdom	736	1.3
Canada	702	1.3
Rest of the world	6,727	12.3
Total TOP 10	**47,873**	**88**
World Total	**54,600**	**100**

Source: GWEC



Country	MW	% Share
PR China*	168,690	34.7
USA	82,184	16.9
Germany	50,018	10.3
India	28,700	5.9
Spain	23,074	4.7
United Kingdom	14,543	3.0
France	12,066	2.5
Canada	11,900	2.4
Brazil**	10,740	2.2
Italy	9,257	1.9
Rest of the world	75,577	15.5
Total TOP 10	**411,172**	**84**
World Total	**486,749**	**100**

Source: GWEC

* *Provisional figures*
** *Projects fully commissioned, grid connections pending in some cases*

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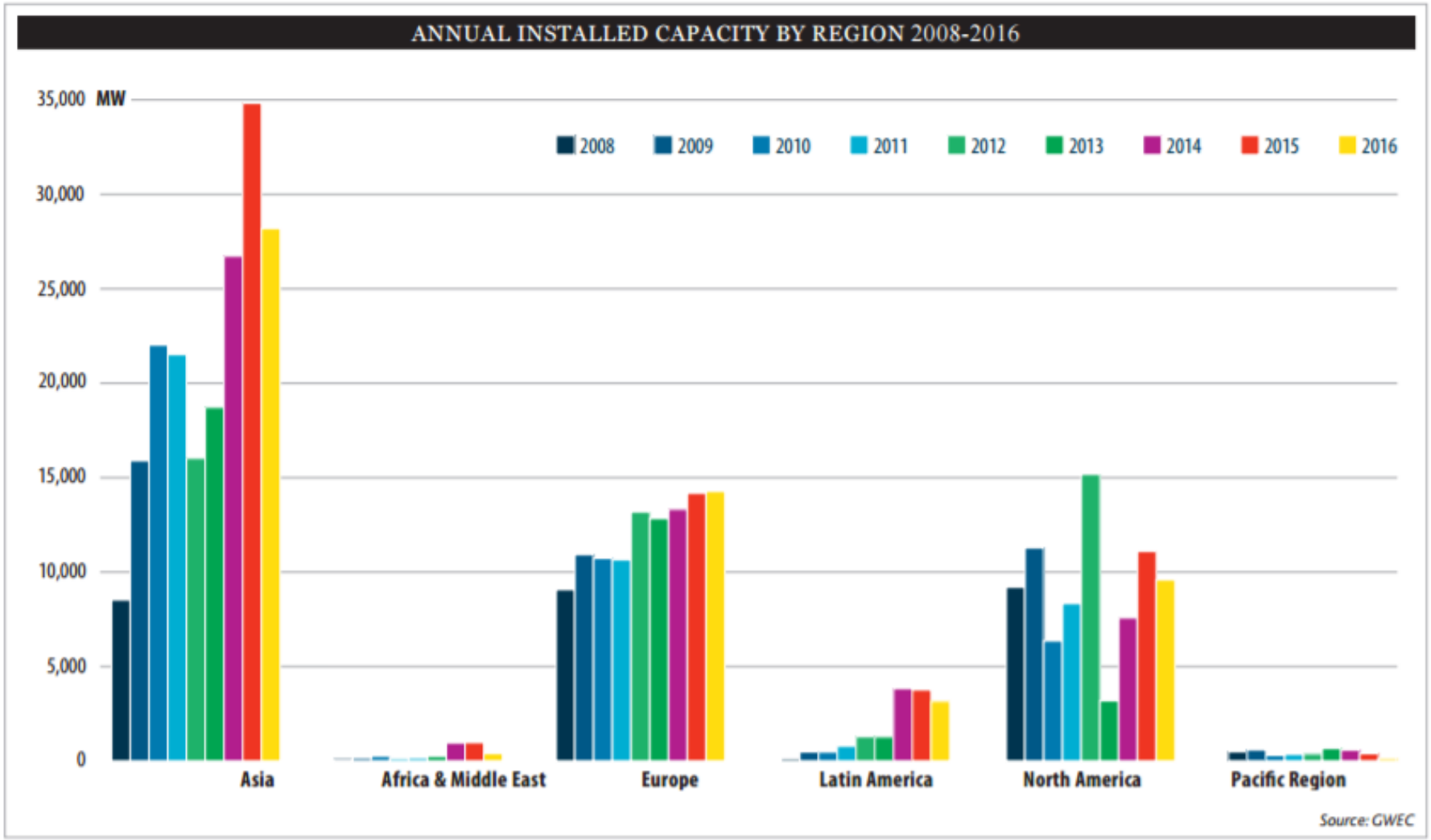

