Offshore Wind Energy

Potential, Challenges and Limitations

Trial Lecture

Valerie-M. Kumer

26. August 2016

Jeff Grybowski
@JGrybowski

Folgen

The #BlockIslandWindFarm is now fully constructed. 1st in US @DeepwaterWind

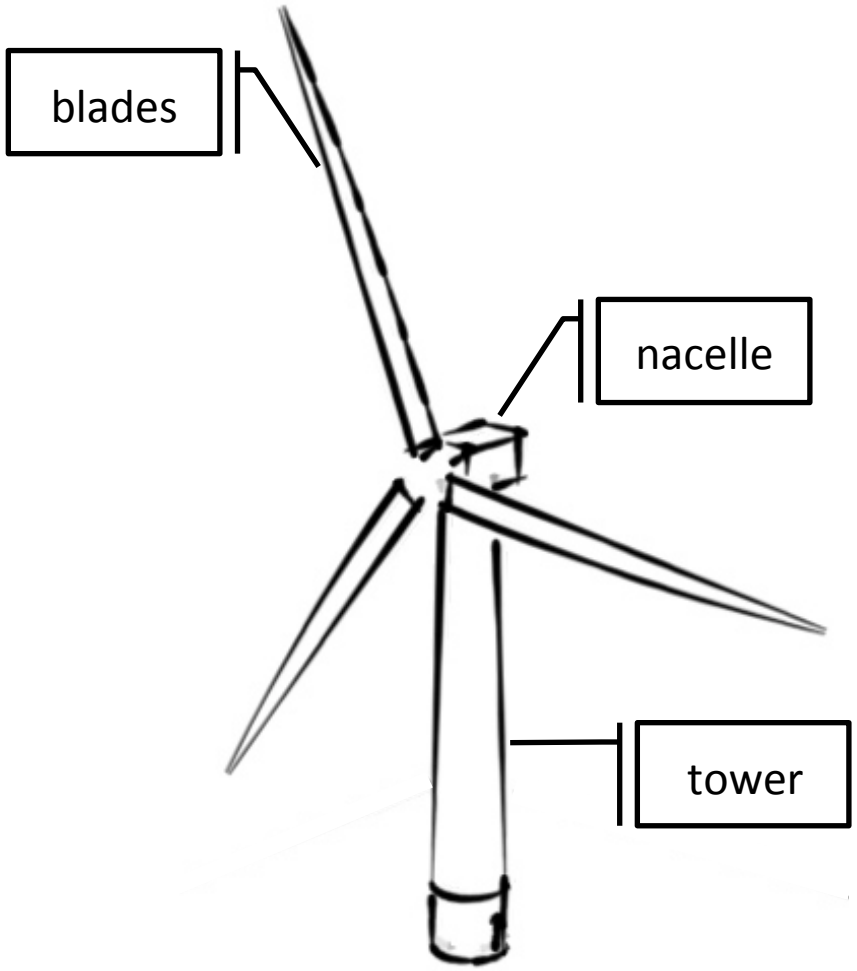
RETWEETS 154 GEFÄLLT 138

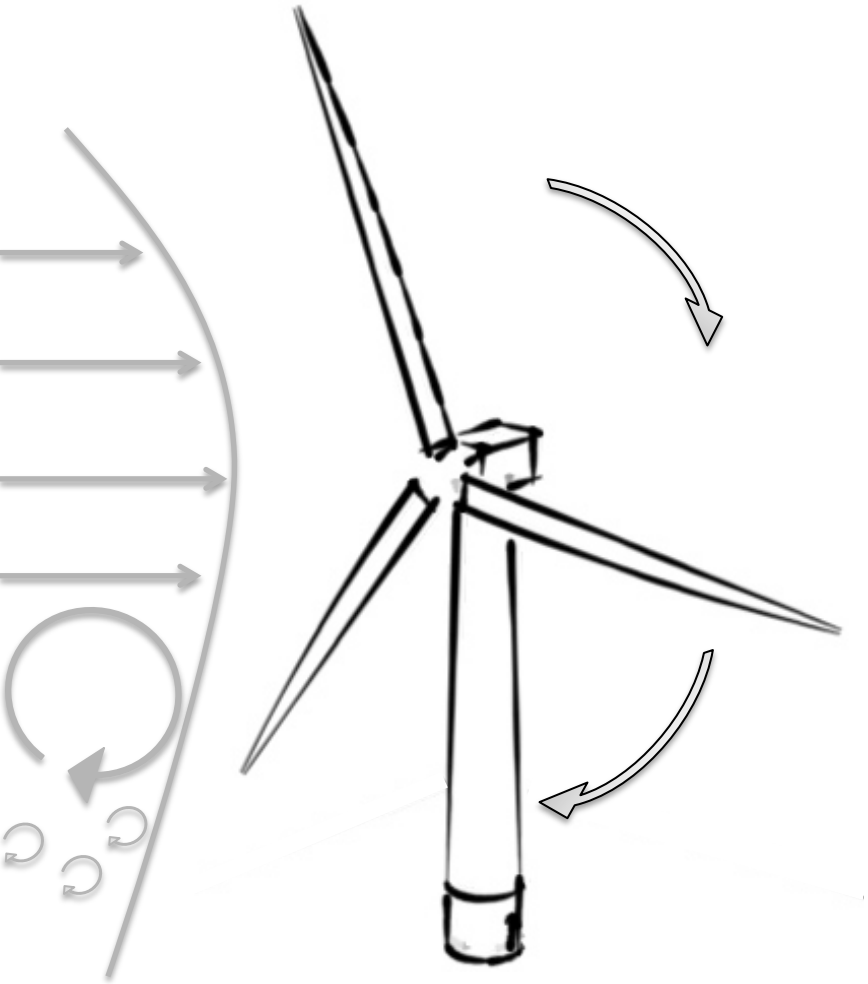
13:12 - 18. Aug. 2016

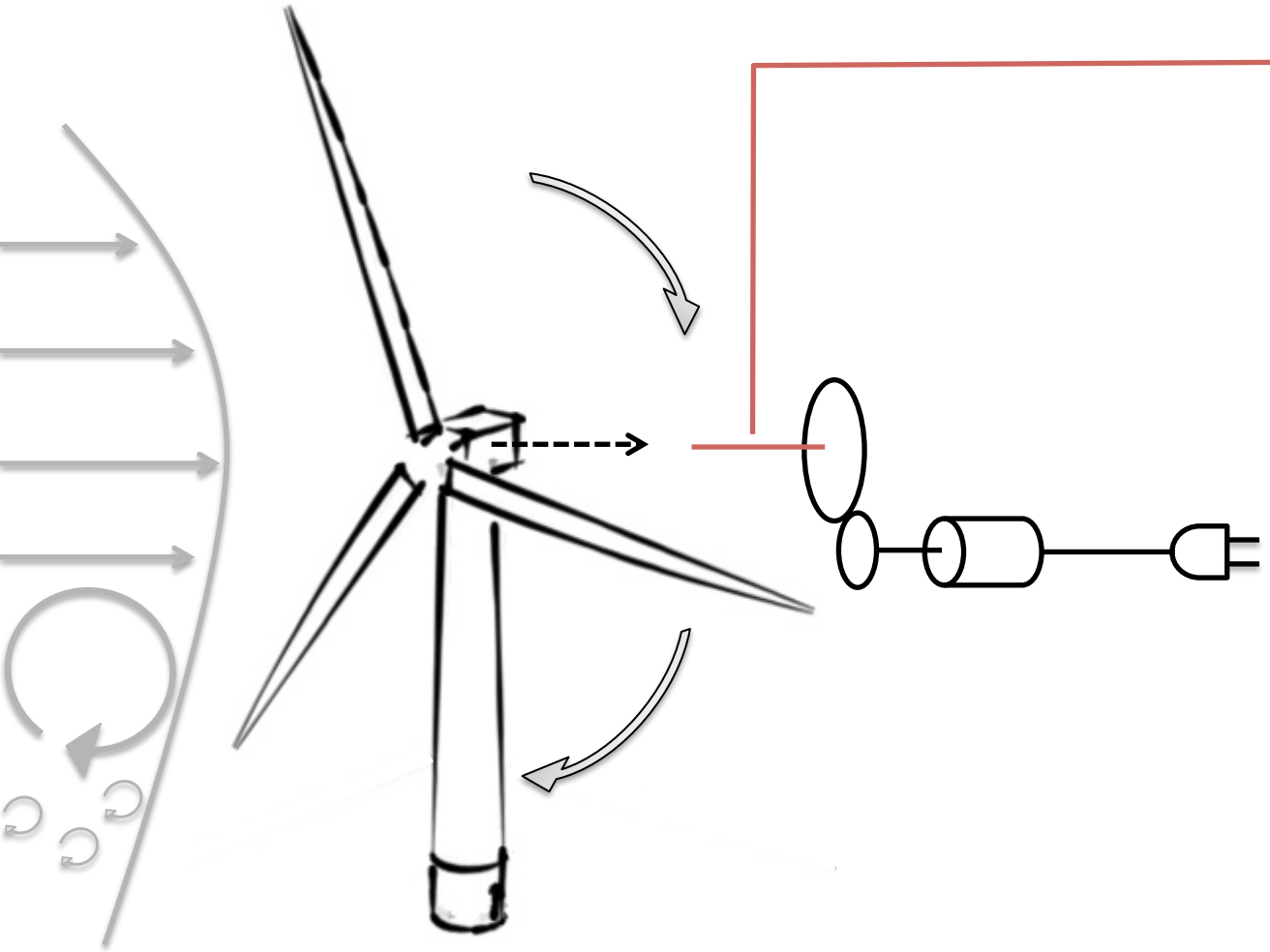
154 138

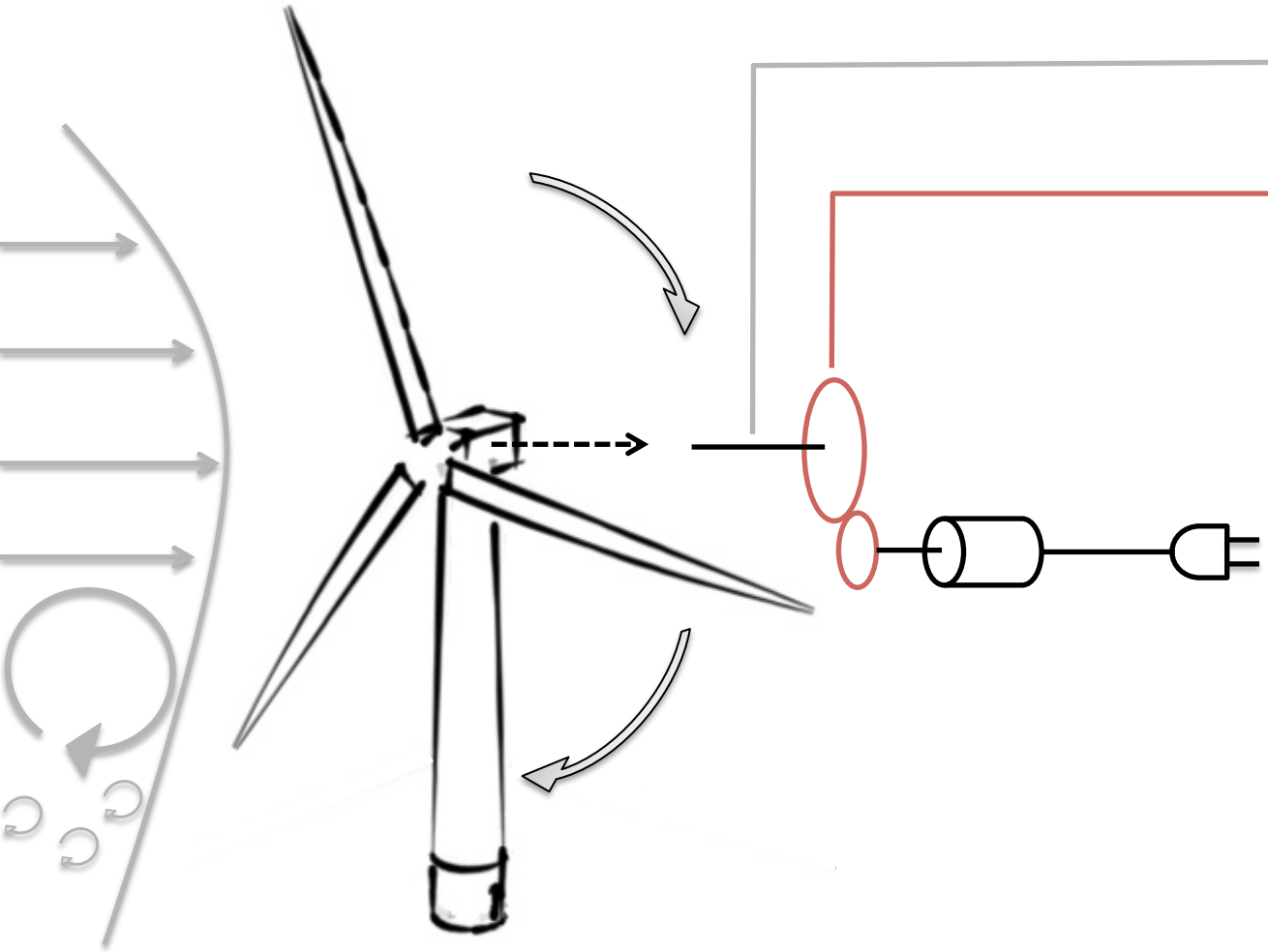
- Technology & Terminology
- Facts
- Challenges
- Norwegian Project: Hywind Scotland
  - First offshore floating wind farm

