

A photograph of an offshore wind farm at sea. The sky is filled with large, dark, dramatic clouds, suggesting a storm or late afternoon. The sea is a deep blue-grey color. In the distance, a long line of wind turbines stretches across the horizon. The text 'Offshore Wind Energy' is written in a large, white, hand-drawn font across the middle of the image. Below it, the subtitle 'Potential, Challenges and Limitations' is written in a smaller, white, hand-drawn font.

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



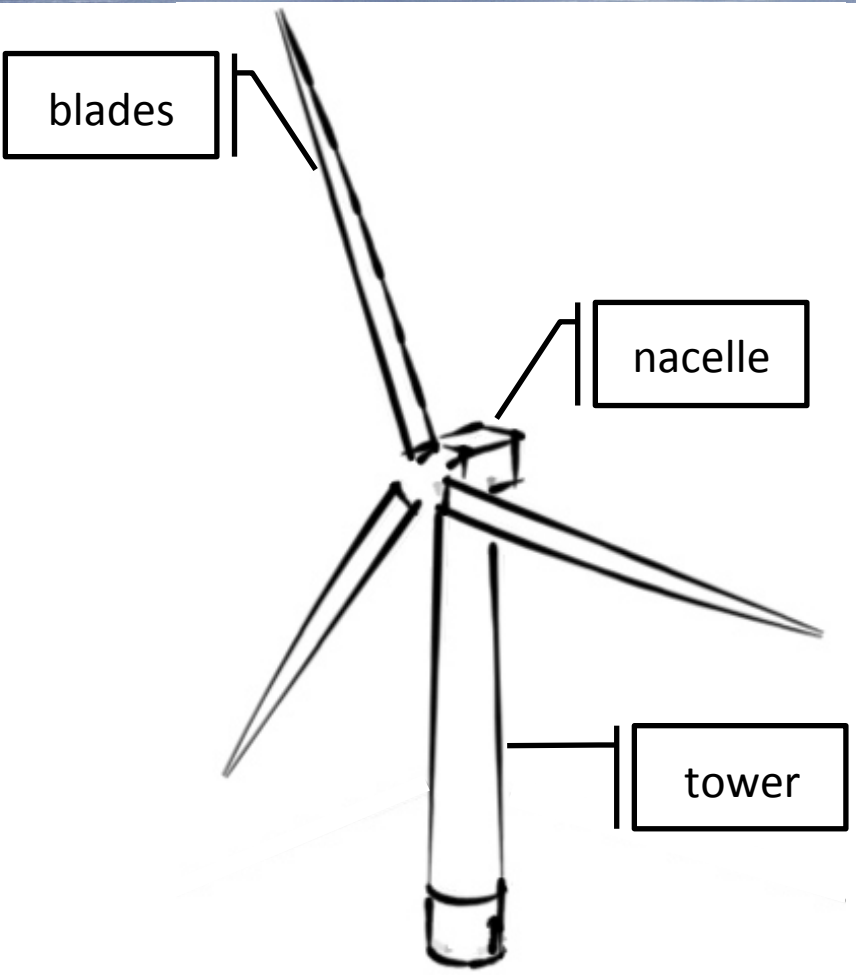
Overview

Technology

Facts

Challenges

Hywind Scotland



blades

nacelle

tower