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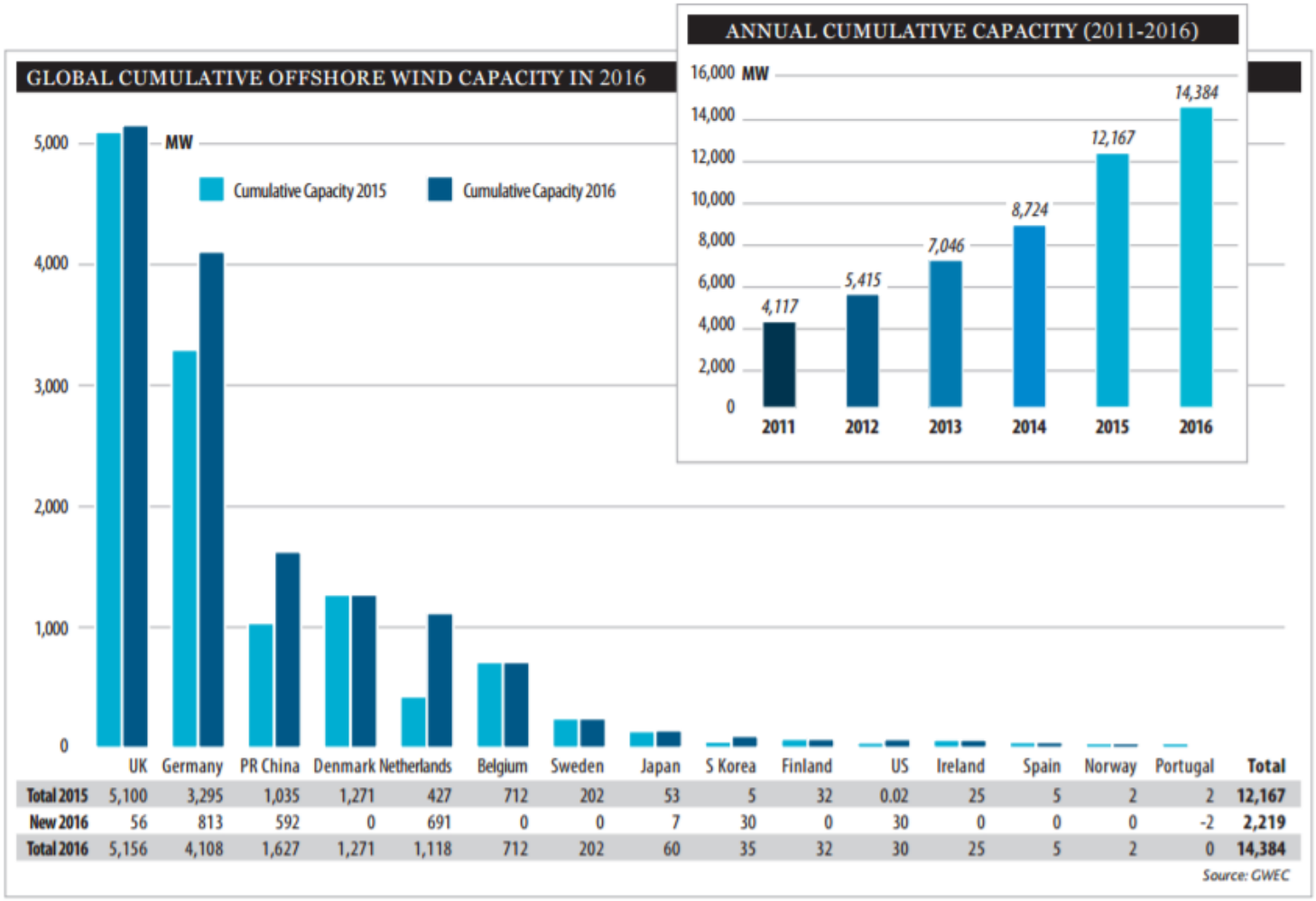
Offshore wind energy in the world