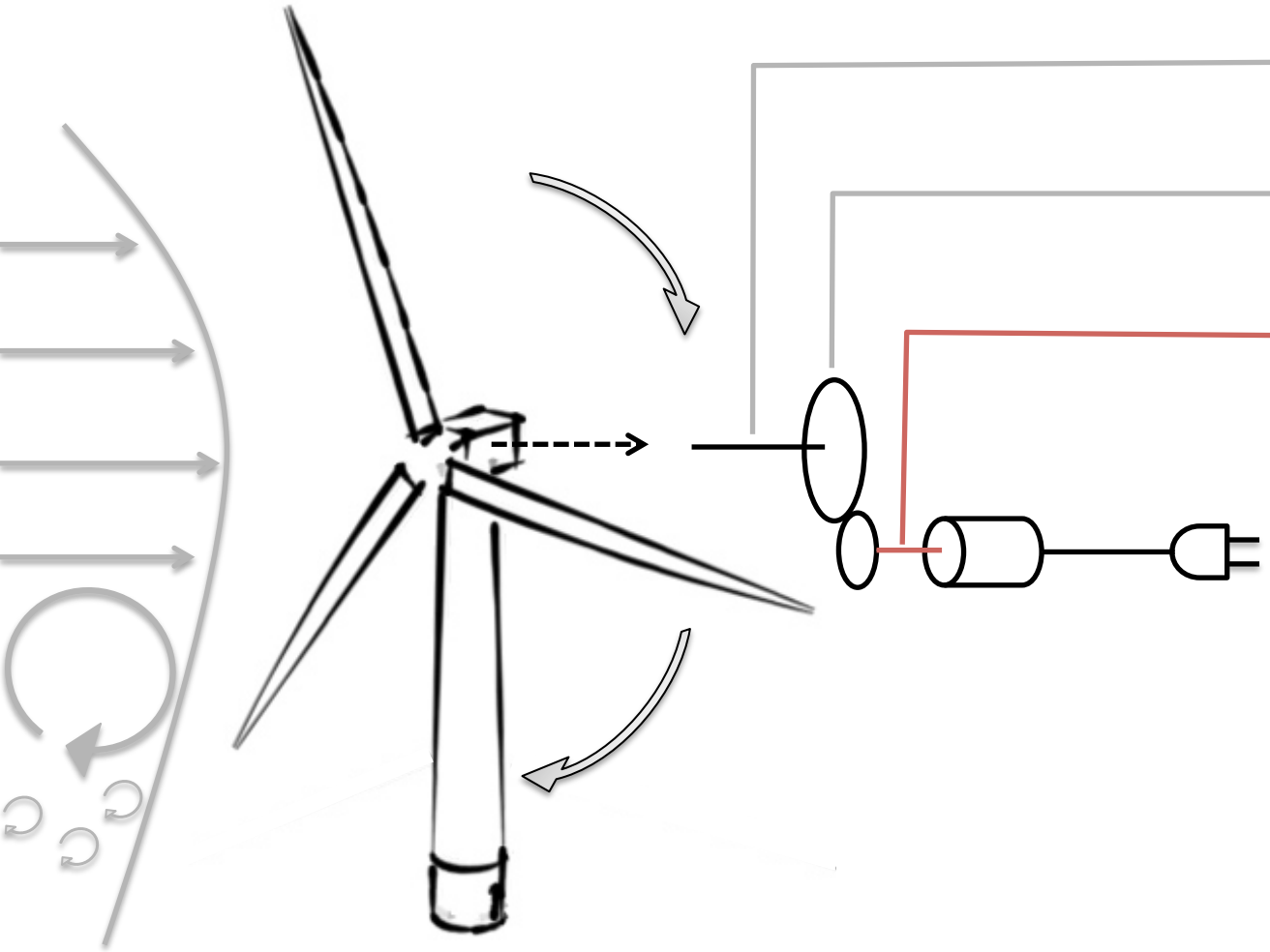

Technology

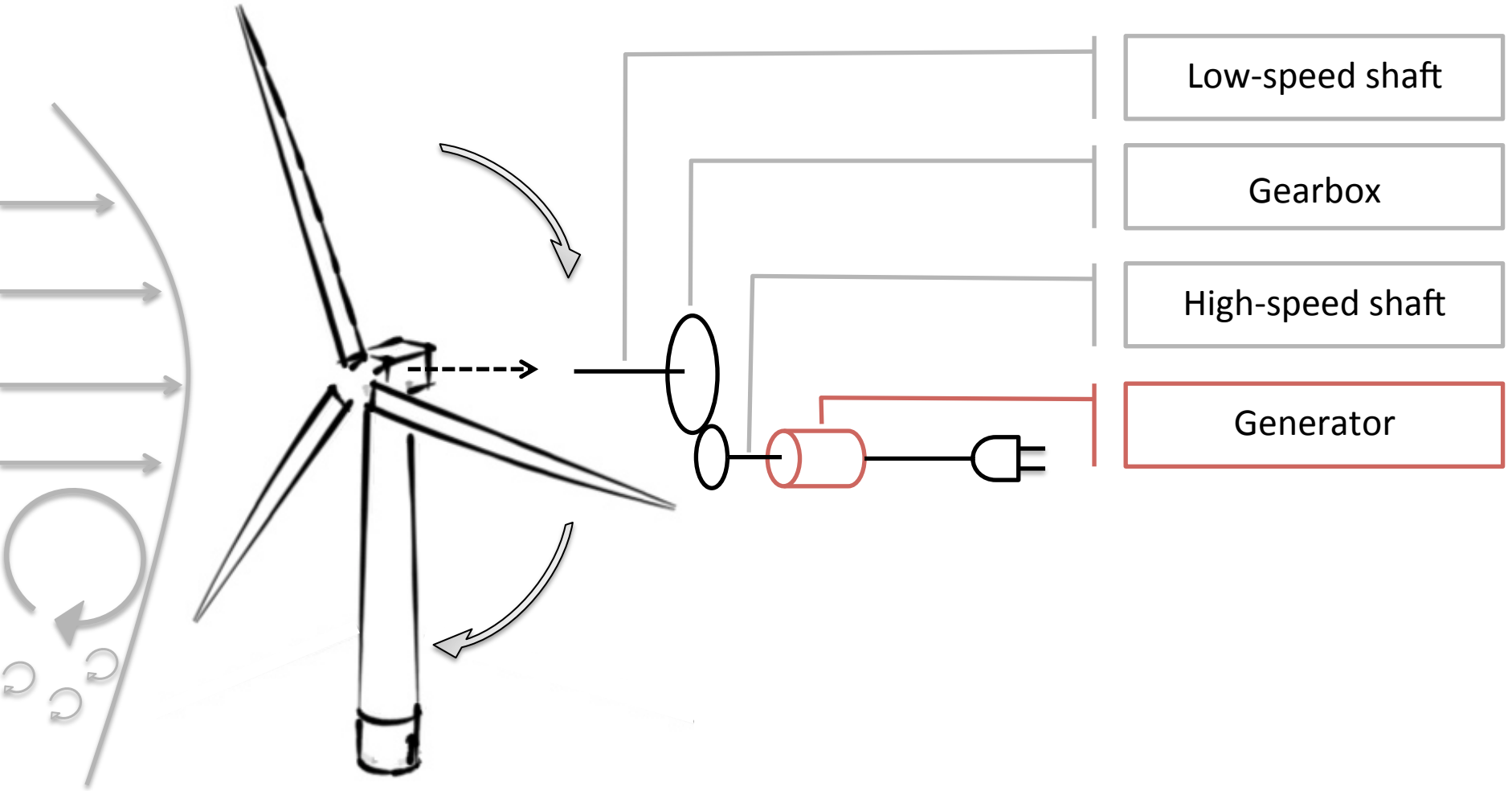

blades
nacelle
tower

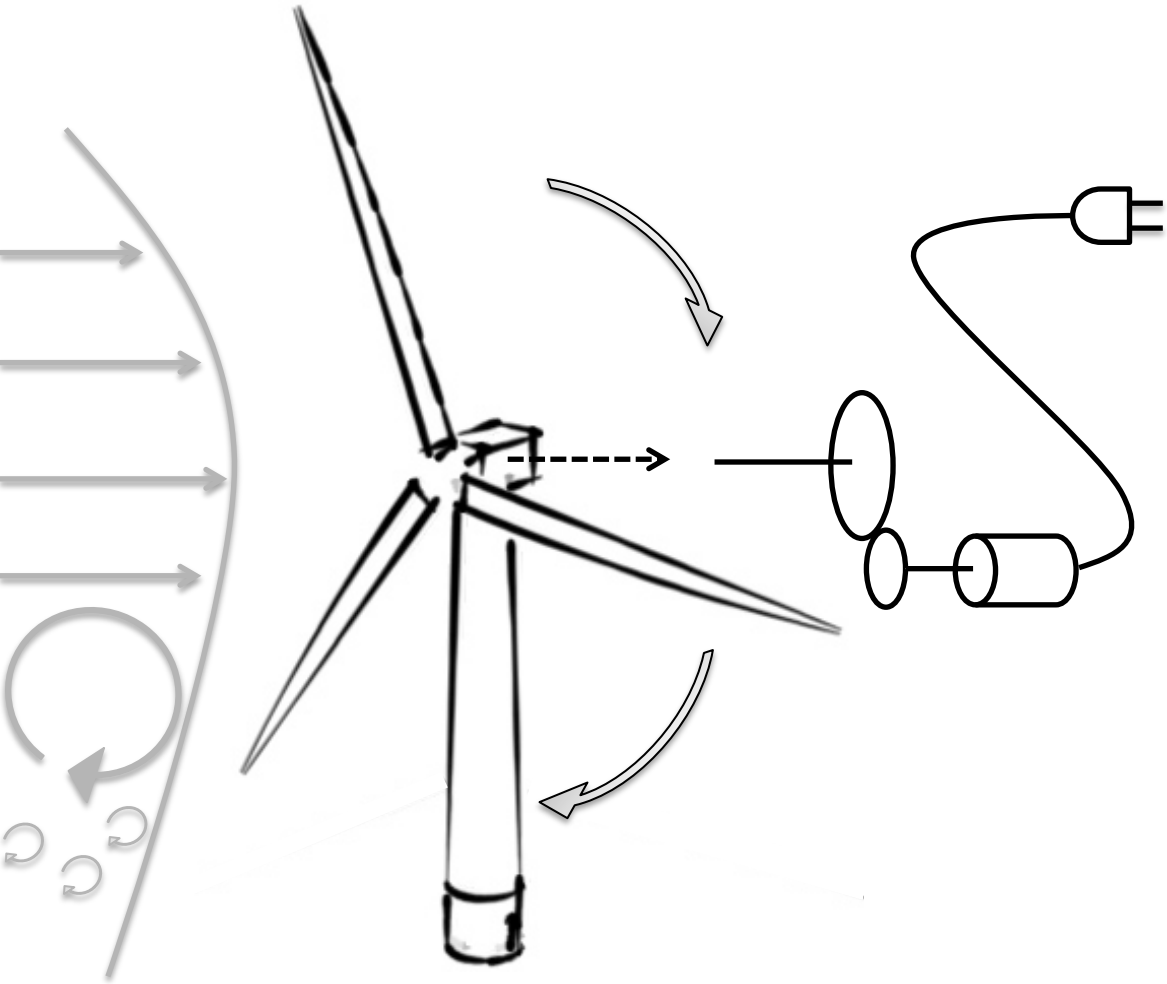



Low-speed shaft


Low-speed shaft
Gearbox


Low-speed shaft
Gearbox
High-speed shaft


Low-speed shaft
Gearbox
High-speed shaft
Generator



$$P_{out} = \frac{1}{2} C_p A \rho v^3$$

P_{out} … electricity output

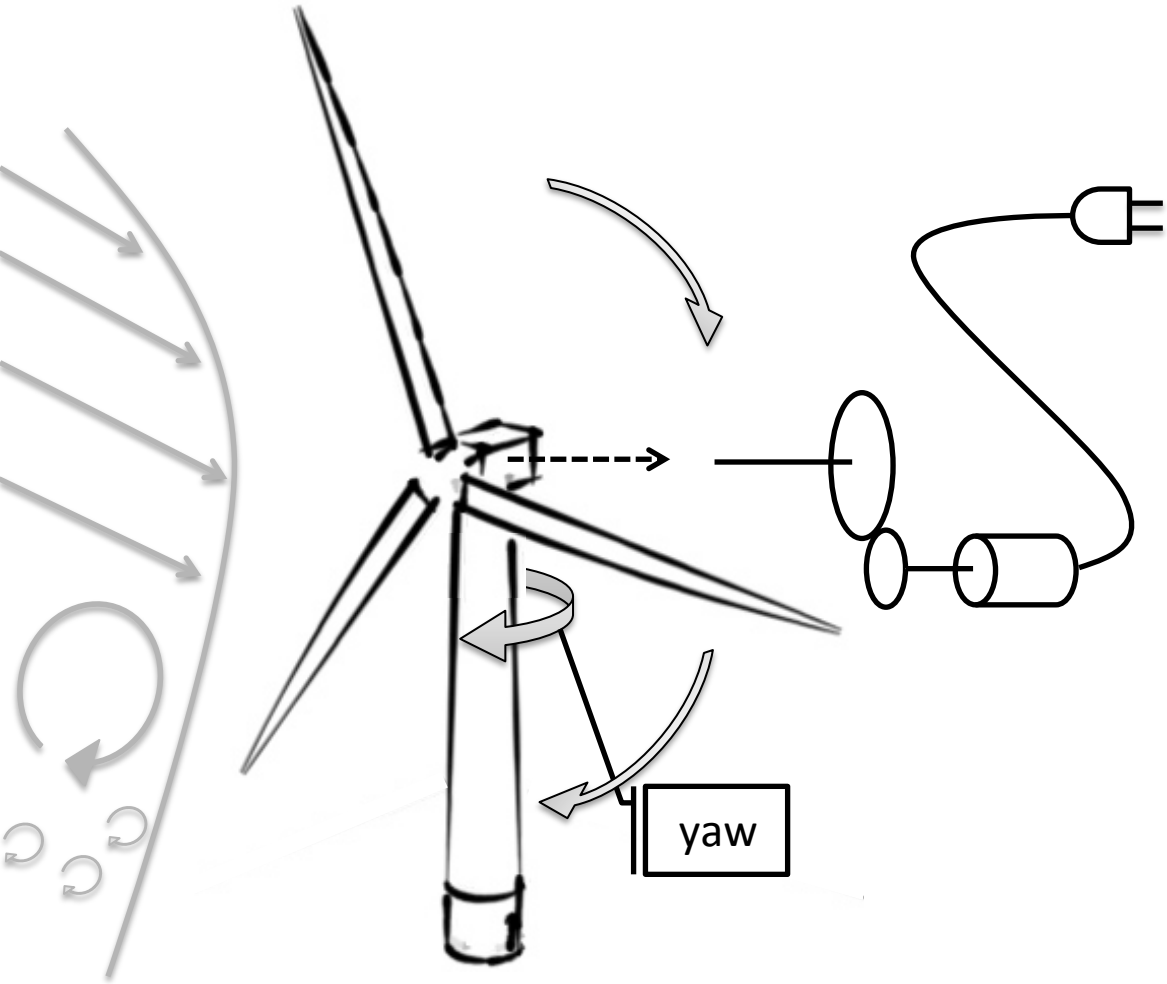
C_p … turbine capacity factor

A … rotor area

ρ … air density

v … wind speed

Betz limit: $C_p = 0.59$



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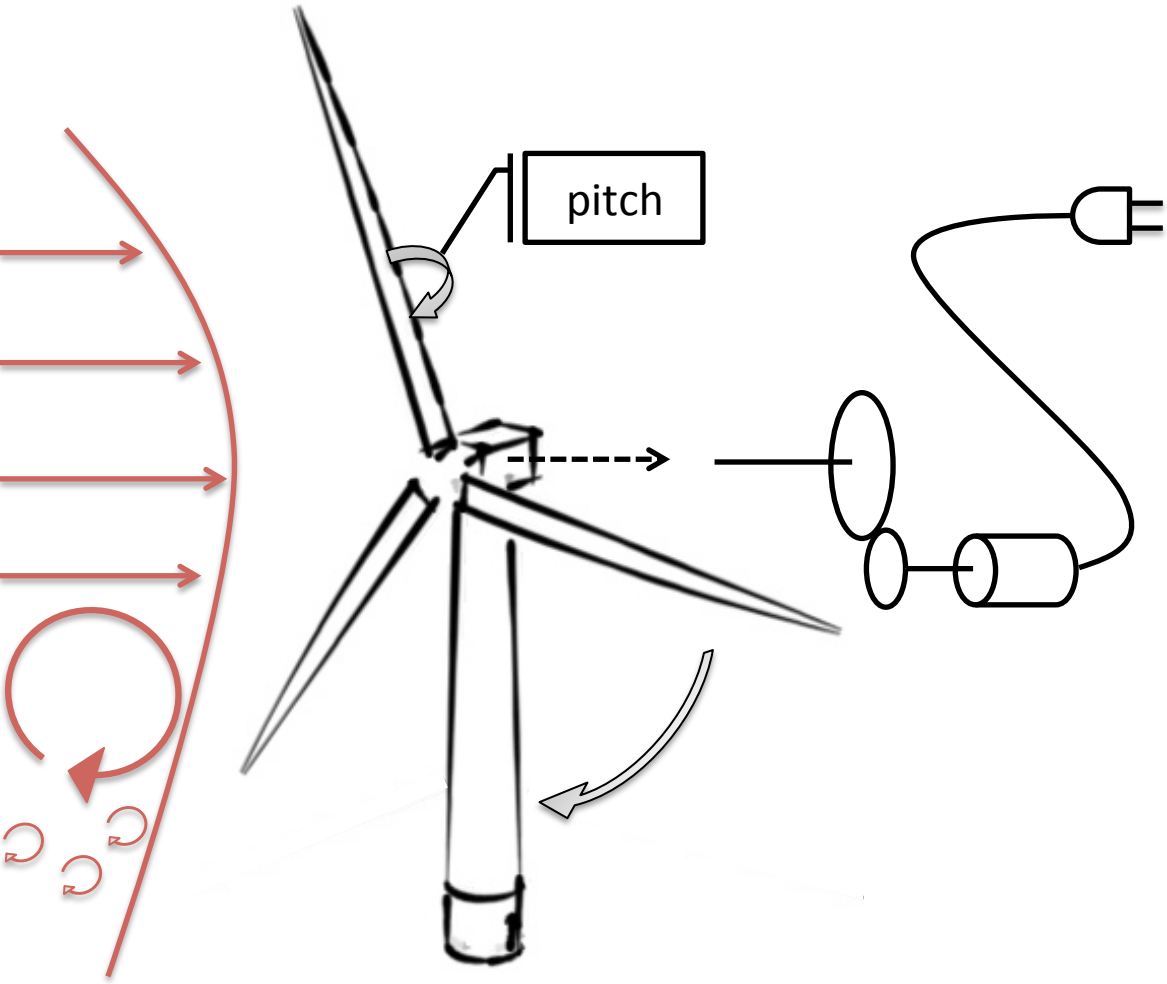