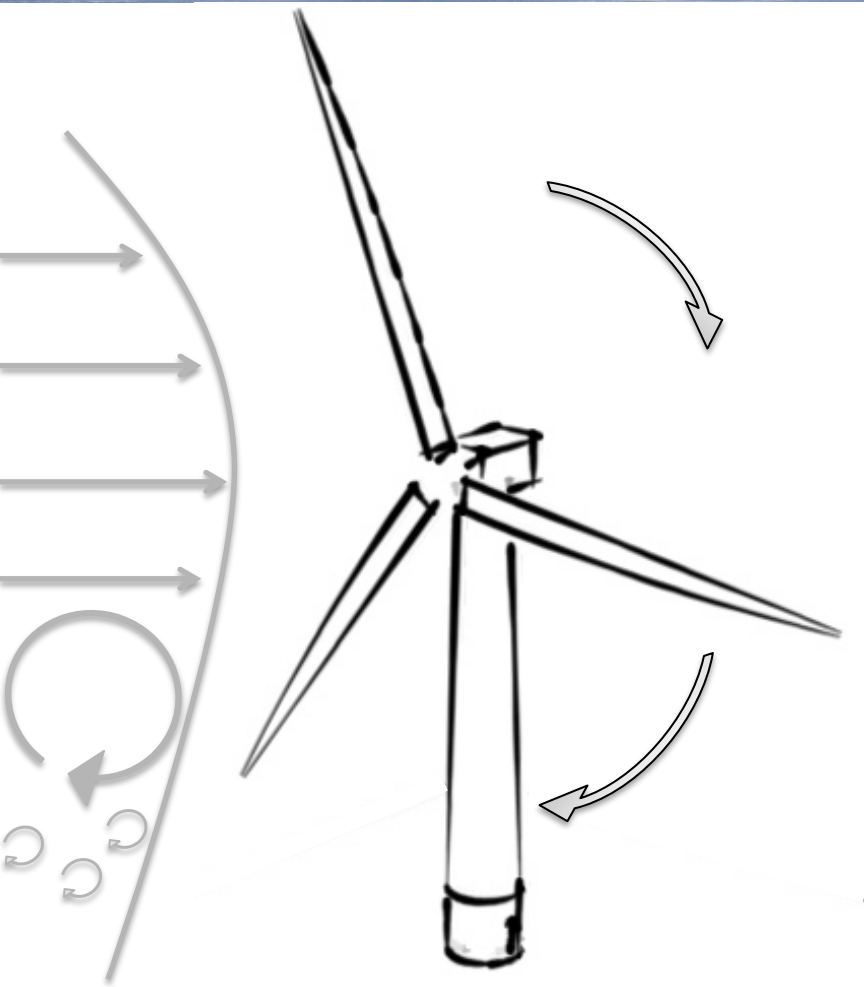
Overview

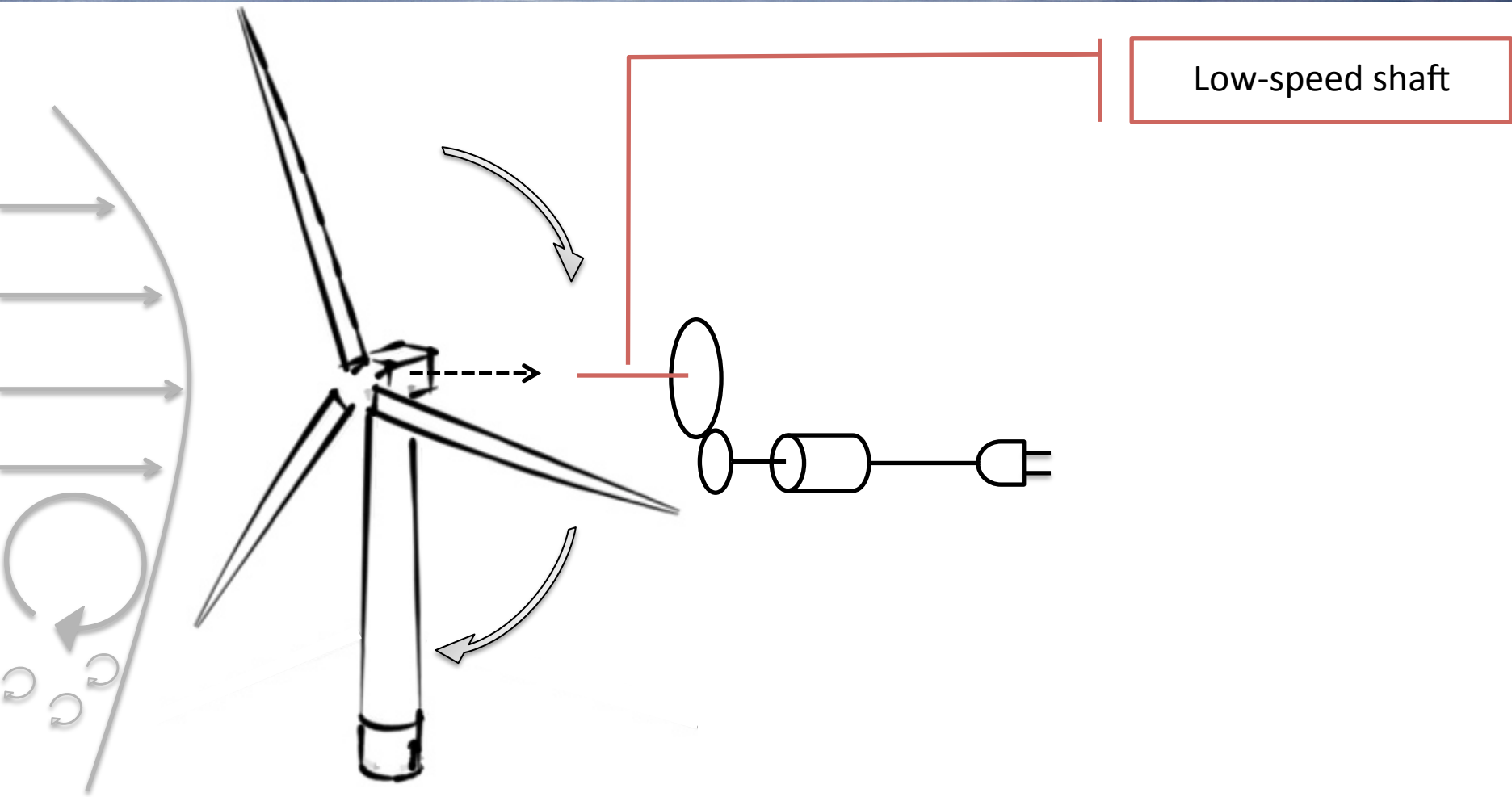
Technology

Facts

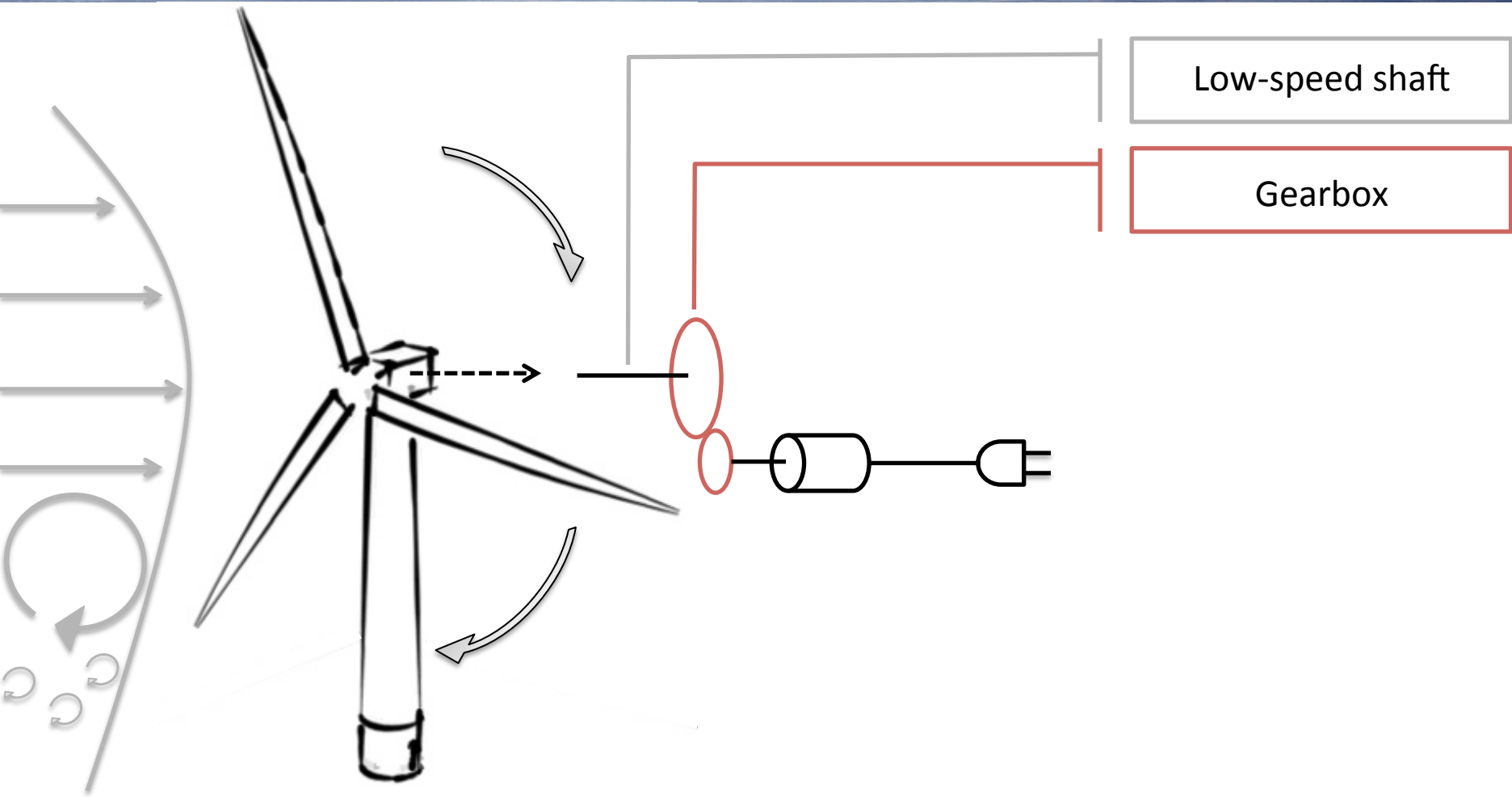
Challenges

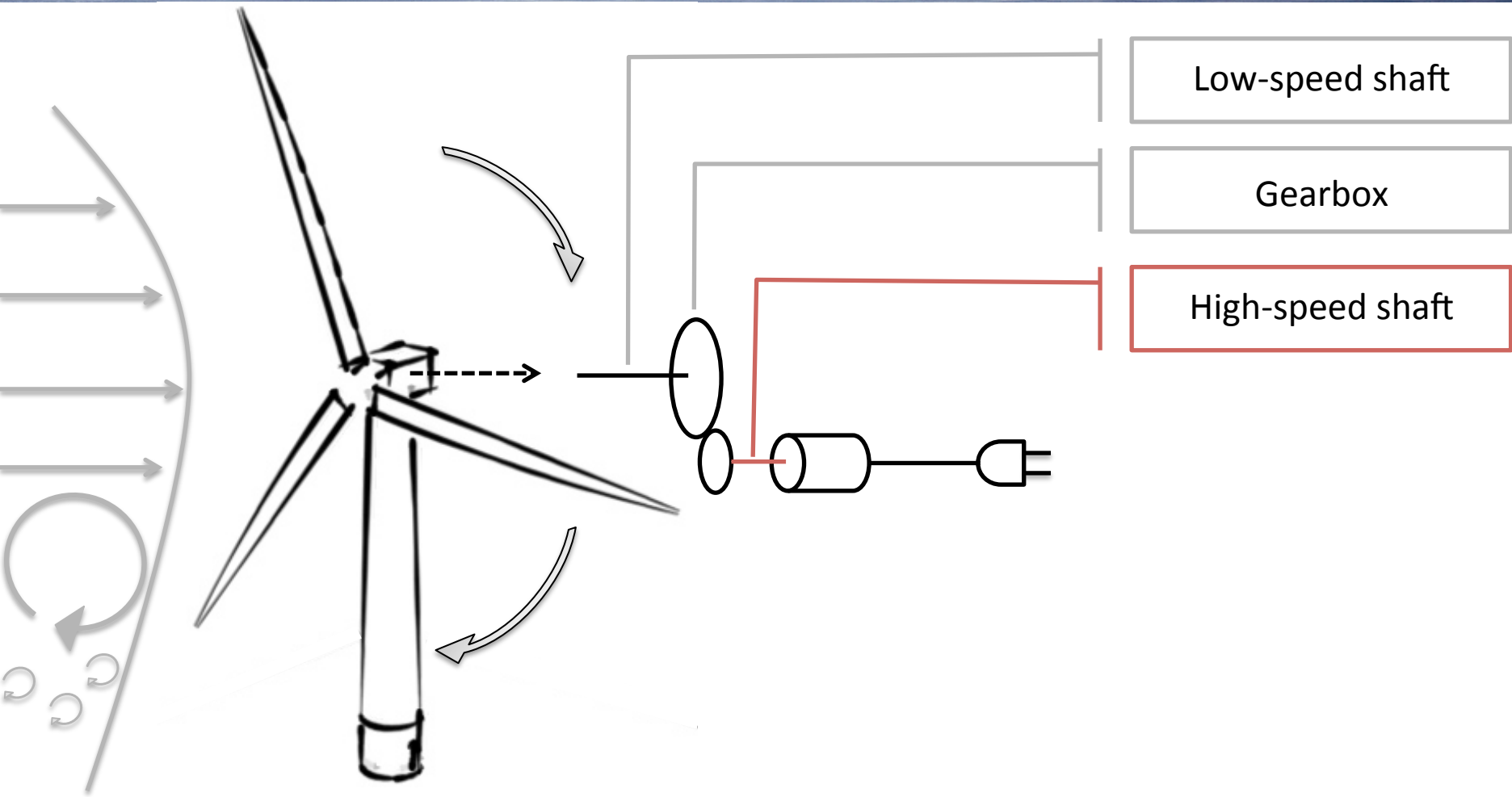
Hywind Scotland





Low-speed shaft







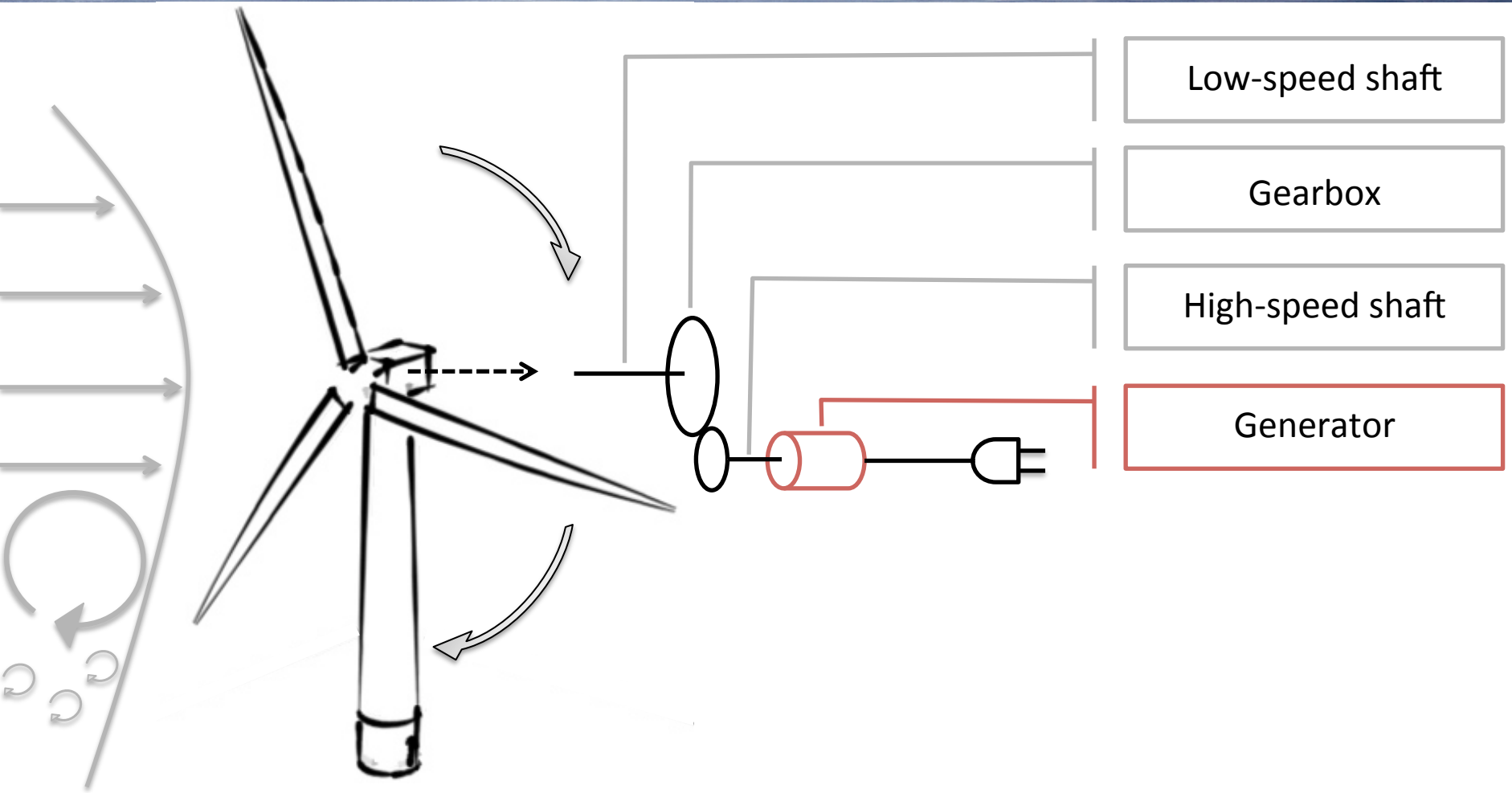
Overview

Technology

Facts

Challenges