	UK	Germany	PR China	Denmark	Netherlands	Belgium	Sweden	Japan	S Korea	Finland	US	Ireland	Spain	Norway	Portugal	Total
Total 2015	5,100	3,295	1,035	1,271	427	712	202	53	5	32	0.02	25	5	2	2	12,167
New 2016	56	813	592	0	691	0	0	7	30	0	30	0	0	0	-2	2,219
Total 2016	5,156	4,108	1,627	1,271	1,118	712	202	60	35	32	30	25	5	2	0	14,384

Source: GWEC

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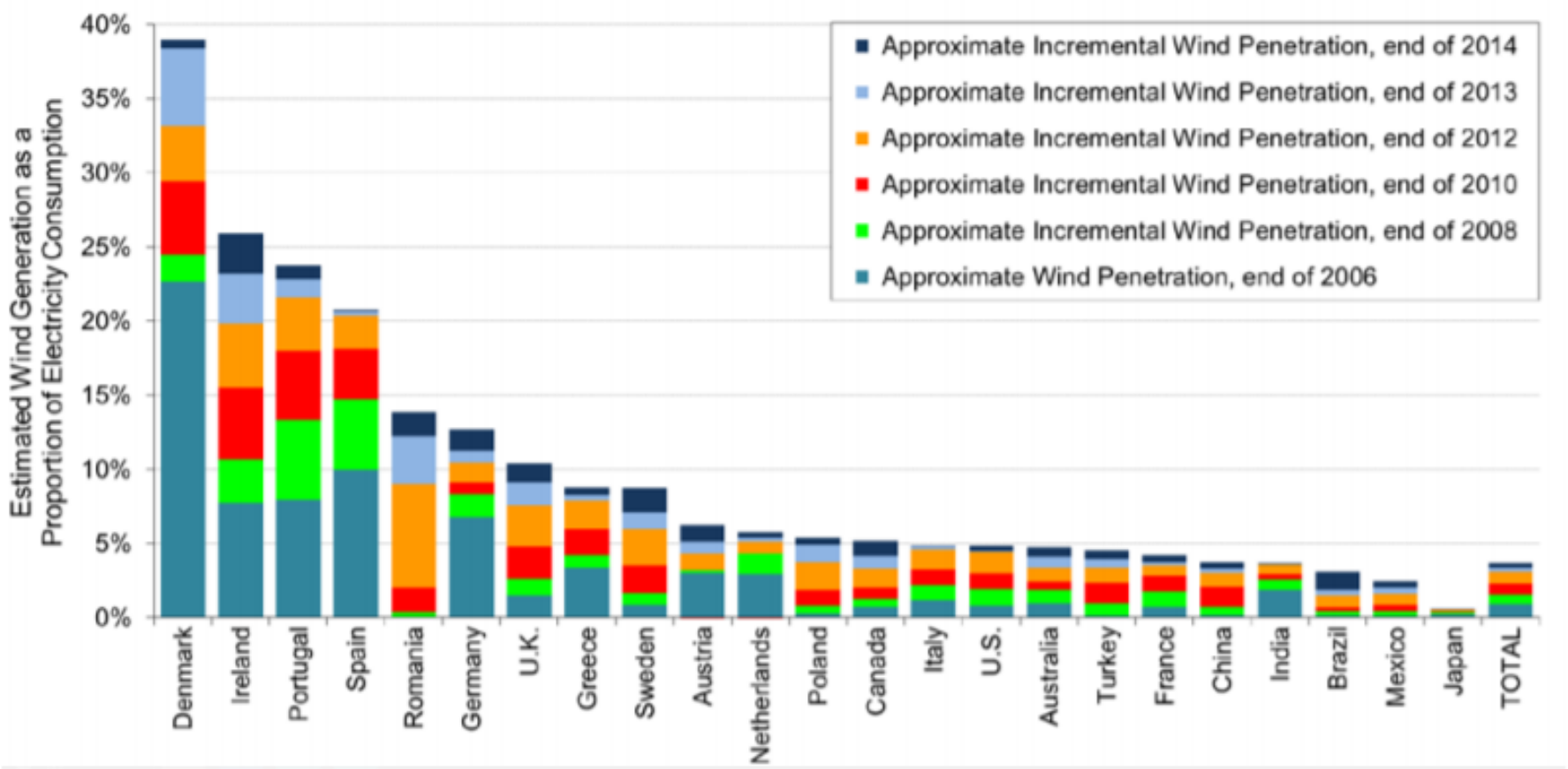
Wind share in electricity mix