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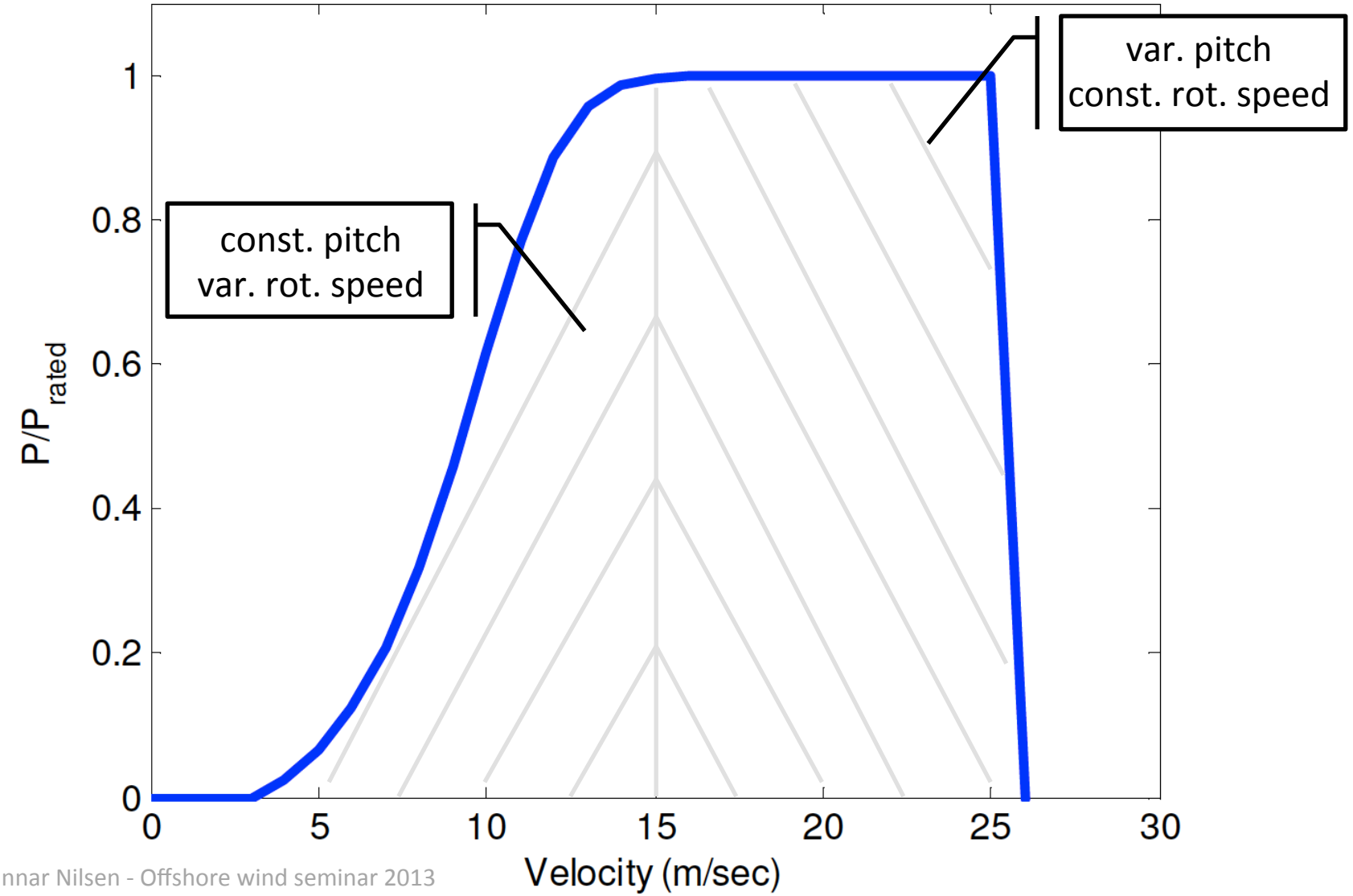
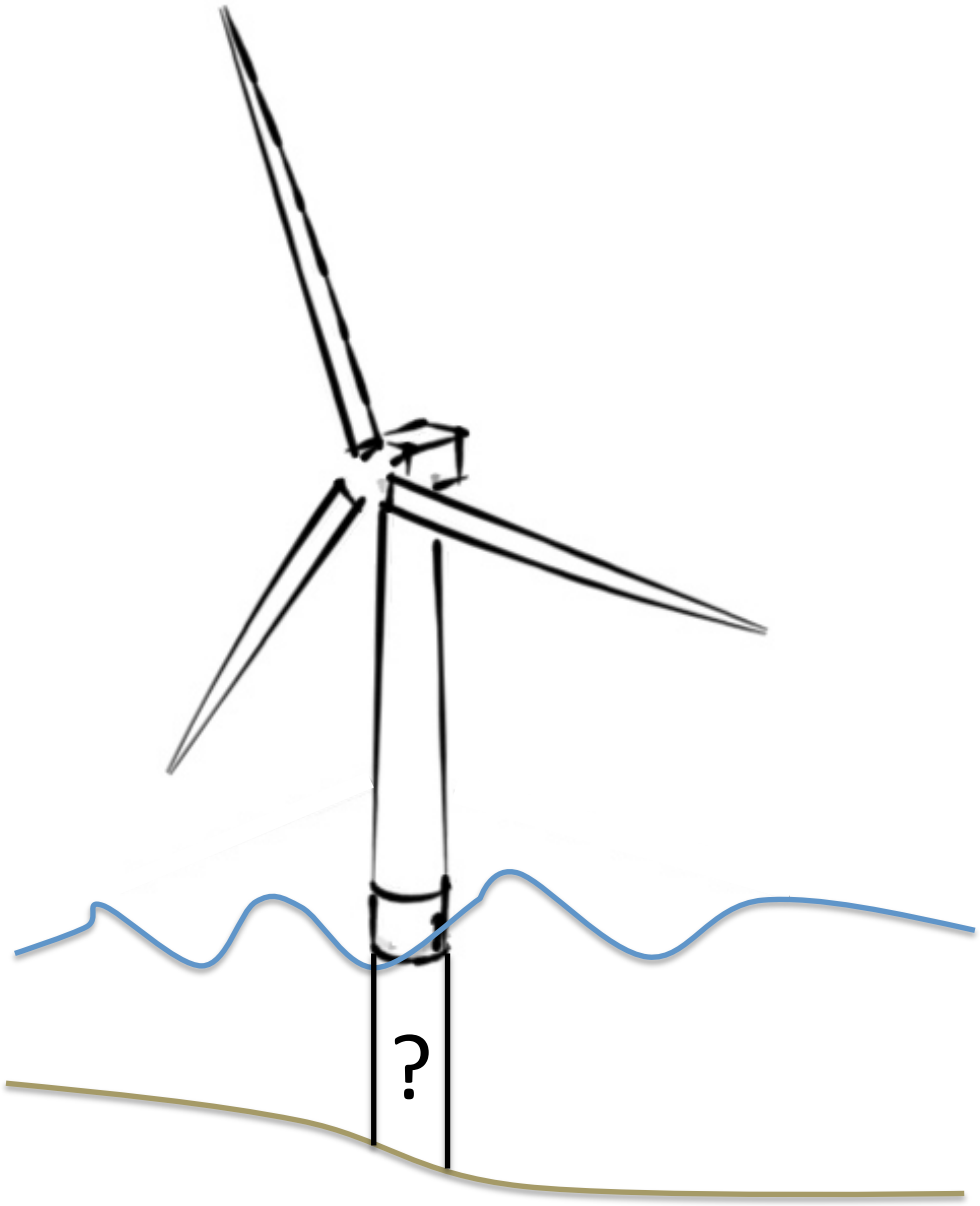
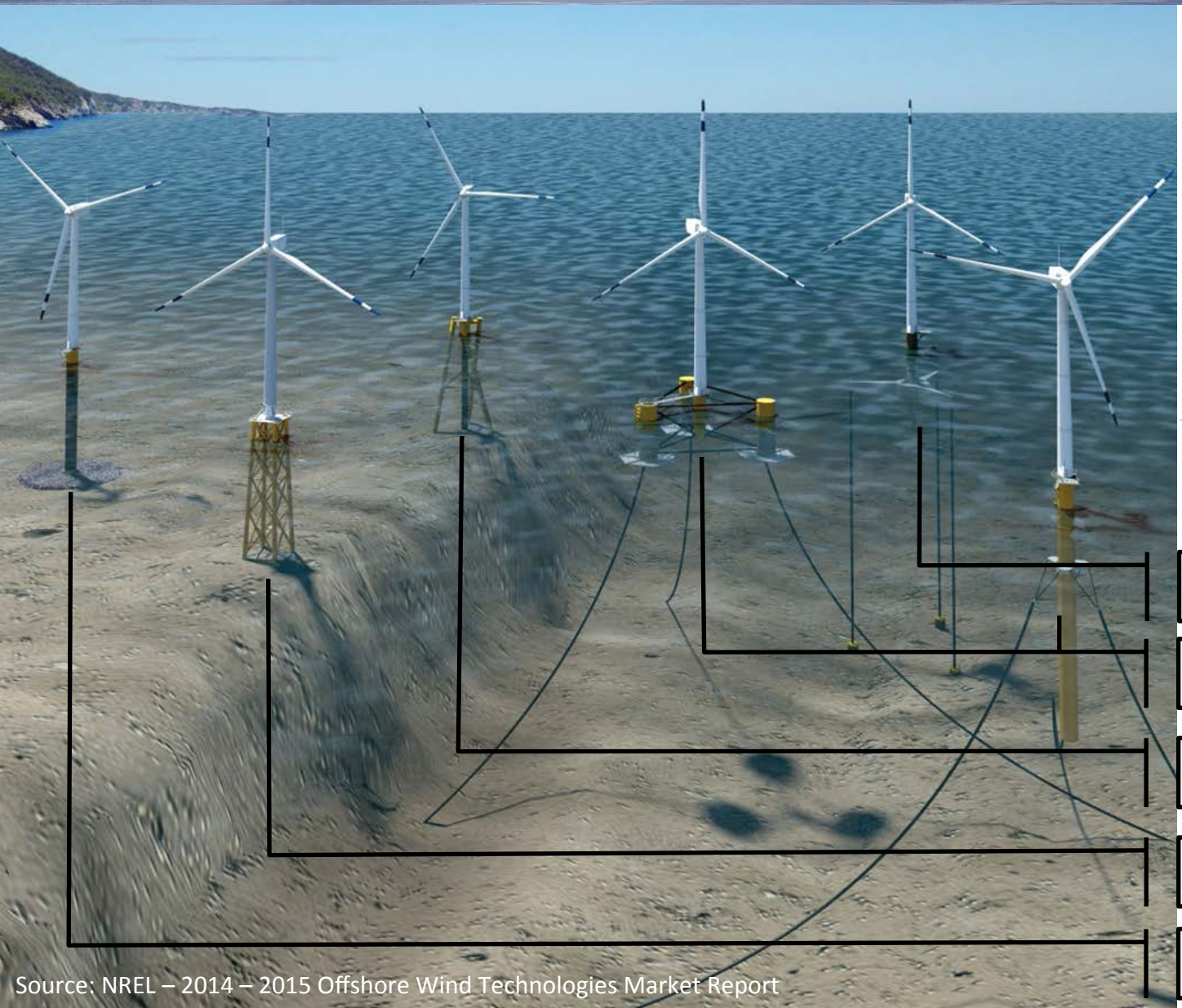
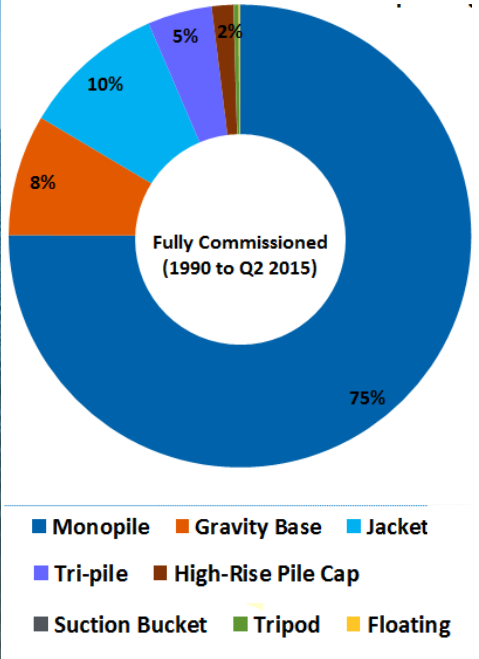