Hywind Scotland



Low-speed shaft

Gearbox

High-speed shaft

Generator



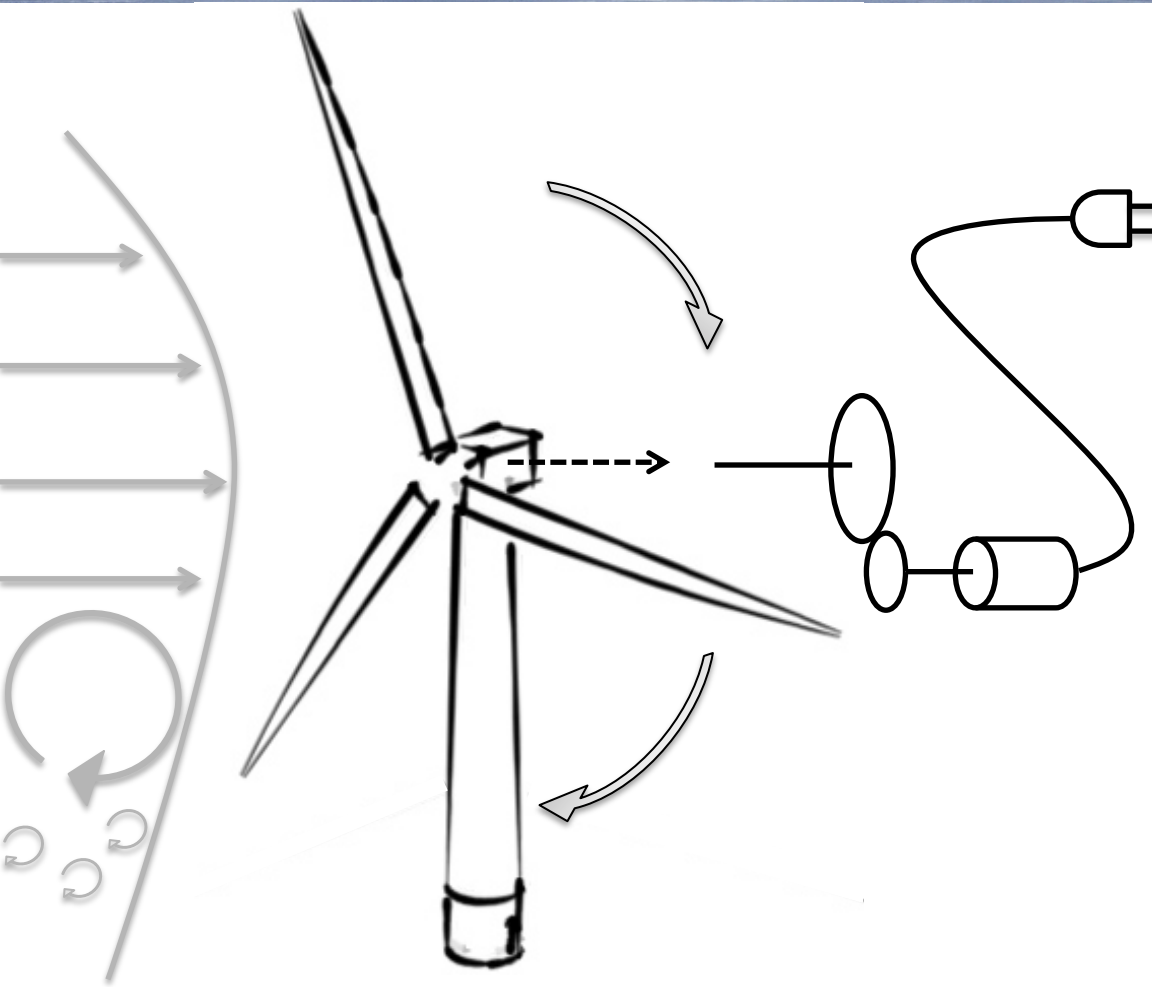
Overview

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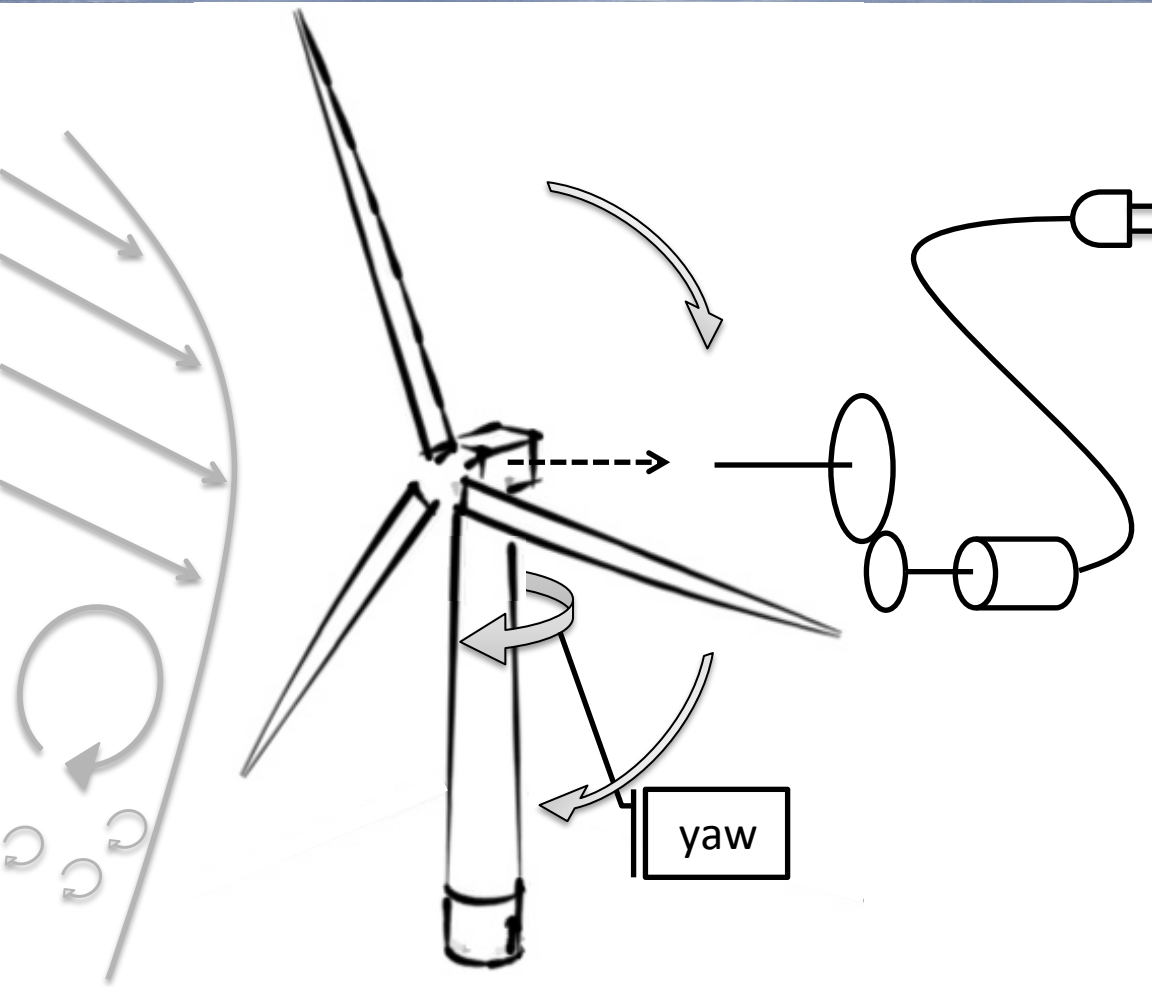
Challenges

Hywind Scotland



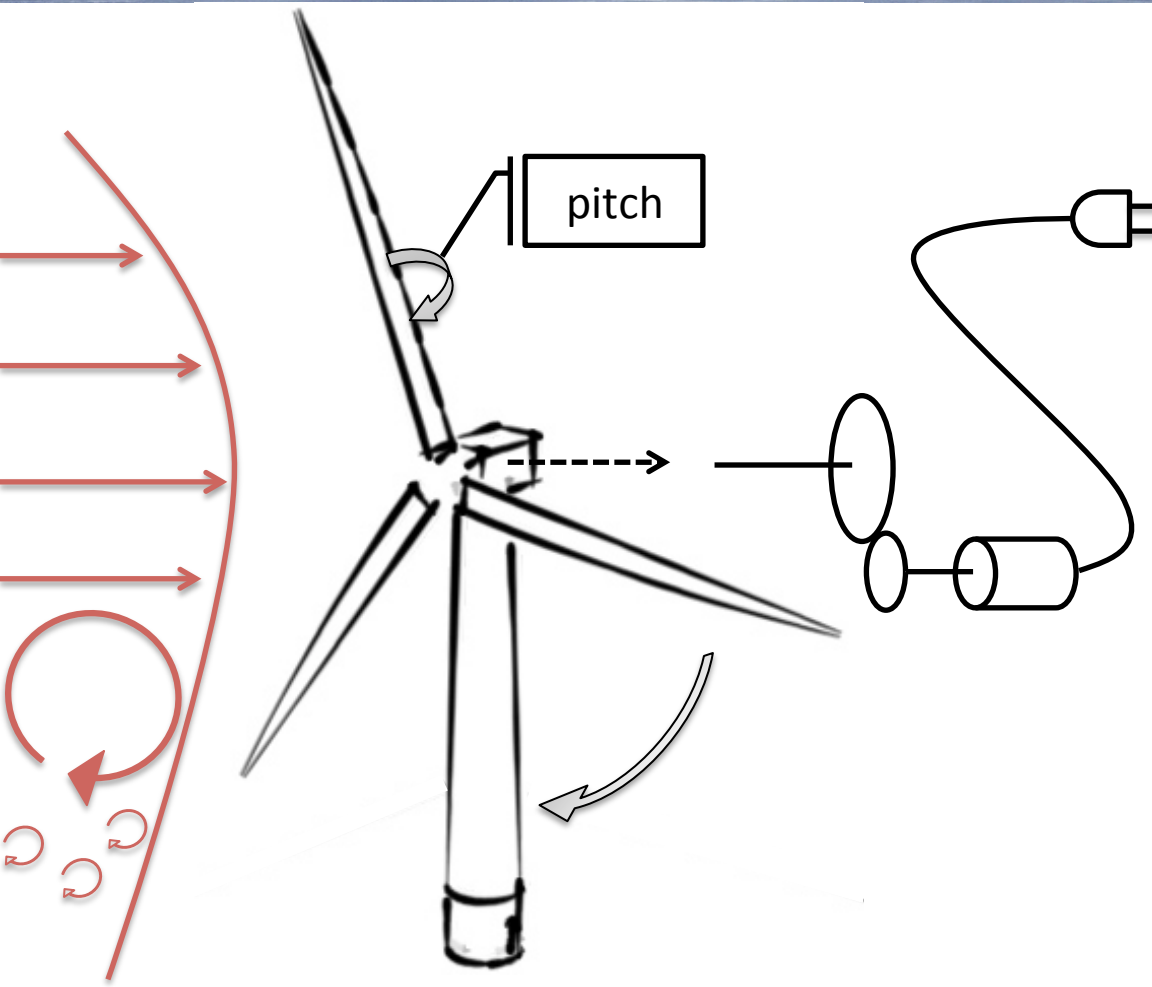
$$P_{out} = \frac{1}{2} C_p A \rho v^3$$