Source: Berkeley Lab estimates based on data from Navigant, EIA, and elsewhere

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Research at the Energy Centre: Wind, hydro correlation and demand

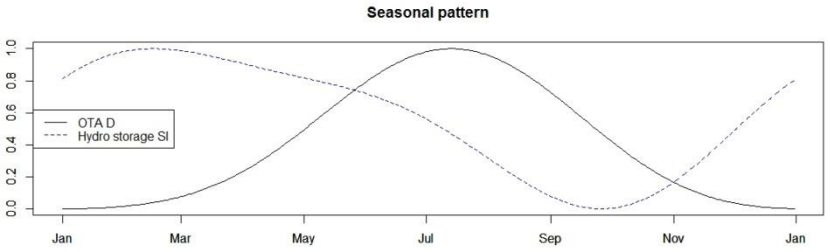
New Zealand's electricity prices are quite vulnerable to the natural fluctuations of hydro power availability due to

- Limited storage capacity,
- High dependence on hydro power,
- Negative seasonal correlation with demand.

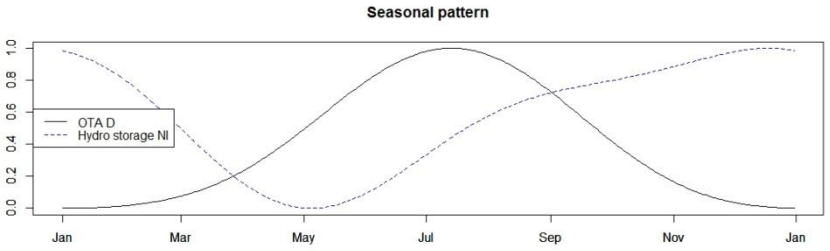
The system must rely on other, generally more expensive, energy sources.

Can wind help?

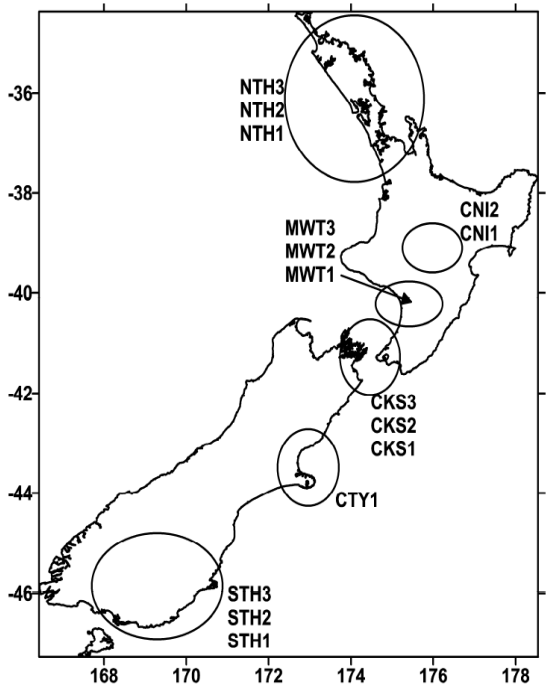
SI hydro



NI hydro



Existing and potential wind development sites



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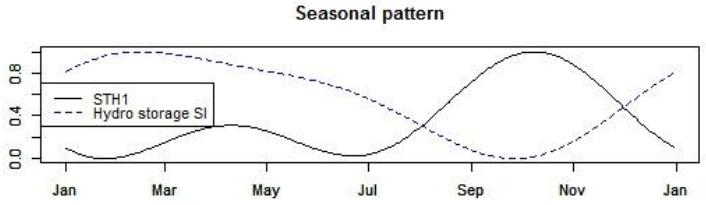
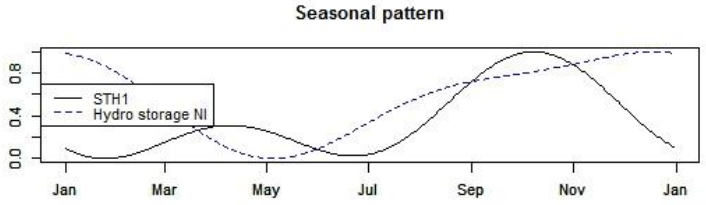
Wind-hydro correlation