Source: Finn Gunnar Nilsen - Offshore wind seminar 2013







60 m < Tripod

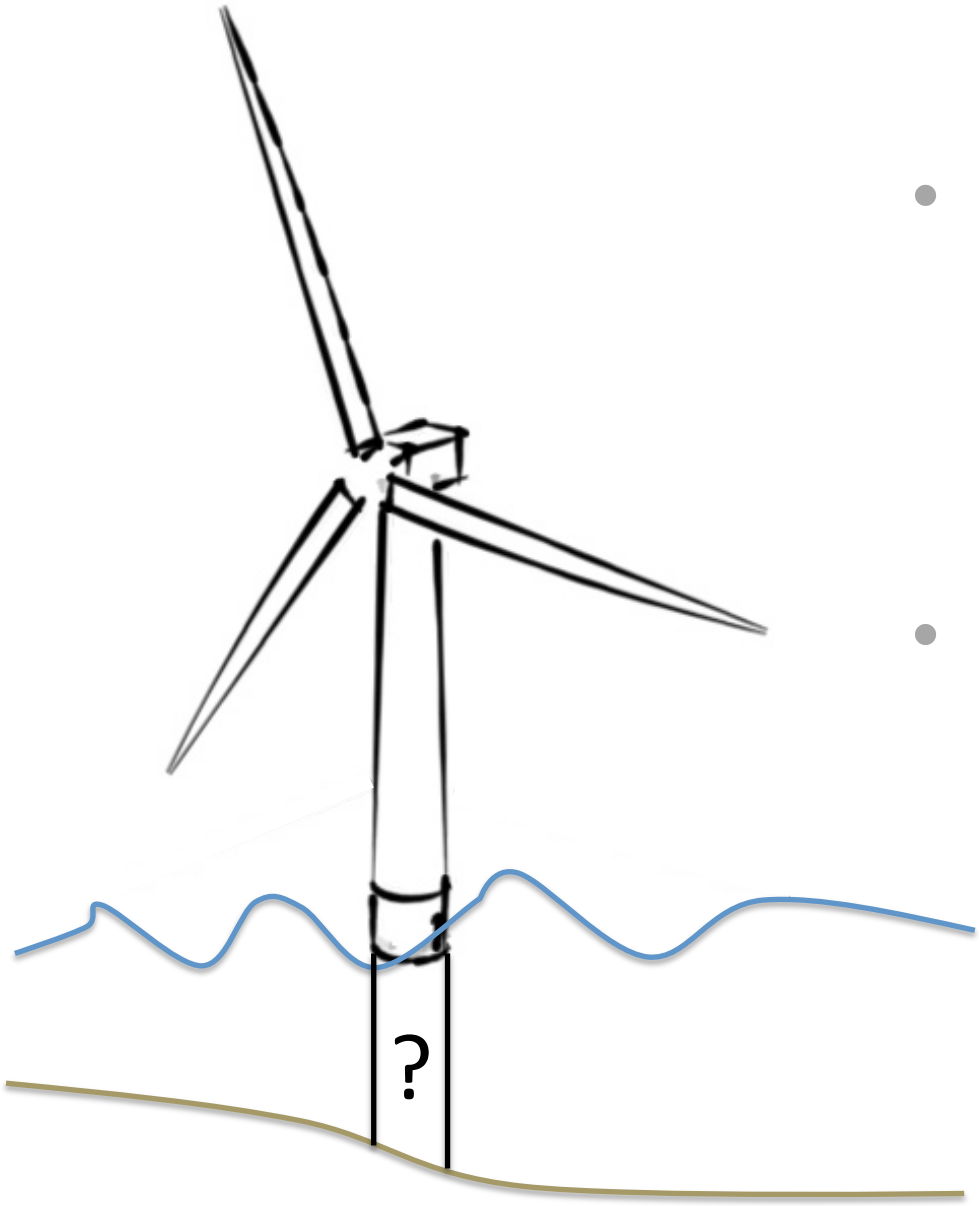
60 m < Floater

30m < Tri-pile < 60 m

30 m < Jacket < 60 m

Monopile < 40 m

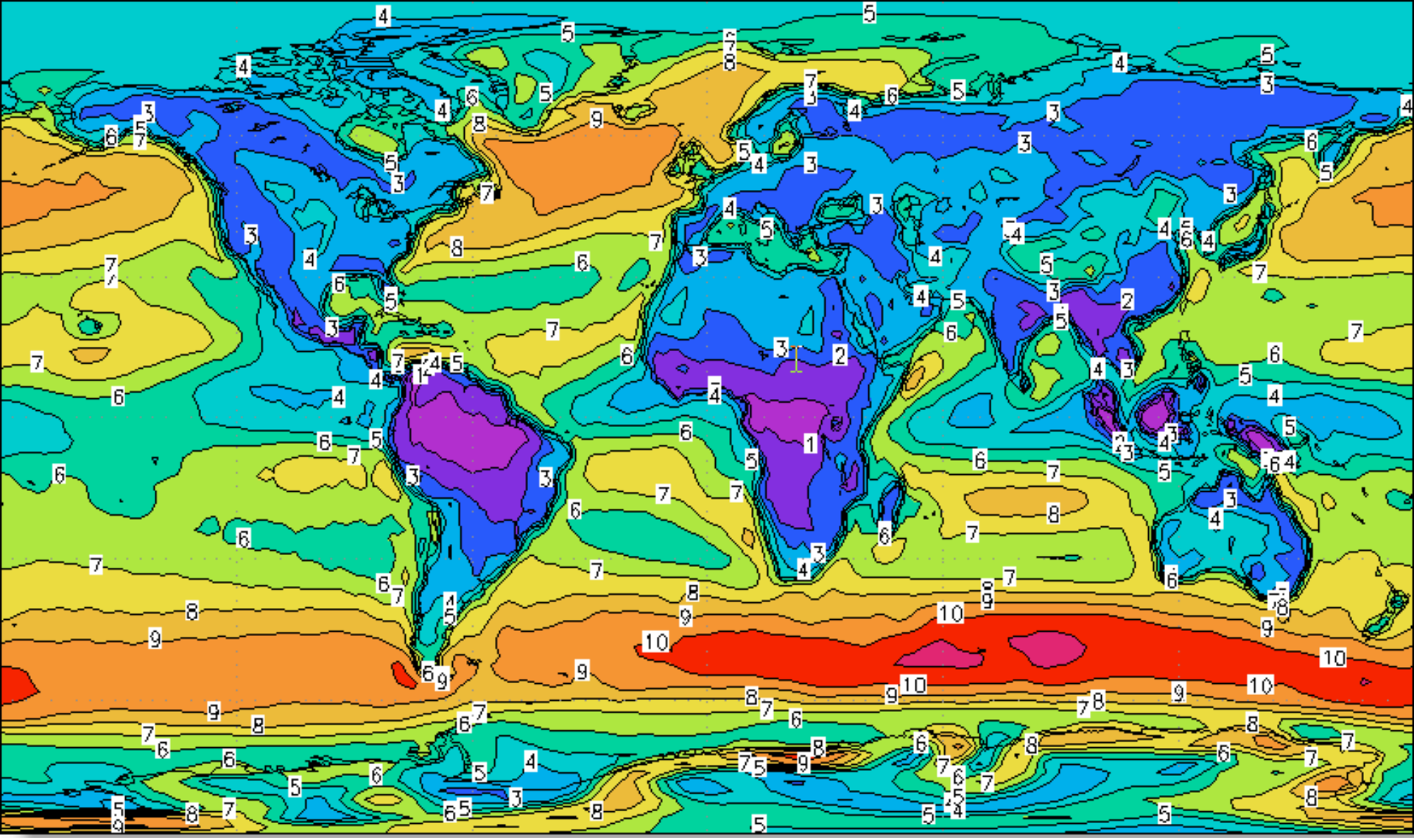
Source: NREL – 2014 – 2015 Offshore Wind Technologies Market Report



- Wind power generation depends on ?
  - Wind speed
  - Rotor diameter
- Substructure type depends on?
  - Water depth

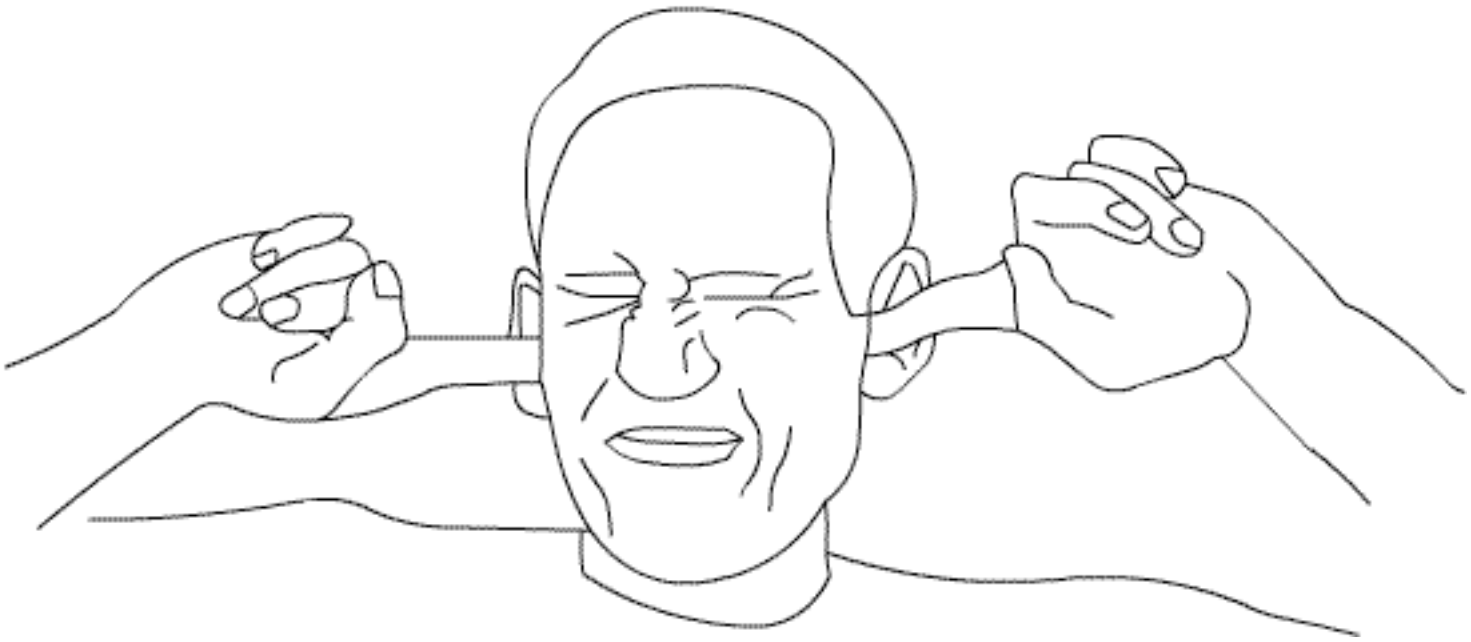

Facts

- Why offshore ?
  - 2 key factors
- Where are we now ?
  - Installed capacity
- Where are we going ?
  - Announced projects



Average wind speed at 10 m between 1976 and 1995 from NCEP

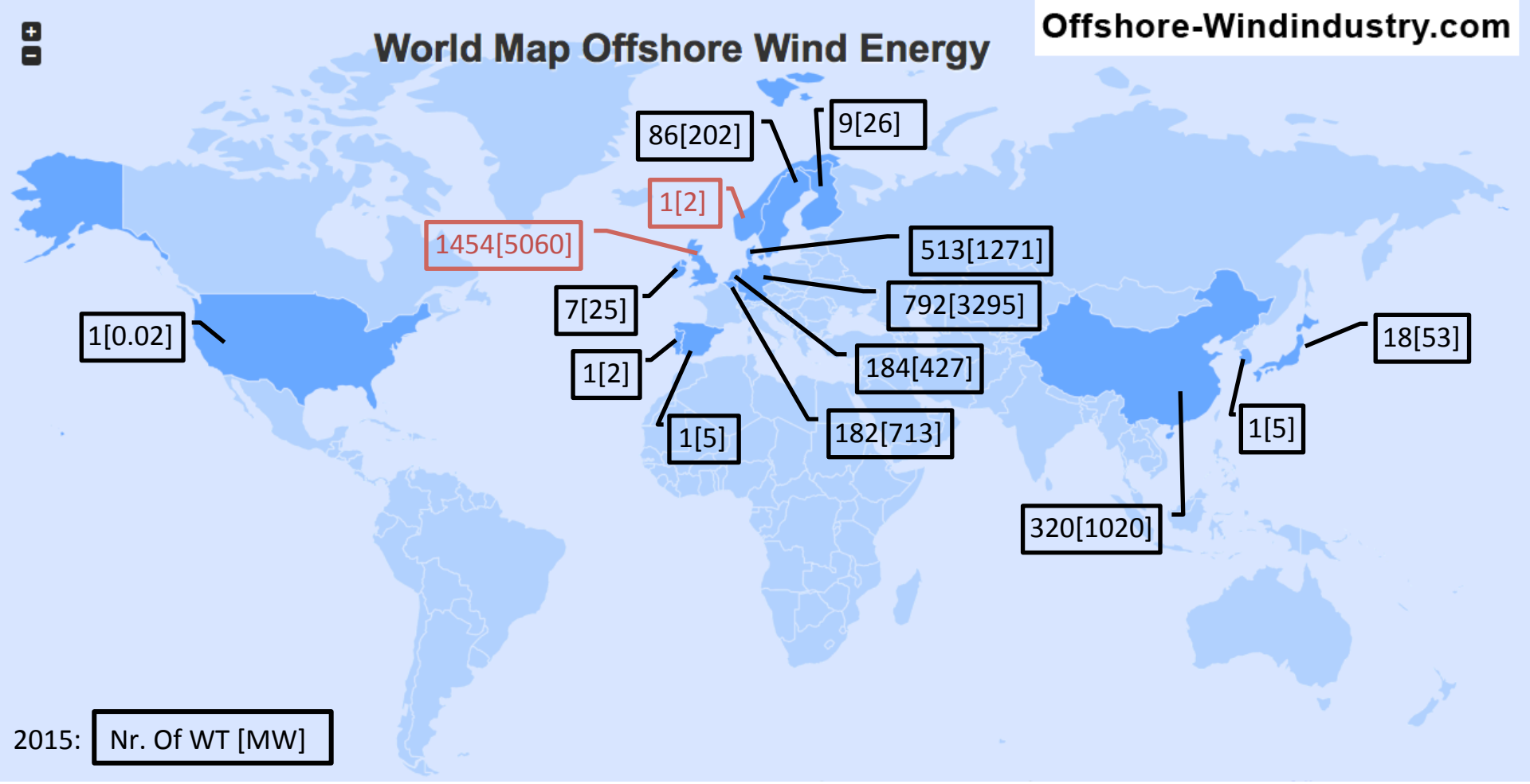
Source: http://www.wasp.dk/DataandTools#wind-atlas__world



- Onshore noise limitation
- small increase in tip speed => large difference in noise level
- Noise limitation = rotor size limitation

$$\lambda = \frac{\Omega R}{U}$$

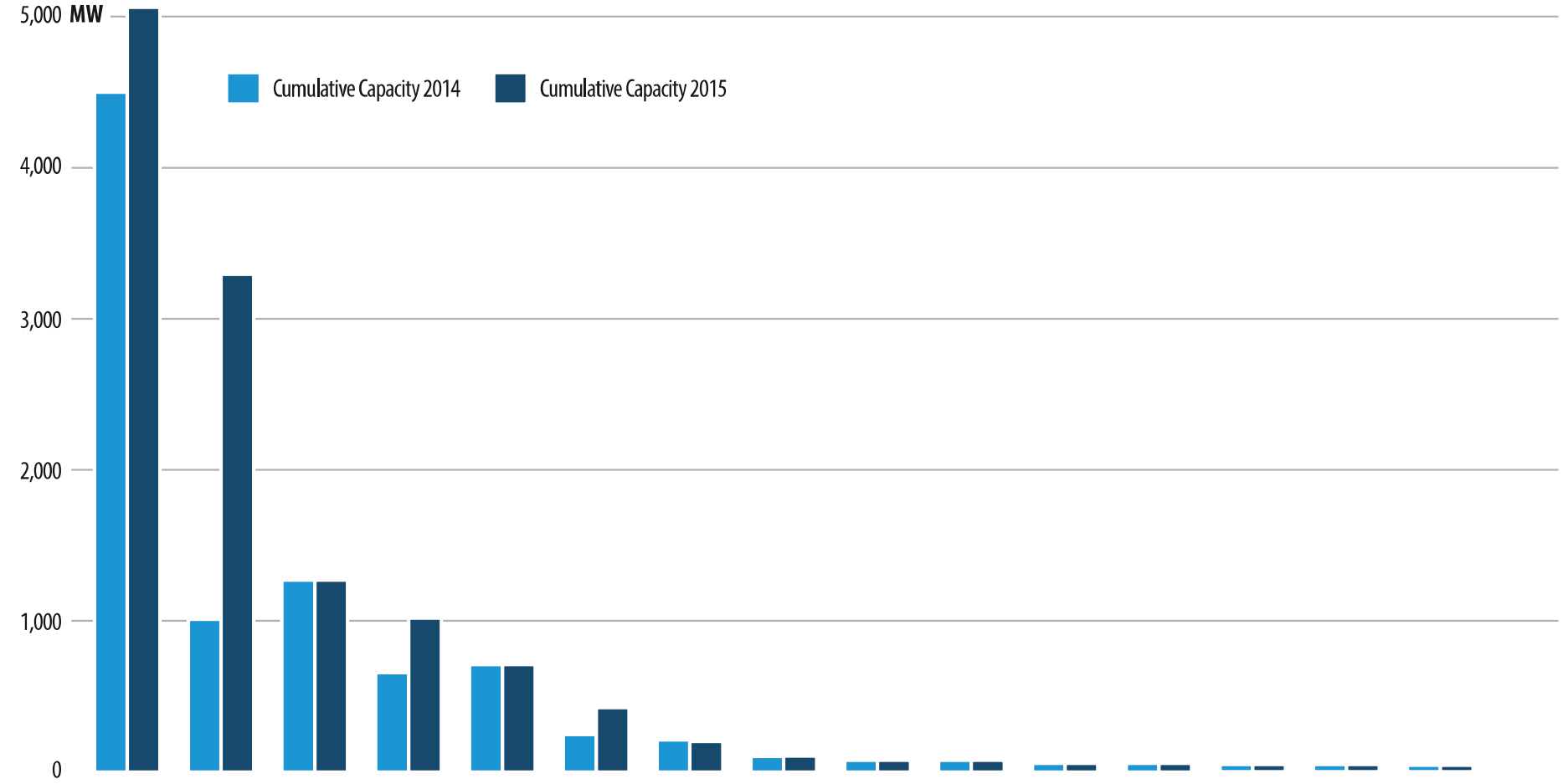
λ … tip speed ratio
Ω … rotor rotation speed
R … rotor radius
U … wind speed