- P_{out} ... electricity output
- C_p ... turbine capacity factor
- A ... rotor area
- ρ ... air density
- v ... wind speed
- Betz limit:** $C_p = 0.59$



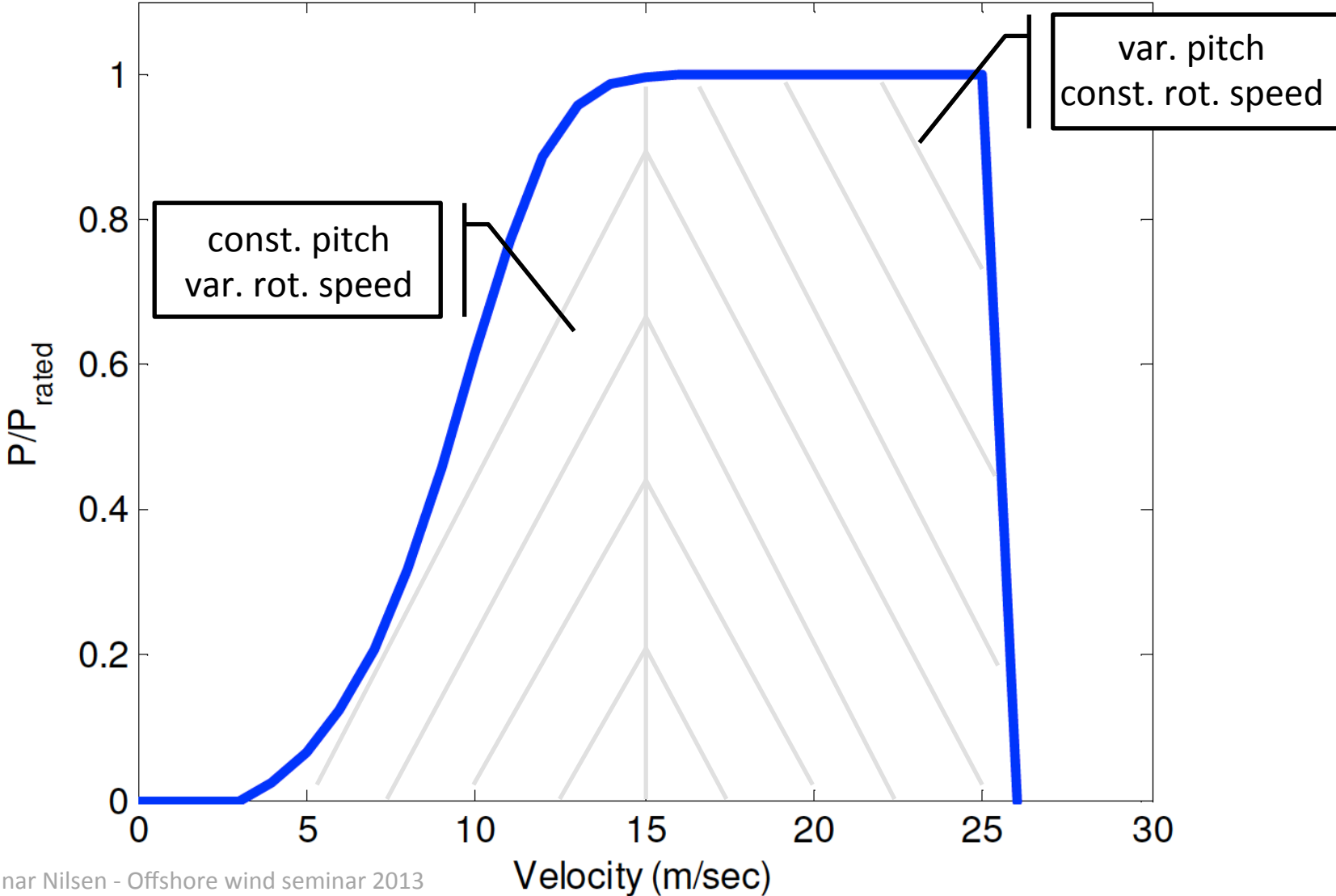
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Source: Finn Gunnar Nilsen - Offshore wind seminar 2013