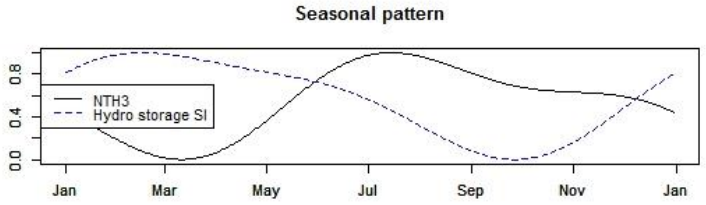
STH1 & SI hydro storage



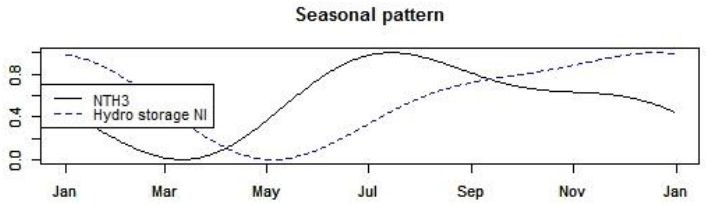
STH1 & NI hydro storage



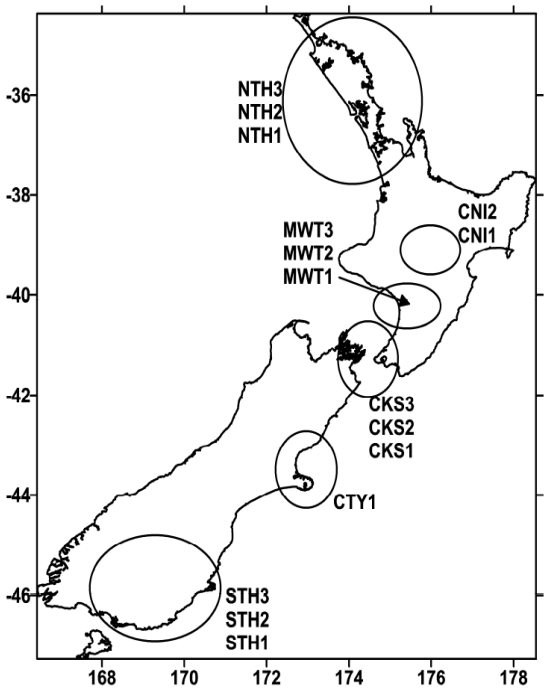
NTH3 & SI hydro storage



NTH3 & NI hydro storage



Existing and potential wind development sites



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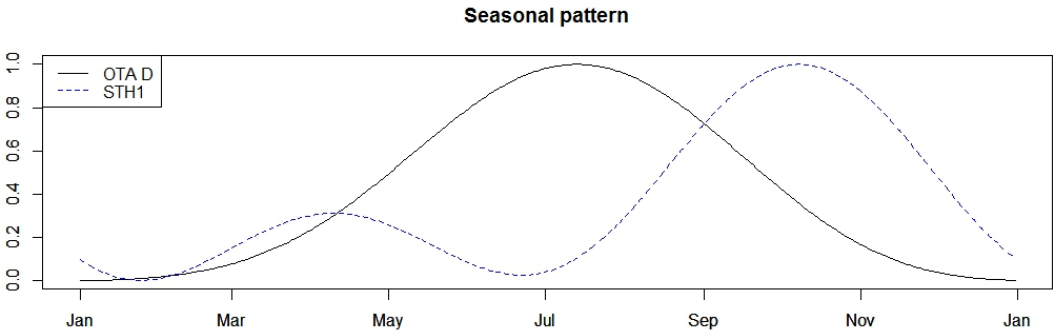
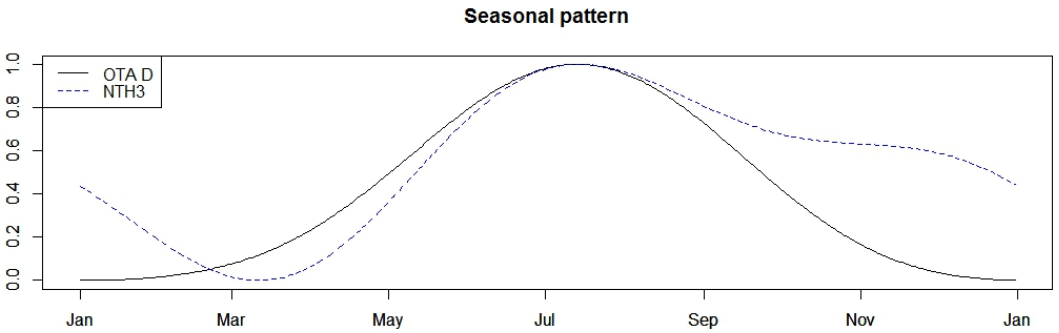
Wind-demand correlation