- Global cumulative offshore capacity 2015:

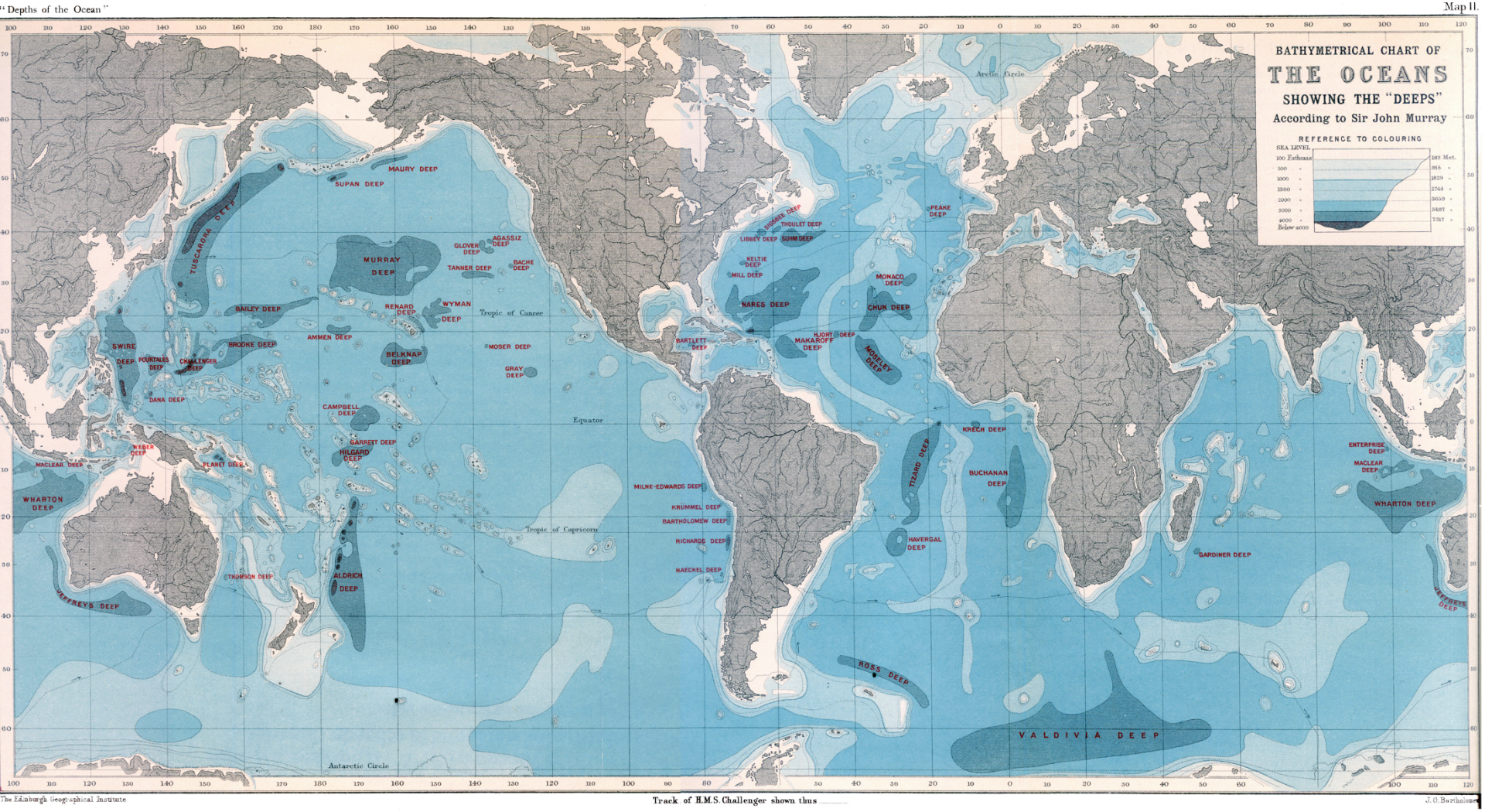
  12.107 GW

GLOBAL CUMULATIVE OFFSHORE WIND CAPACITY IN 2015



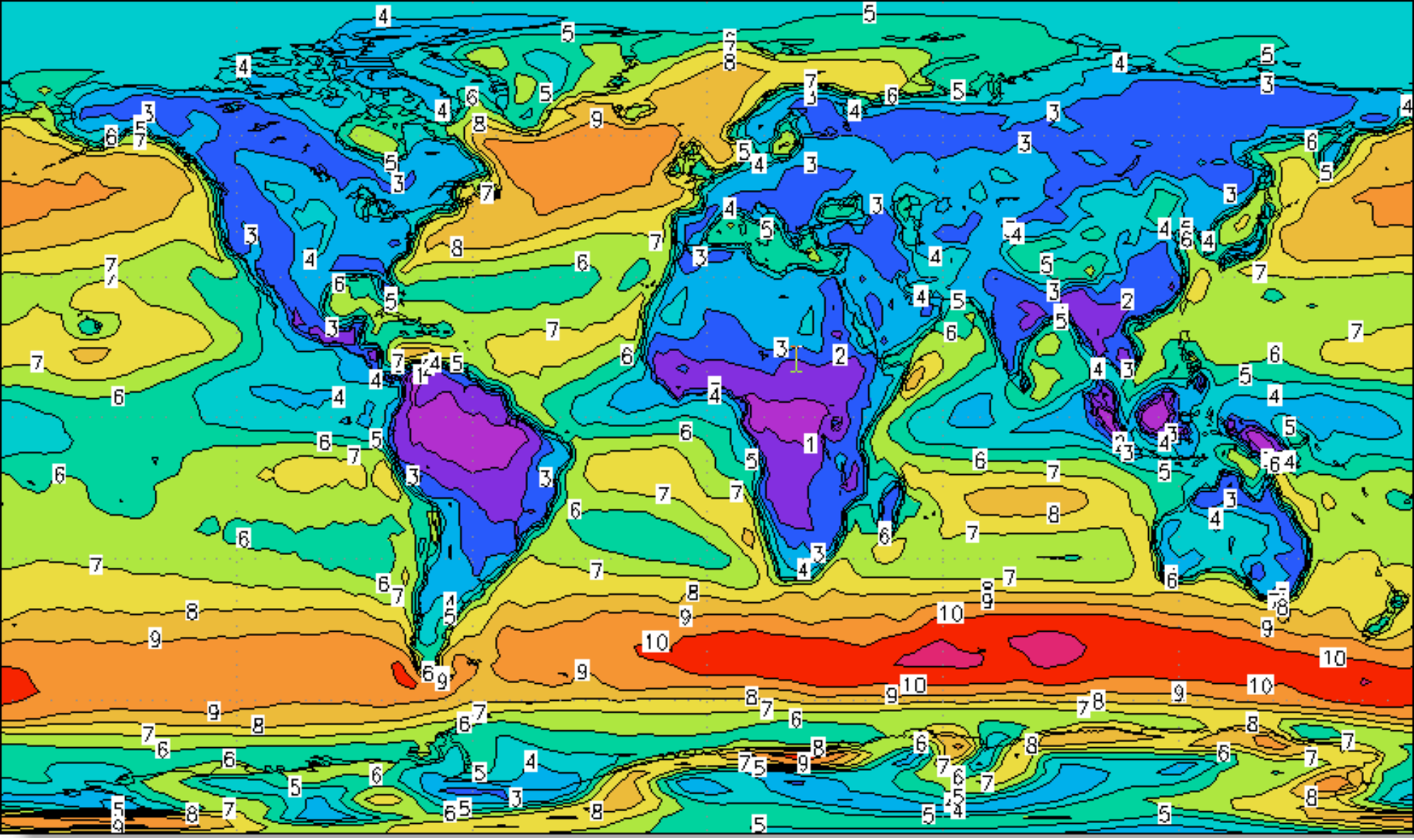
	UK	Germany	Denmark	PR China	Belgium	Netherlands	Sweden	Japan	Finland	Ireland	S Korea	Spain	Norway	Portugal	US	Total
Total 2014	4,500.4	1,012	1,271	654	712	247	212	50	26	25	5	5	2	2	0.02	**8,724**
New 2015	572.1	2,282.4	0	360.5	0	180	0	3	0	0	0	0	0	0	0	**3,398**
Total 2015	5,066.5	3,294.6	1,271.3	1,014.7	712.2	426.8	201.7	53	26.3	25.2	5	5	2.3	2	0.02	**12,107**