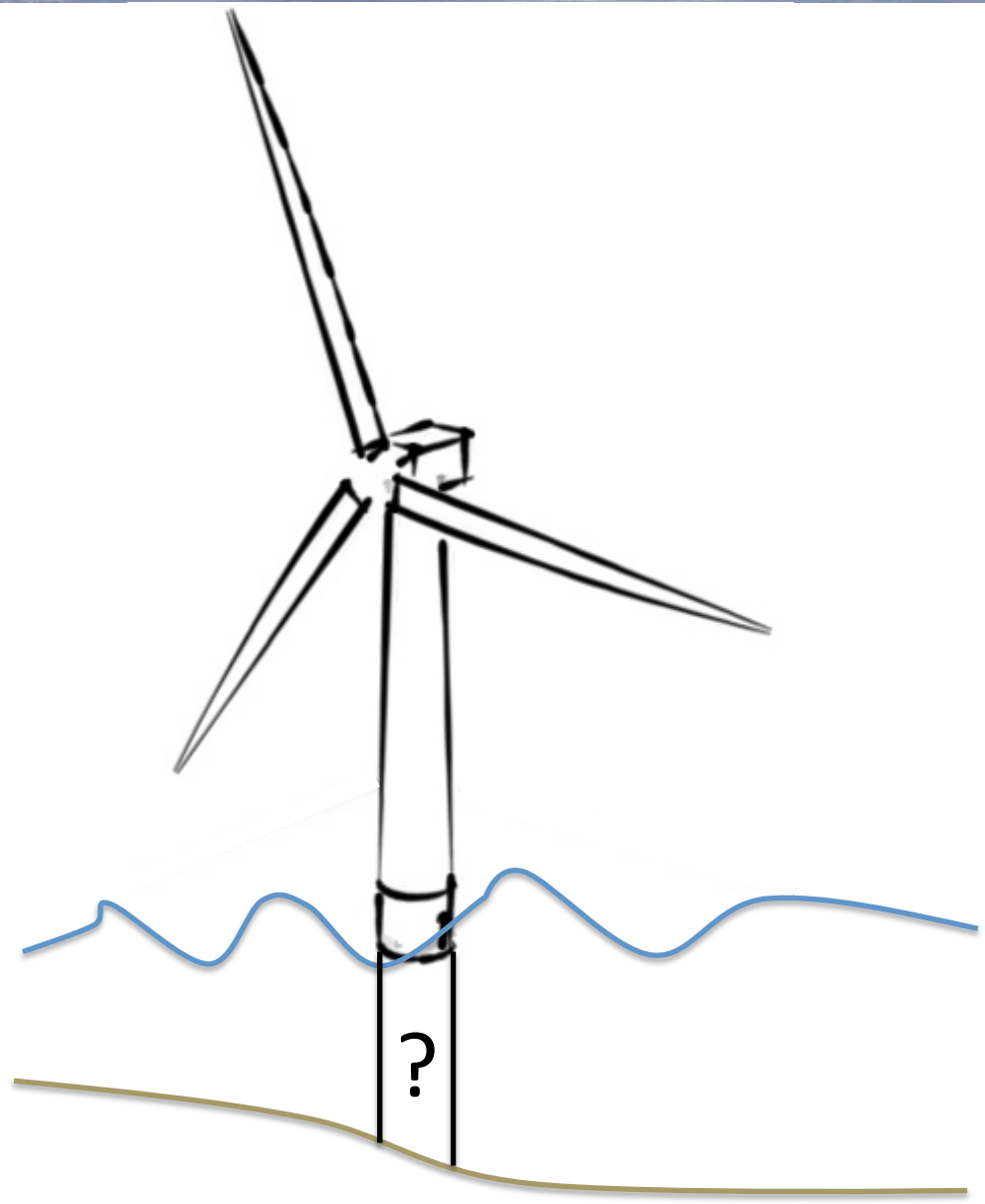
Overview

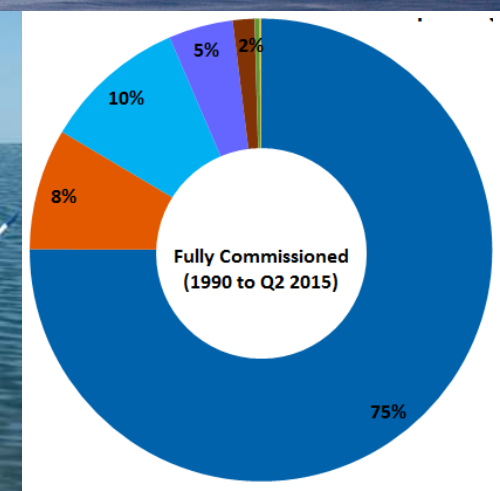
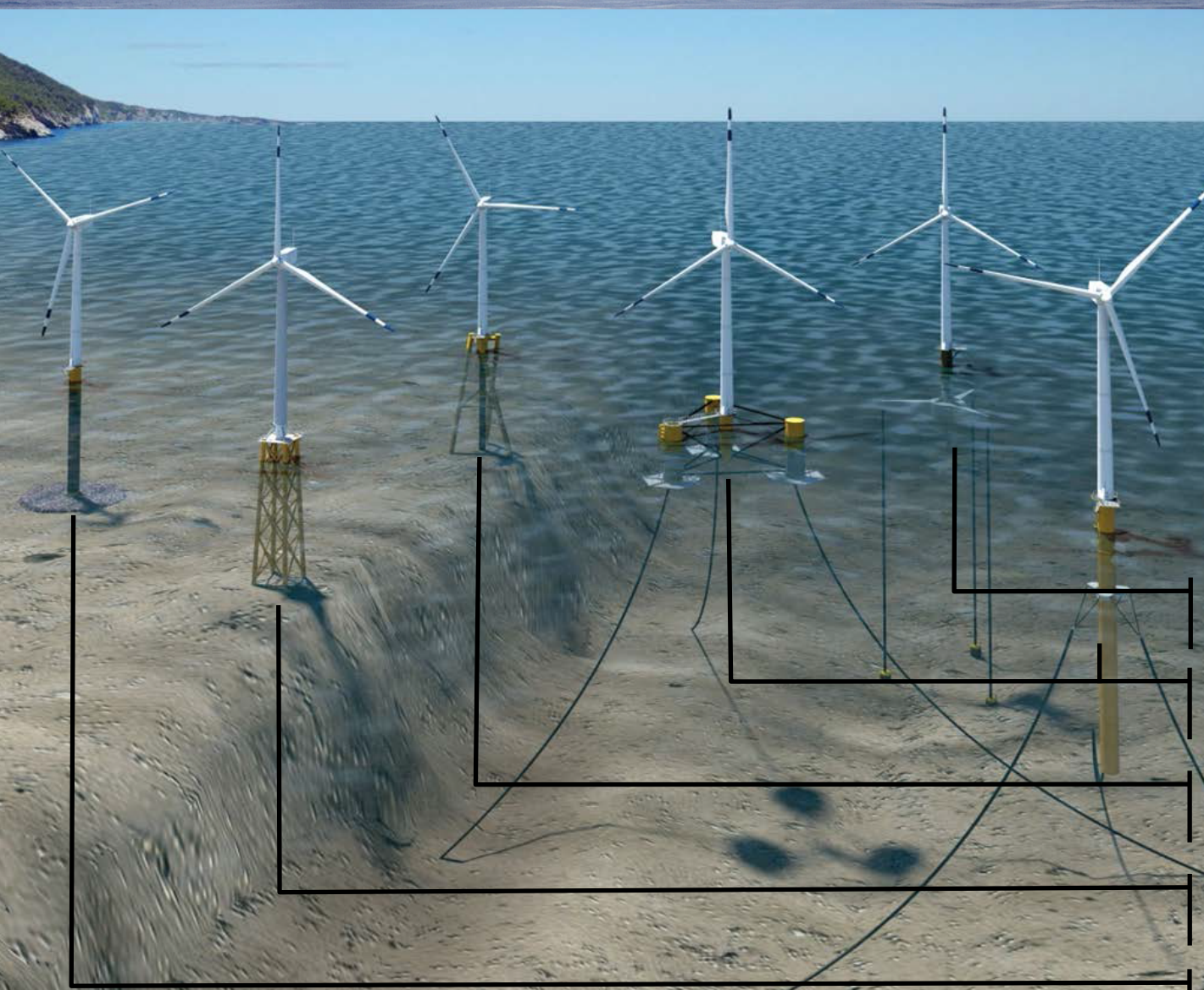
Technology

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Challenges

Hywind Scotland



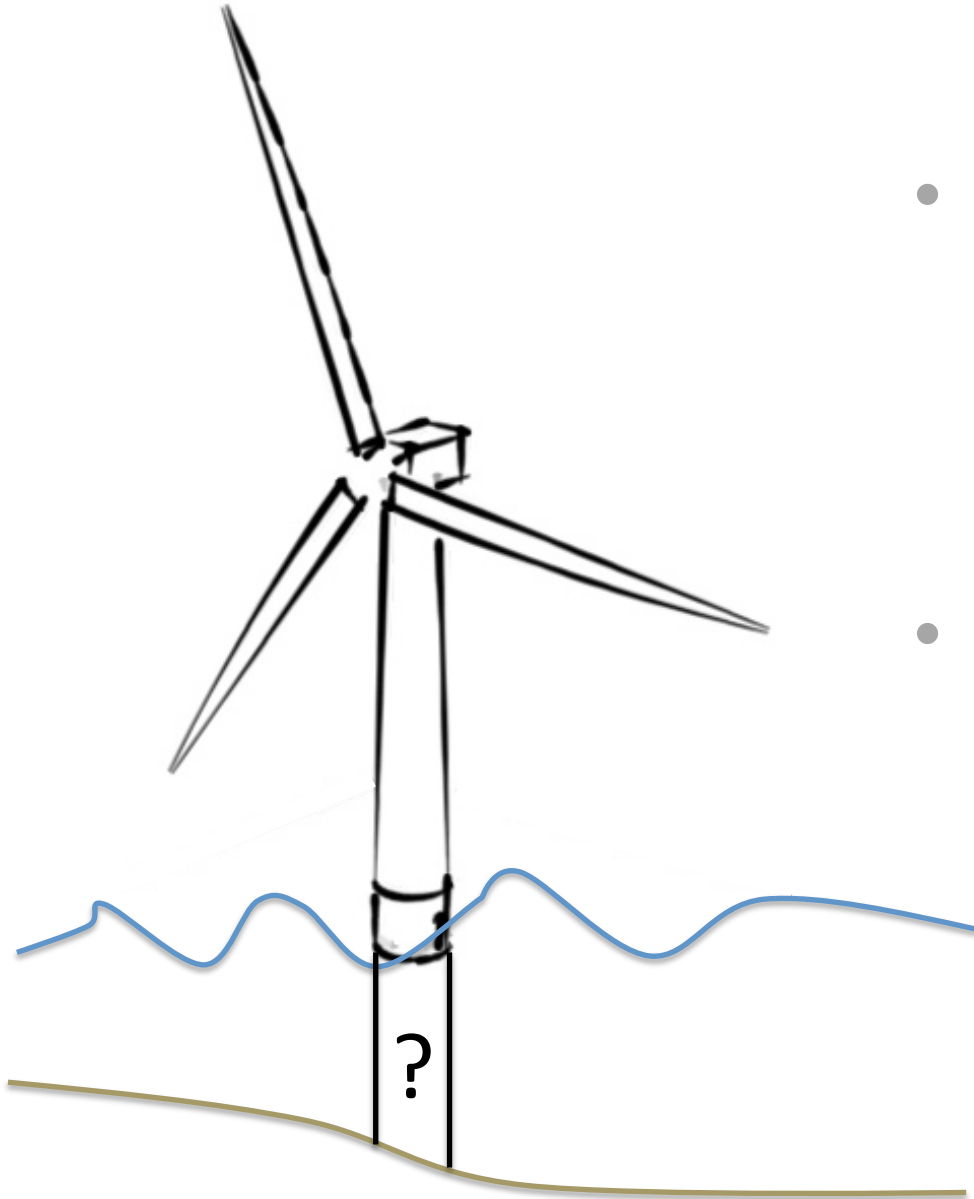


- Monopile
- Gravity Base
- Jacket
- Tri-pile
- High-Rise Pile Cap
- Suction Bucket
- Tripod
- Floating