STH1



NTH3



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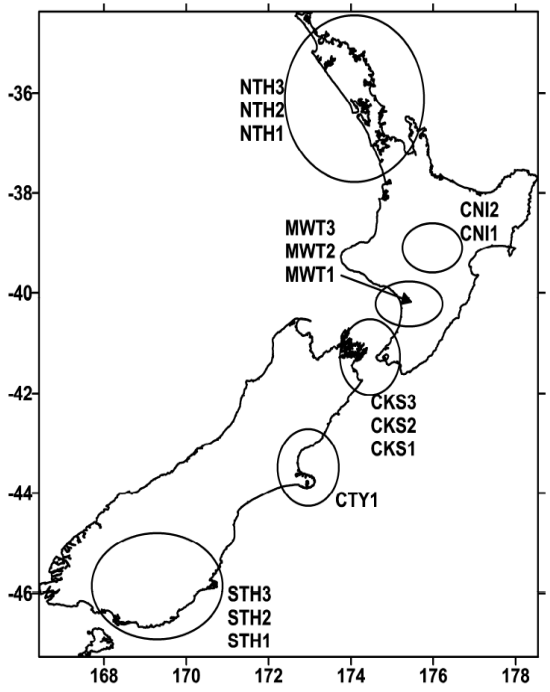
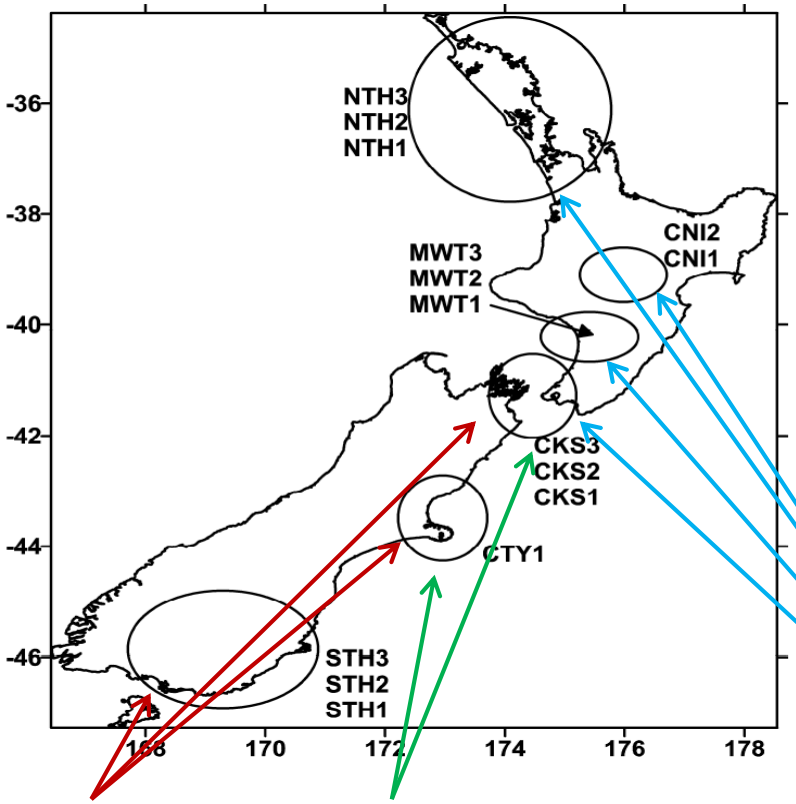


Wind and hydro correlations with demand and prices



Well-suited during months of low SI hydro

Suitable for balancing SI hydro in general

Well correlated with NI demand (& NTHs, CNIs with prices!)