Source: GWEC, 2016



Depth of the ocean

Source: nationalgeographic.com

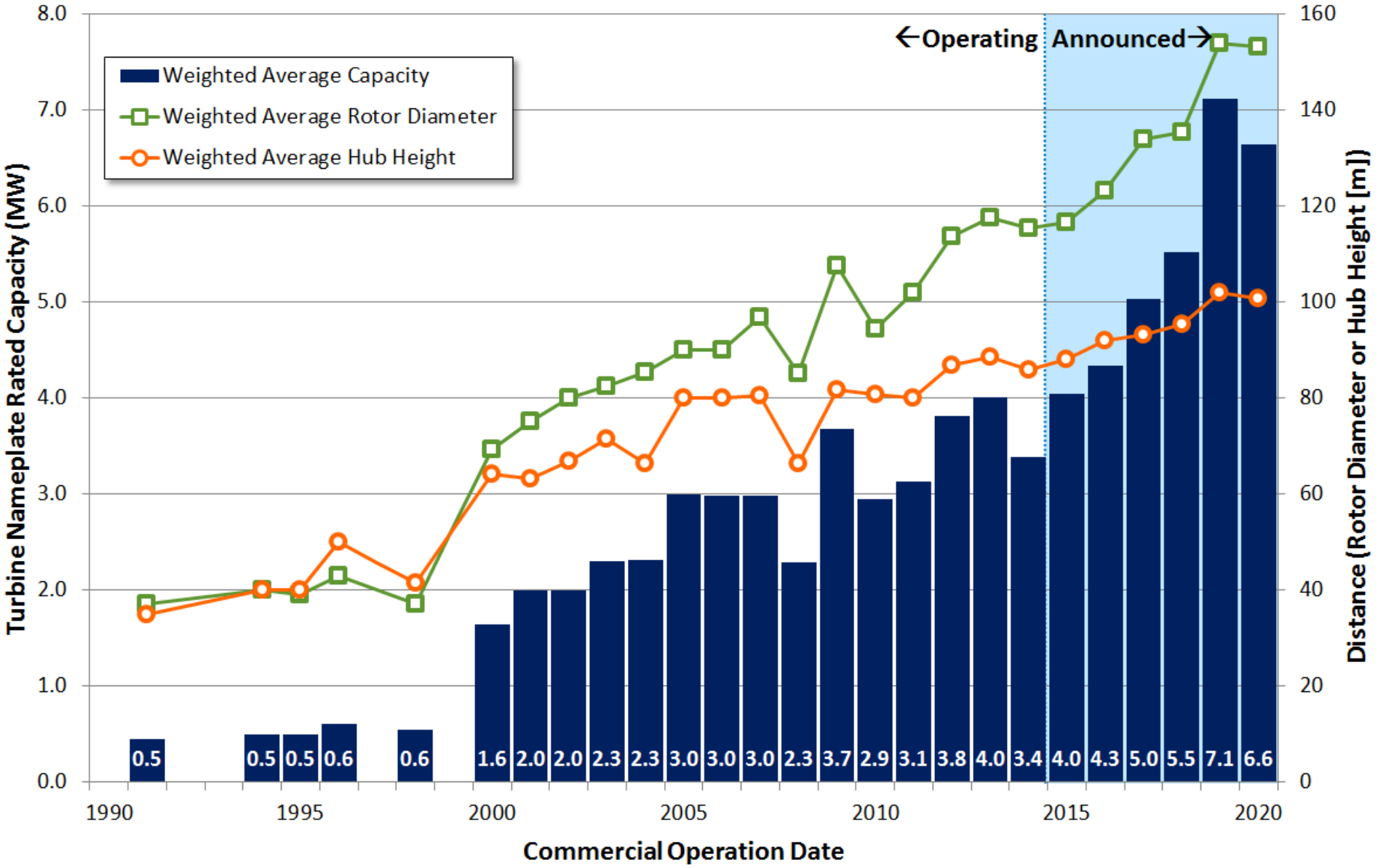


Average wind speed at 10 m between 1976 and 1995 from NCEP

Source: http://www.wasp.dk/DataandTools#wind-atlas__world

45 GW:  **42 Mil.** homes supplied

Source: NREL – 2014 – 2015 Offshore Wind Technologies Market Report



Source: NREL – 2014 – 2015 Offshore Wind Technologies Market Report

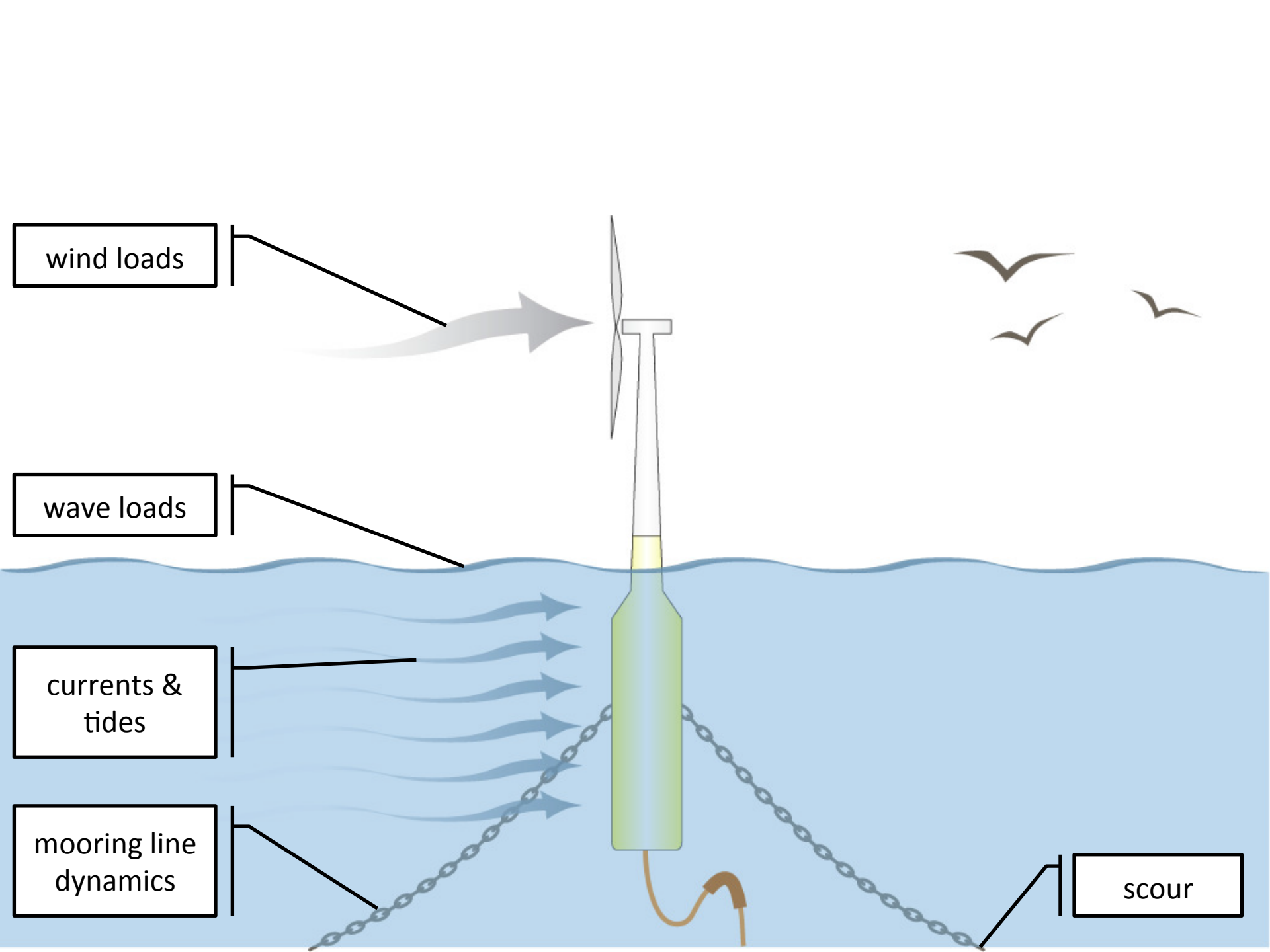
Rotor diameter: 154 m
Turbine capacity: 6 MW

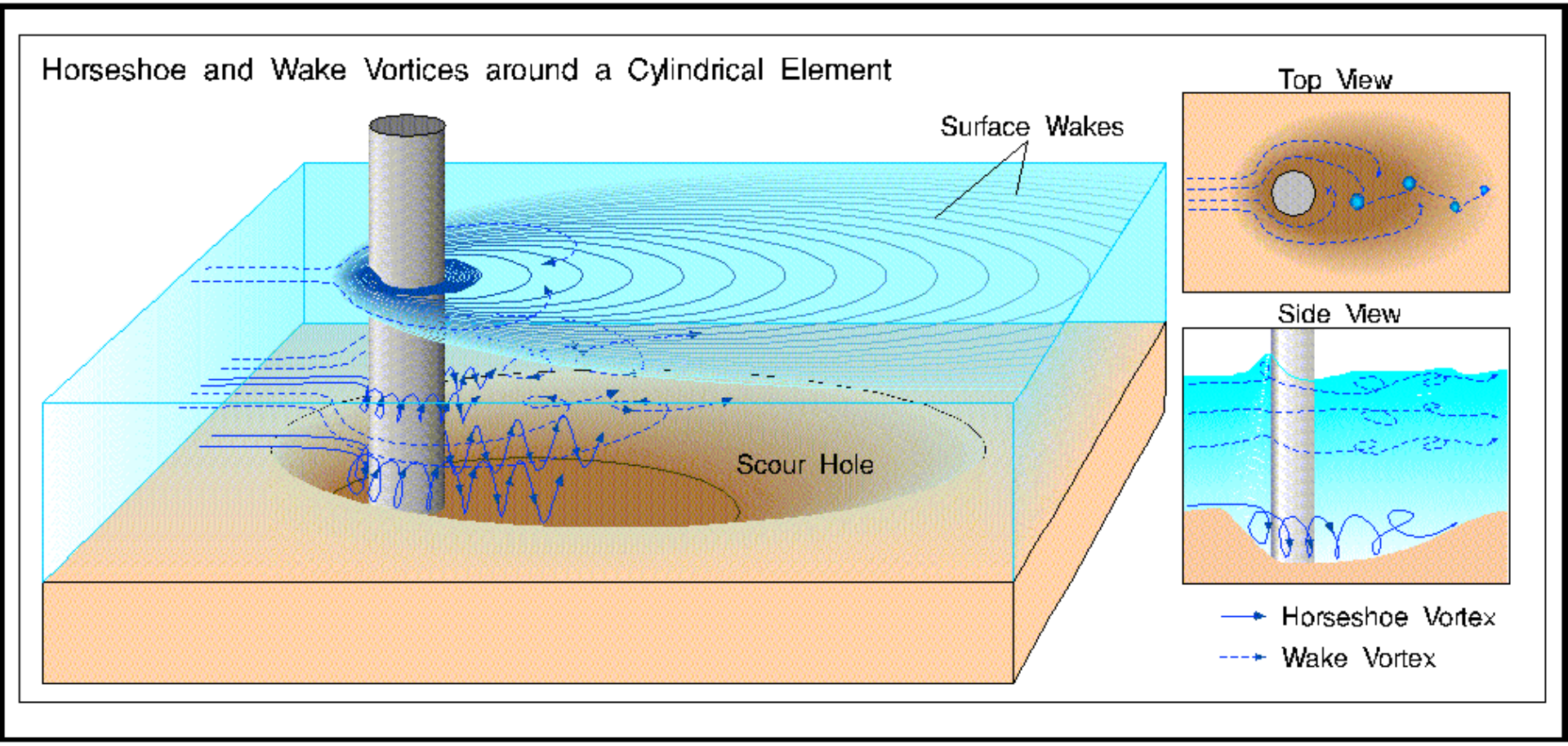
Source: http://www.jeccomposites.com/knowledge/international-composites-news/siemens-build-major-offshore-wind-manufacturing-site-uk

- Why offshore ?
  - Higher wind potential
  - Higher capacity with bigger rotors
- Where are we now ?
  - Global cumulative offshore capacity 2015: 12.107 GW
- Where are we going ?
  - 45.5 GW announce to be operating in 2020 with bigger rotors

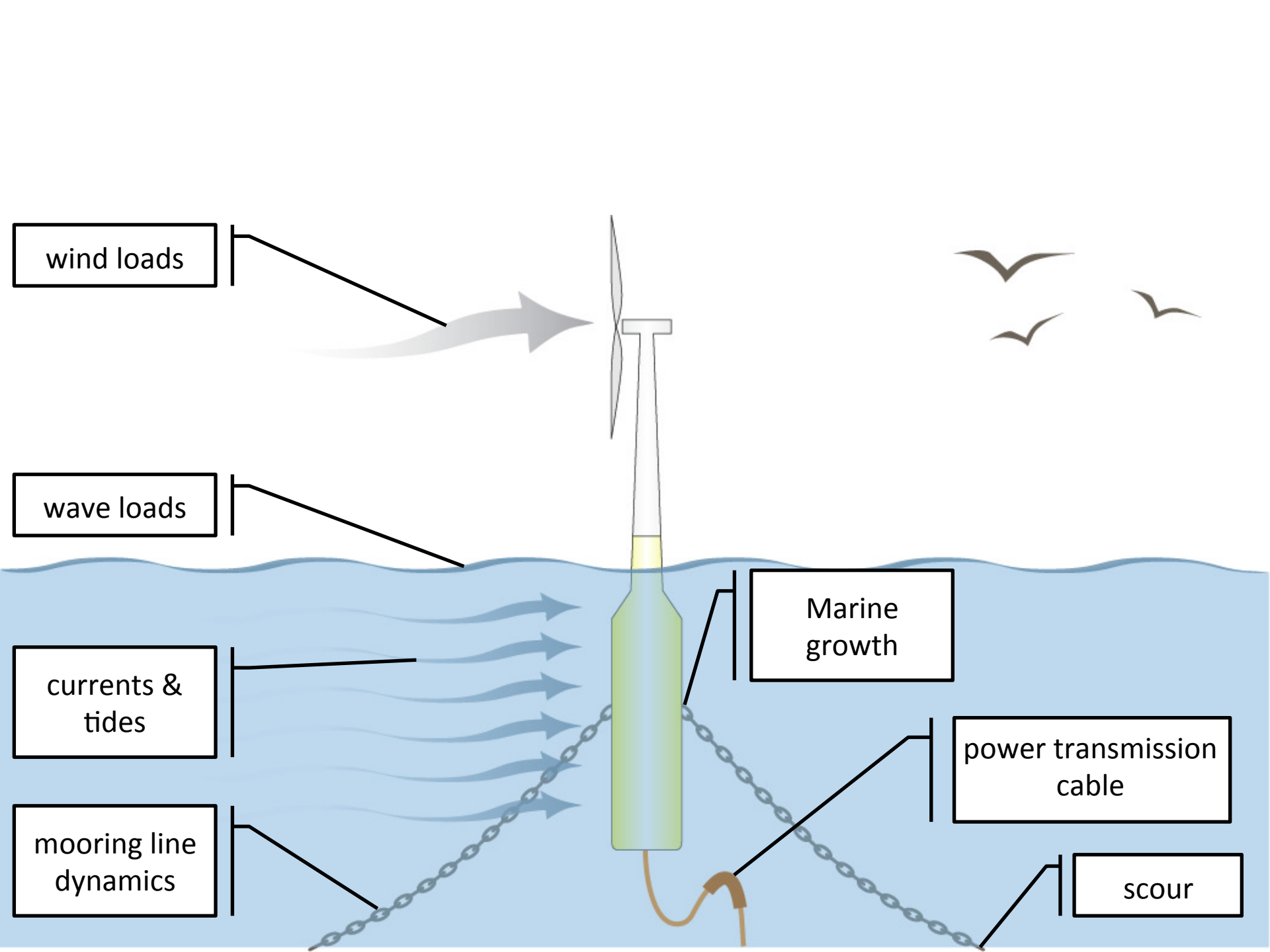

Challenges

- System dynamics
- Environment
- Turbine & Farm Wakes
- Installation, Operation & Maintenance
- Costs of Energy


wind loads
wave loads
currents & tides
mooring line dynamics
scour



Source: http://hmf.enseeiht.fr/travaux/CD1011/bei/beiere/groupe2/node/137

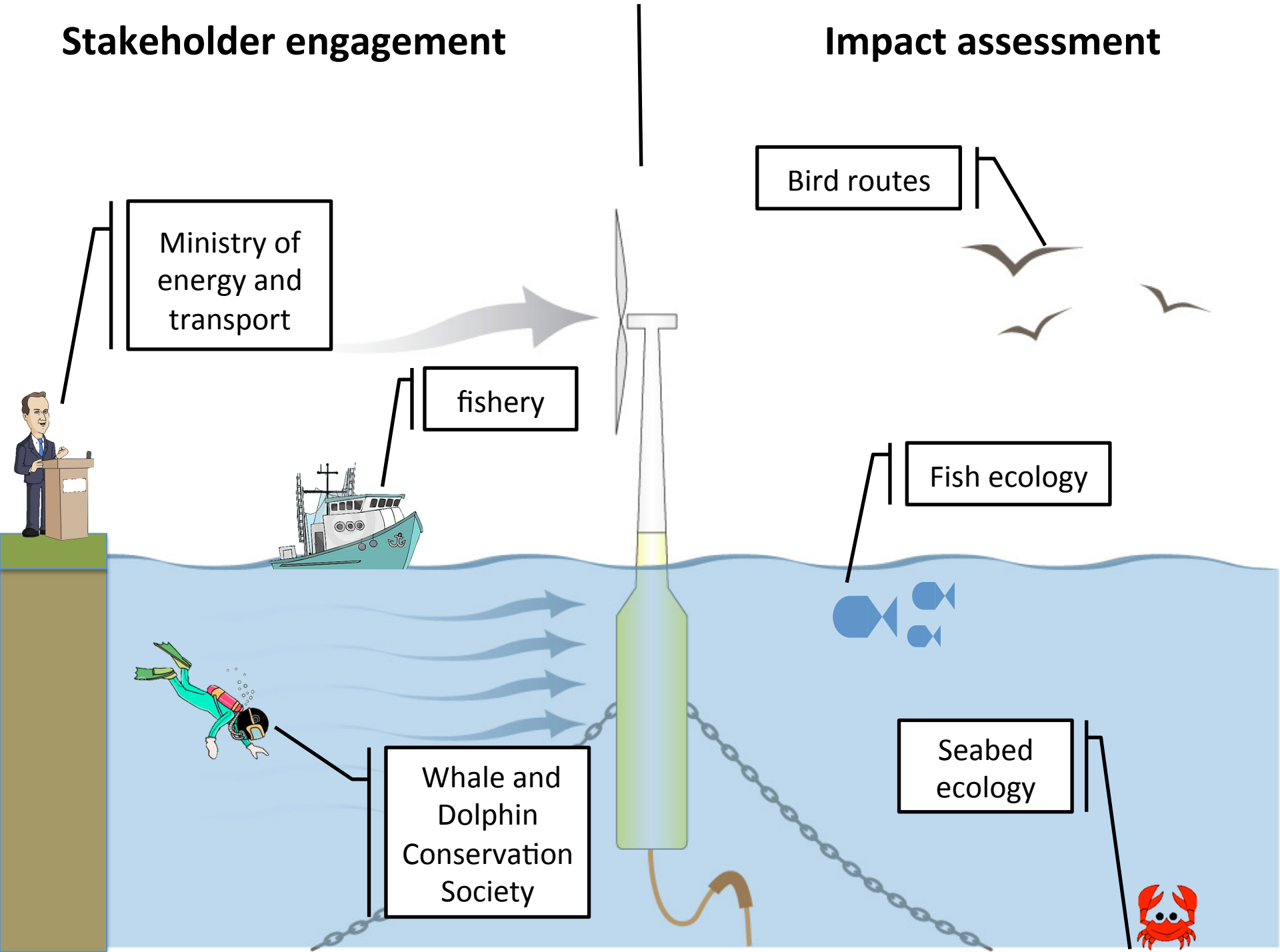

wind loads
wave loads
currents & tides
mooring line dynamics
Marine growth
power transmission cable
scour