- 60 m < Tripod
- 60 m < Floater
- 30m < Tri-pile < 60 m
- 30 m < Jacket < 60 m
- Monopile < 40 m



Overview Technology Facts Challenges Hywind Scotland



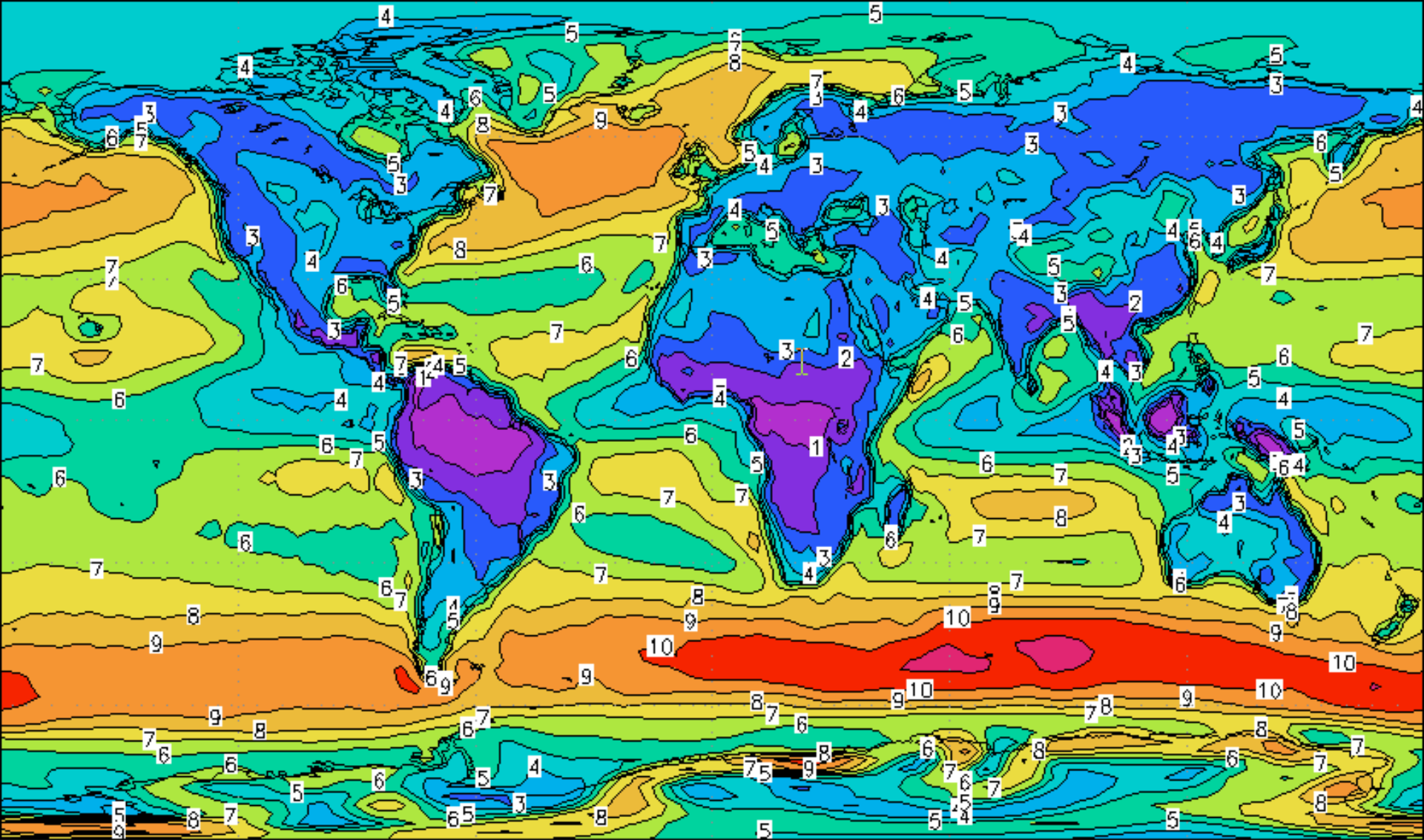
- Wind power generation depends on ?
 - Wind speed
 - Rotor diameter
- Substructure type depends on?
 - Water depth