Cable damage at British offshore wind farms

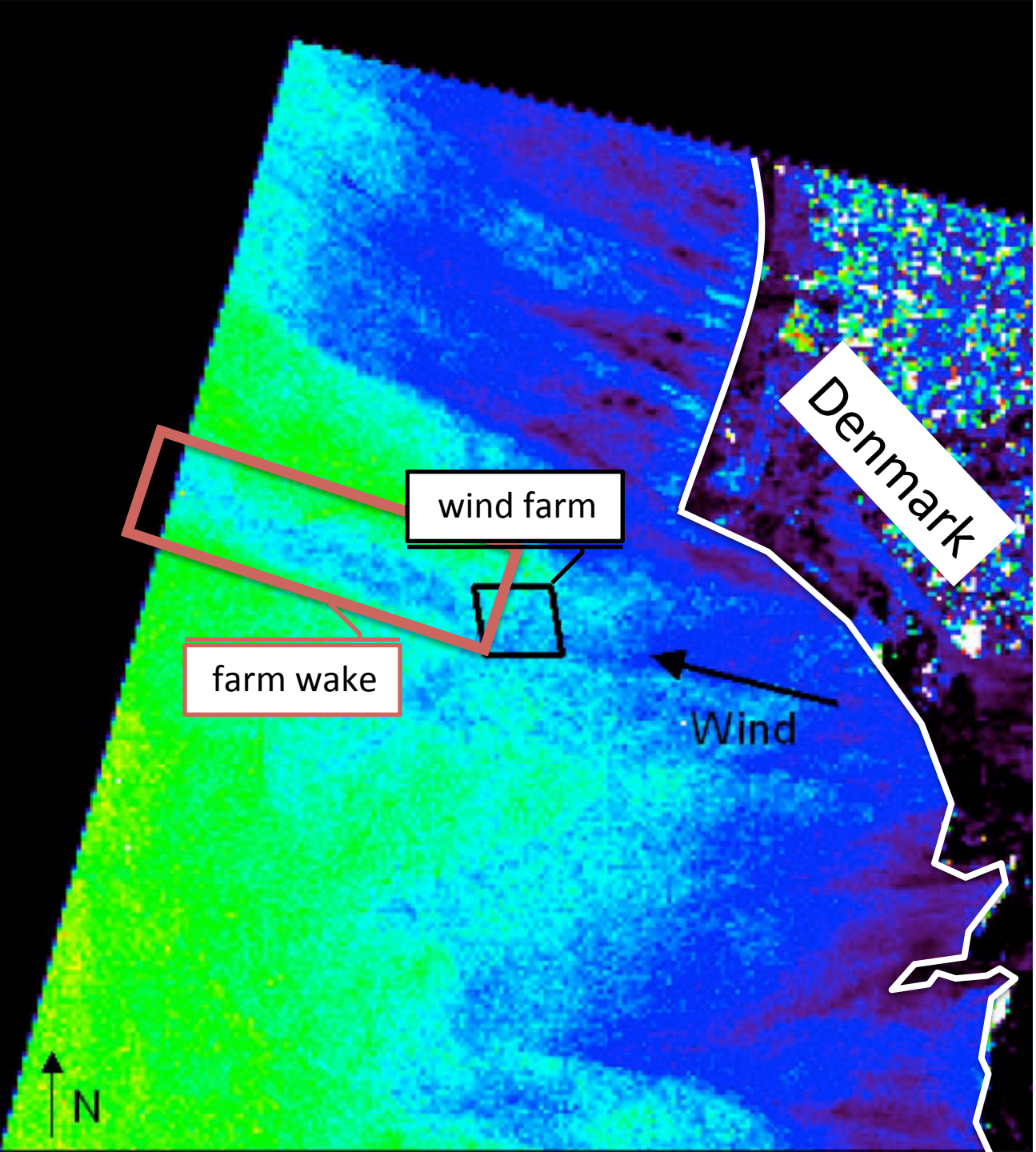
The offshore wind farm London Array has been fighting with problems with its export cables. (Photo: London Array)

Source: http://www.sunwindenergy.com/news/cable-damage-british-offshore-wind-farms

- System dynamics
- Environment


Stakeholder engagement
Impact assessment
Bird routes
Ministry of energy and transport
fishery
Fish ecology
Whale and Dolphin Conservation Society
Seabed ecology

- System dynamics
- Environment
- Turbine & Farm Wakes



Satellite image of surface wind speed

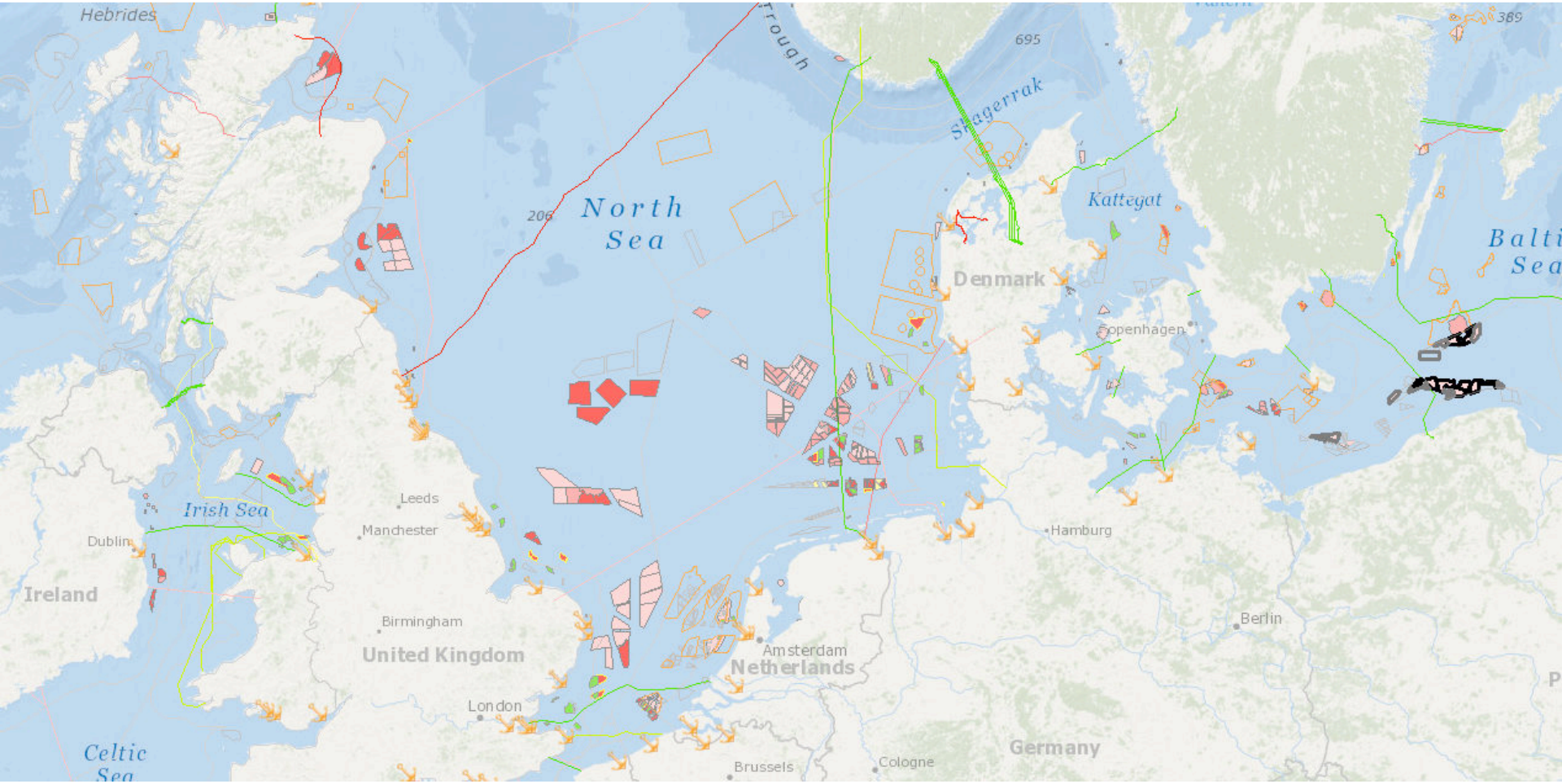
Low wind speed

high wind speed

land

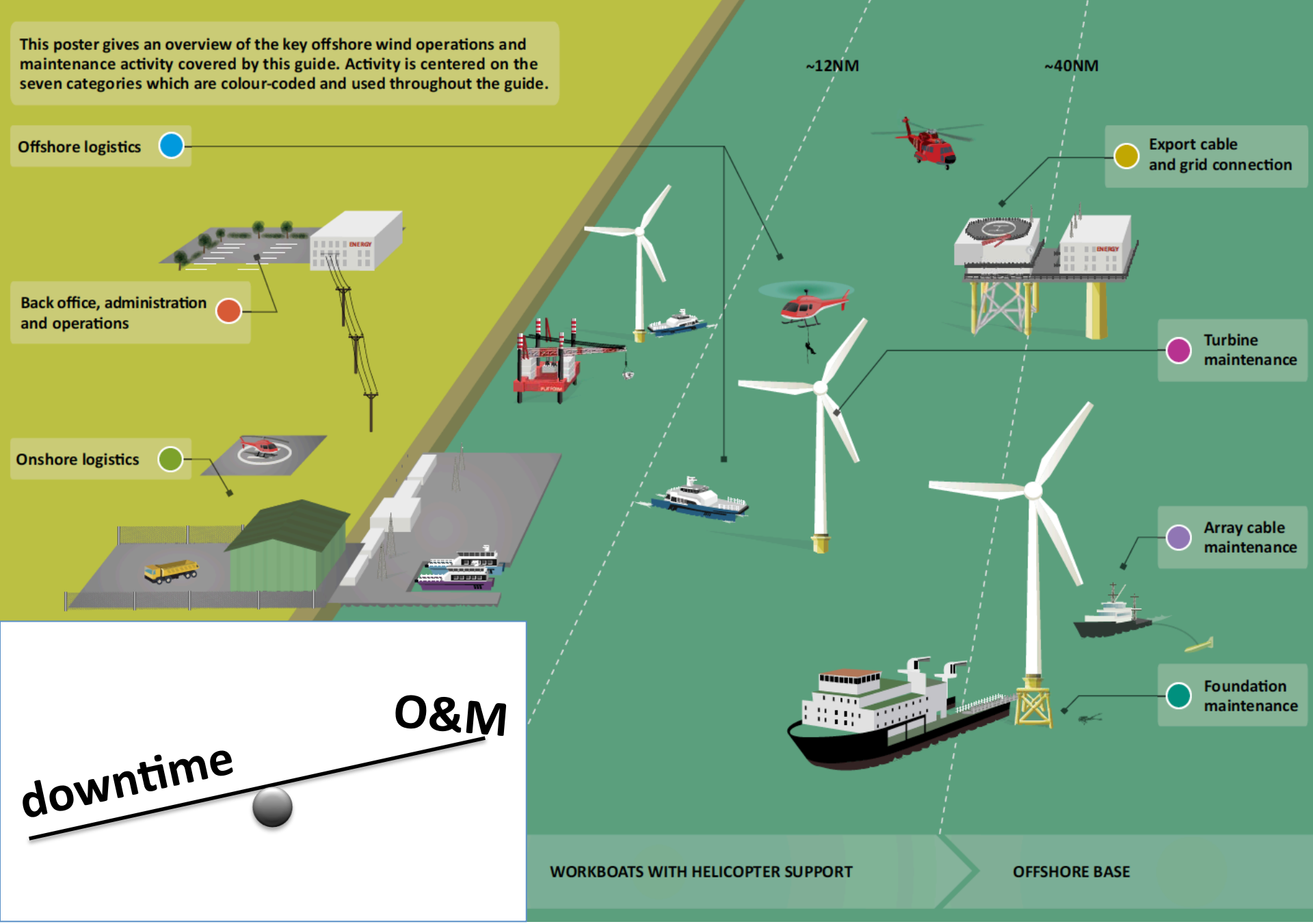
Source: http://galathea3.emu.dk/satelliteeye/projekter/wind/back_uk.html

Wind farm wakes in site assessment



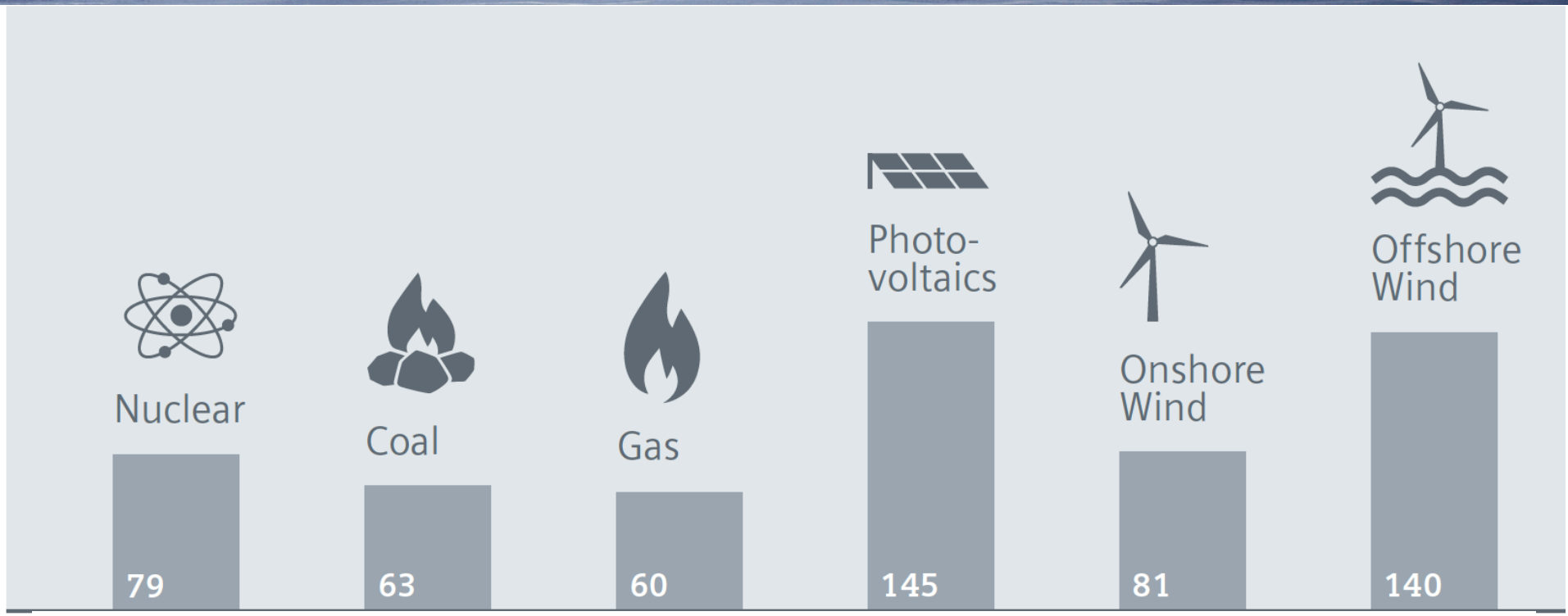
Source: http://www.4coffshore.com/offshorewind/

- System dynamics
- Environment
- Turbine & Farm Wakes
- Installation, Operation & Maintenance



Source: Scottish Enterprise - Guide to Offshore Wind Report

- System dynamics
- Environment
- Turbine & Farm Wakes
- Installation, Operation & Maintenance
- Costs of Energy

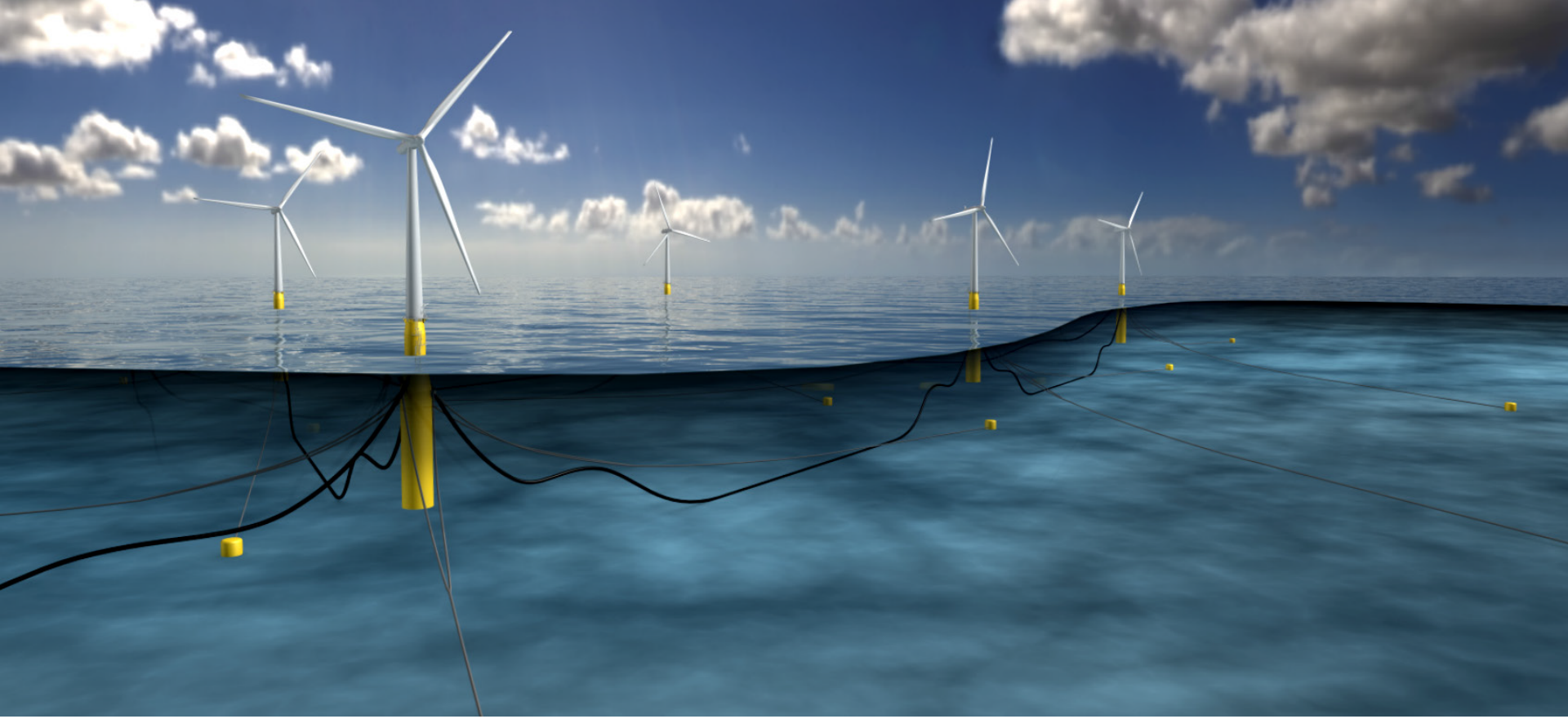


Levelized cost of energy (LCOE) for all primary energy sources in UK for 2013 in €/MWh

$$LCOE = \frac{\text{Total costs over lifetime}}{\text{Electricity produced over lifetime}}$$

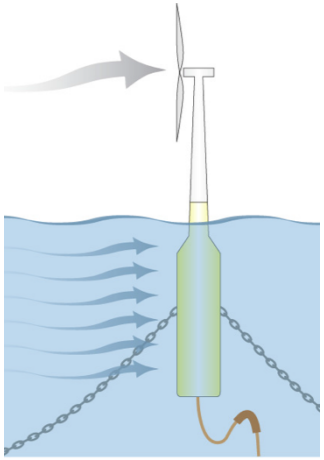
Source: http://www.energy.siemens.com/br/pool/hq/power-generation/renewables/wind-power/SCOE

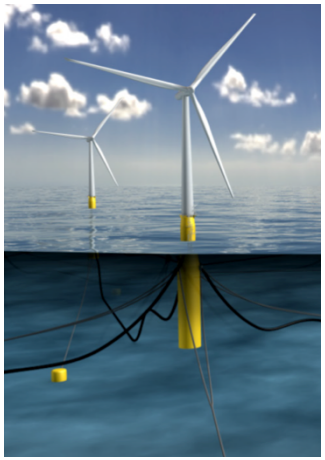

Hywind Scotland



- World's first offshore floating wind park
- The Hywind Project
- Timescale & Challenges on the Way

Source: Statoil



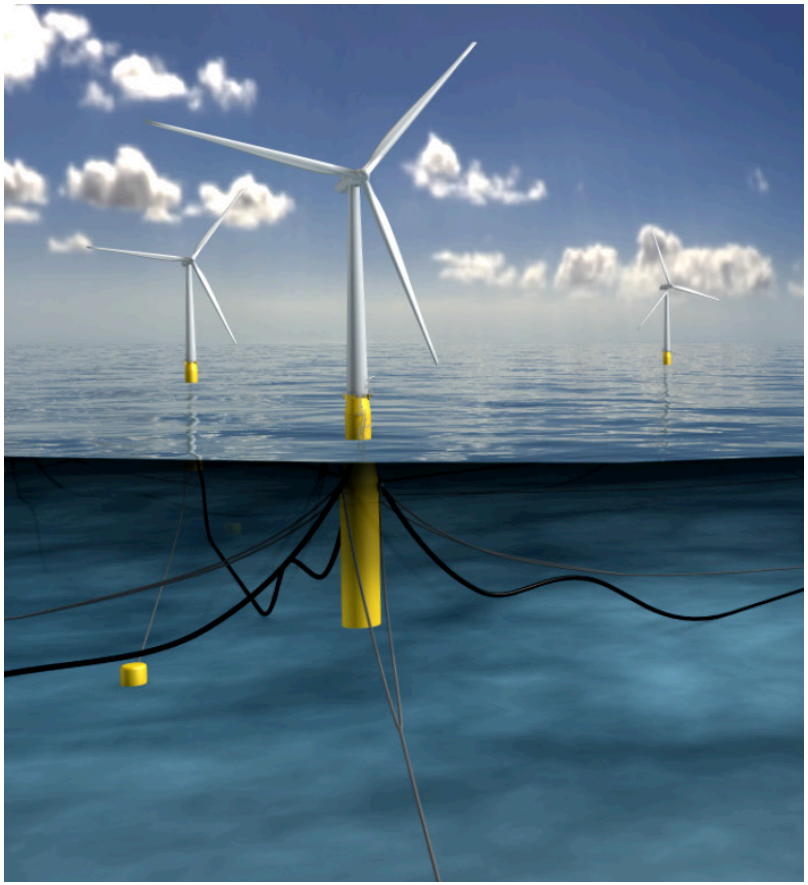


Concept **2001** → Model Test **2005** → Prototype **2009** → Pilot Park **2017** → Large Parks **< 10 years**

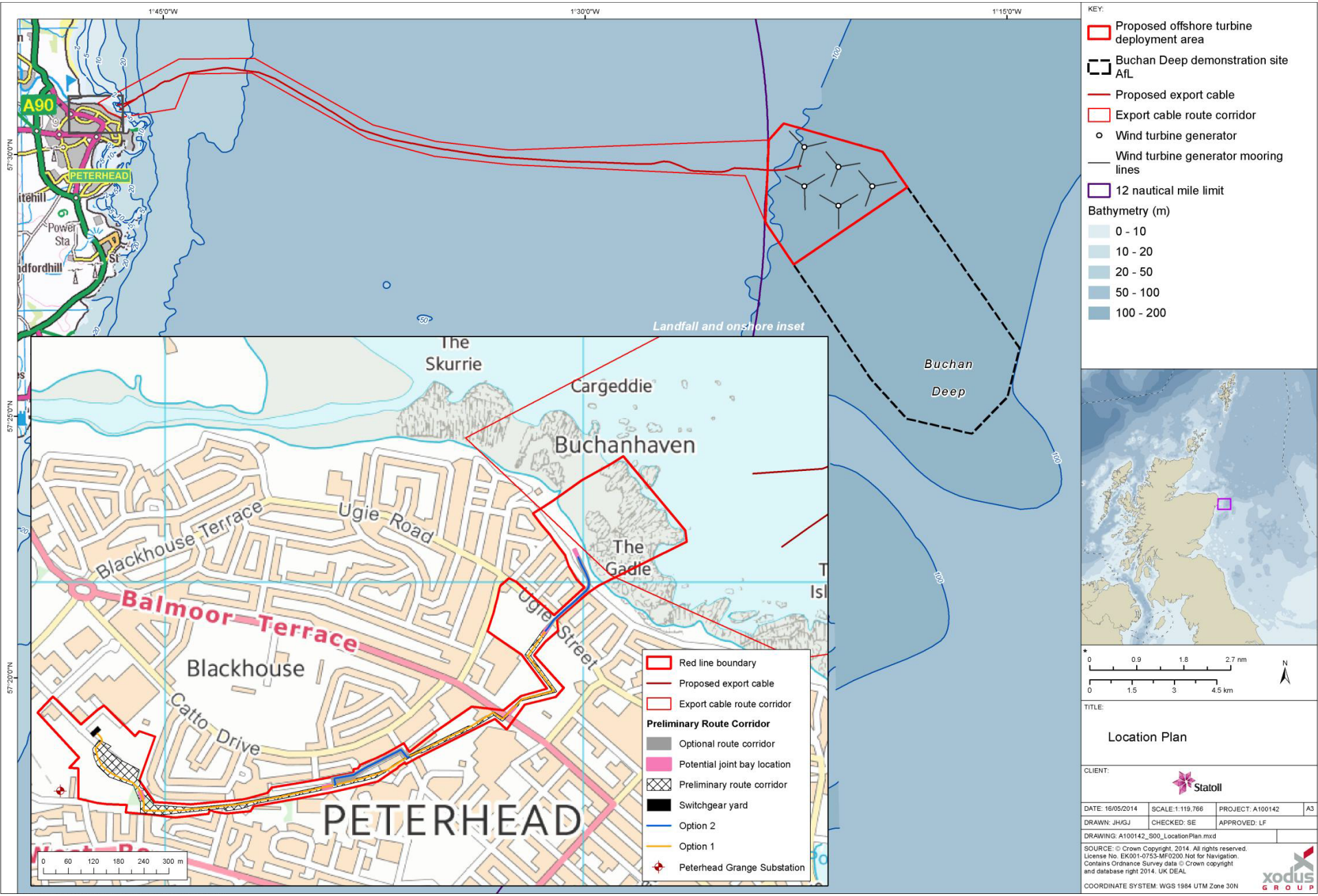
Source: Statoil

Hywind Scotland

- Turbine capacity: 6 MW
- Nr. of turbines: 5
- Location:
  - depth 95 to 120 m
  - 25 km off the Scottish North-East Coast



Source: Statoil



Source: Statoil

- System dynamics
- Environment
- Turbine & Farm Wakes
- Installation, Operation & Maintenance
- Costs of Energy

- From prototype to pilot park:
  - Different floater
  - Different rotor diameter
  - Different control system
  - Turbine spacing

Hywind Scotland

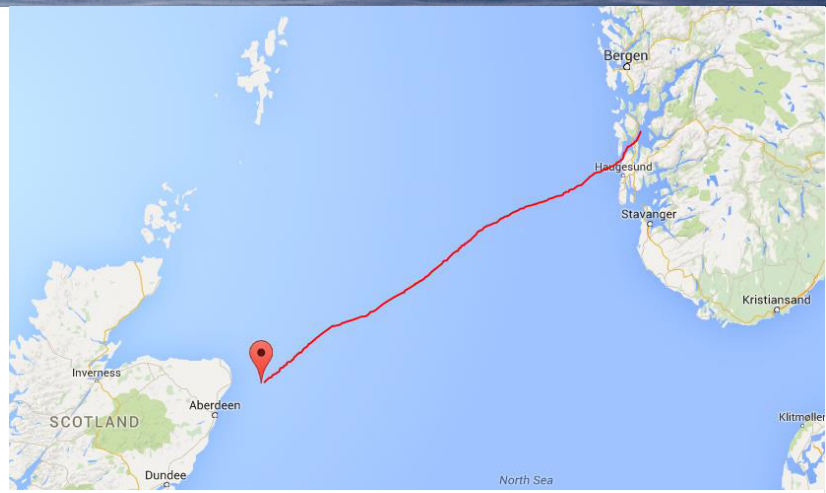
Hywind Demo

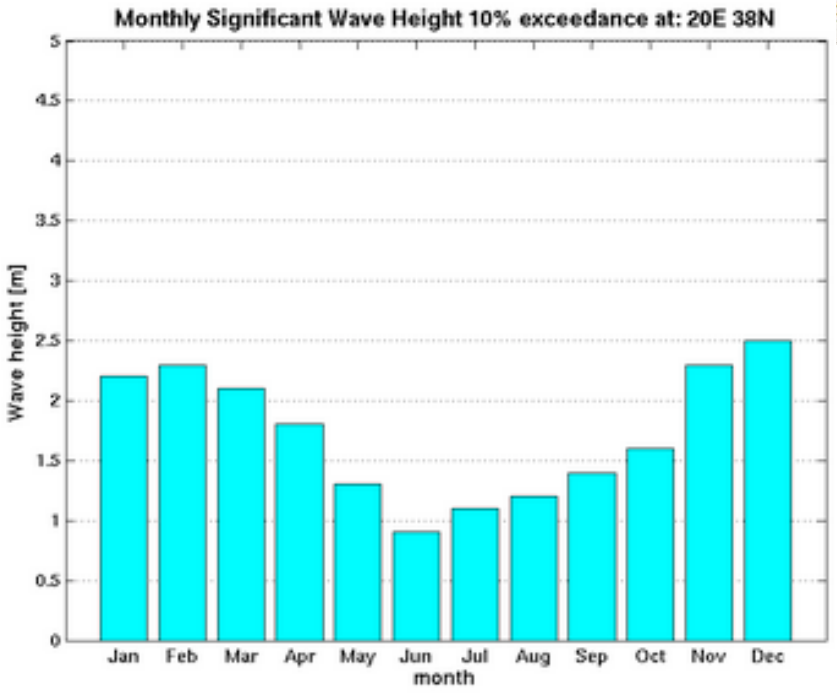
Cost ↑ Cost ↓

Source: Statoil

- System dynamics
- Environment
- Turbine & Farm Wakes
- Installation, Operation & Maintenance
- Costs

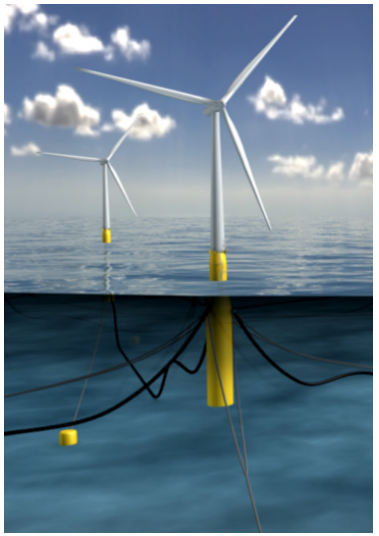
- Turbine assembling in Norway
- Towing to Scotland
  - 4 days
  - Route dependent on ocean depth between 76 - 80 m
  - Transfer dependent on wave height





Source: ocean.dmi.dk

- Facts
  - World's first offshore floating wind farm bringing power for ~ 20 000 households
- Challenges
  - Is the scaled up turbine working nicely in an array?
  - Is the towing of the turbines across North Sea working and cost efficient?



Prototype **2009** → Pilot Park **2017**

Source: Statoil

Trial Lecture

Valerie-M. Kumer

26. August 2016