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

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

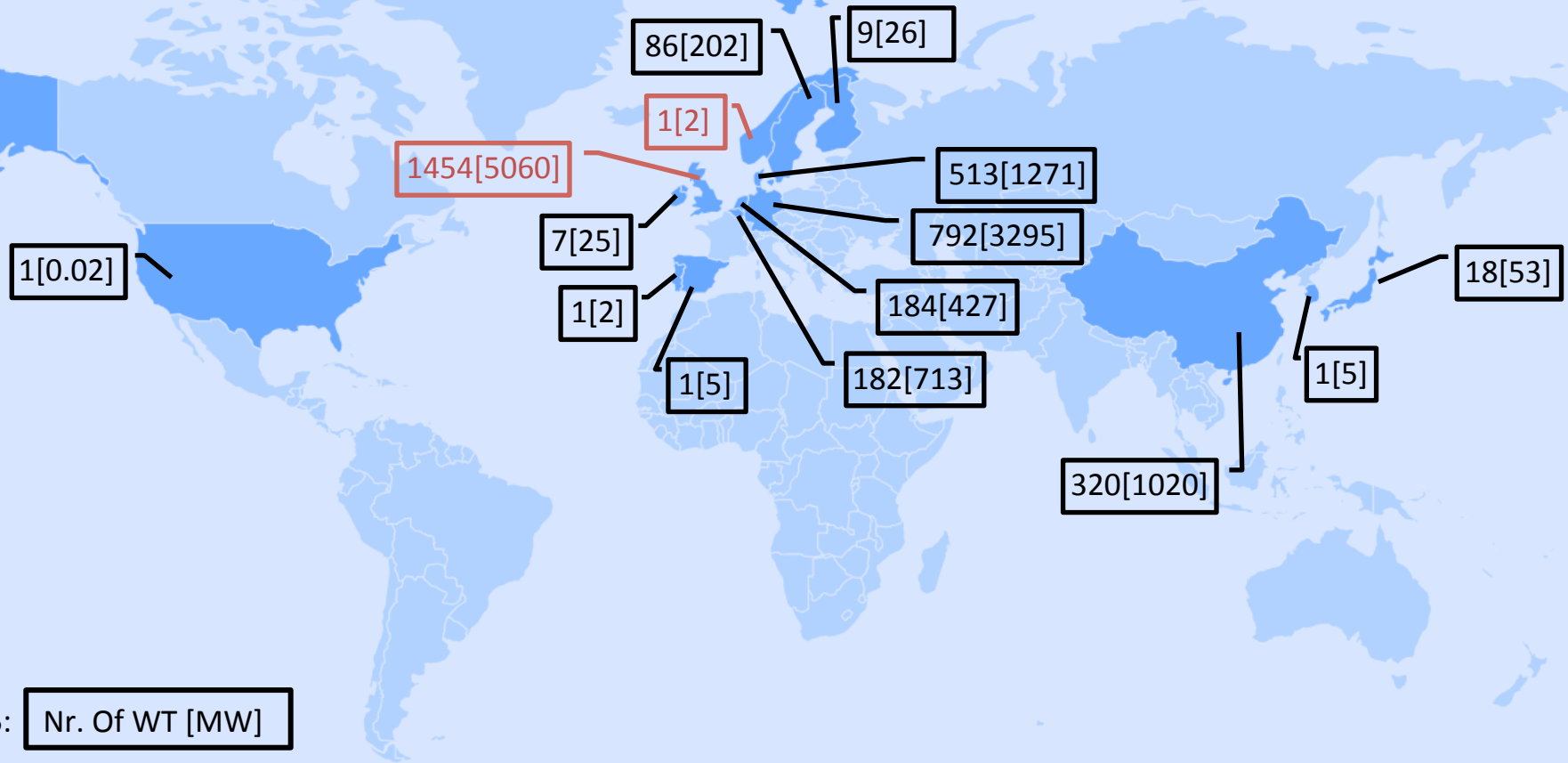
λ ... tip speed ratio

Ω ... rotor rotation speed

R ... rotor radius

U ... wind speed

World Map Offshore Wind Energy

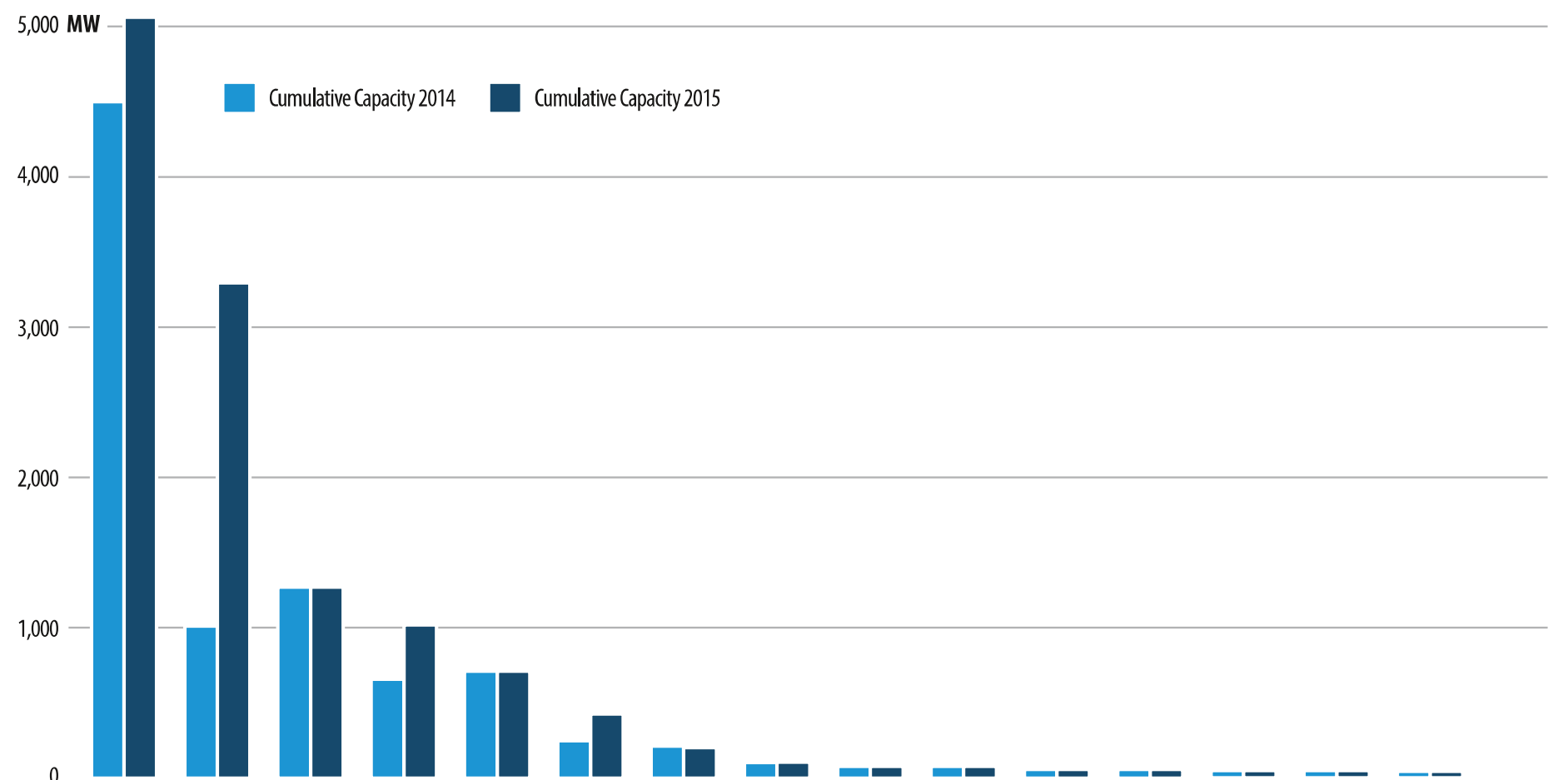


- Global cumulative offshore capacity 2015:
12.107 GW



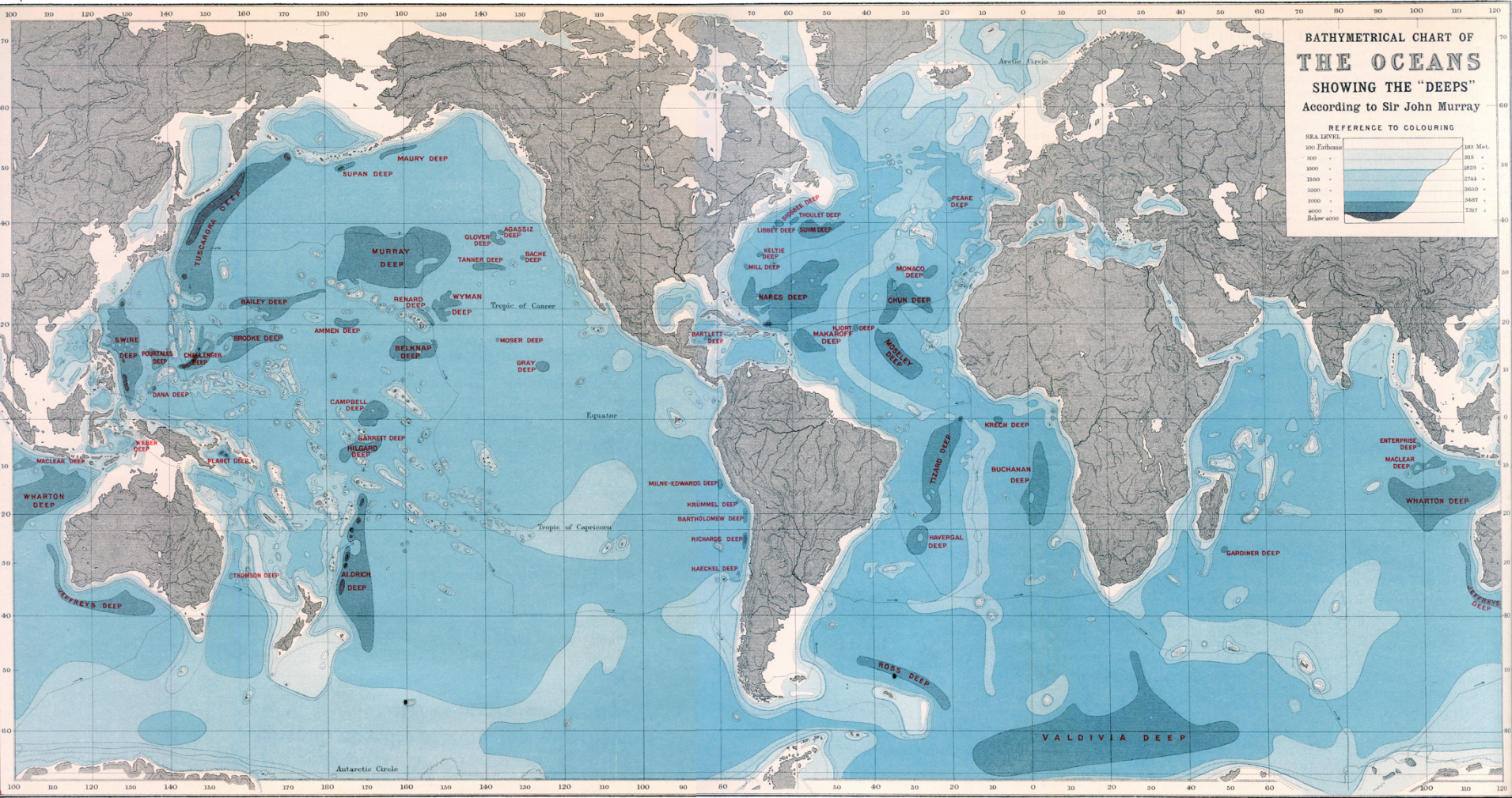
Overview Technology Facts Challenges Hywind Scotland

GLOBAL CUMULATIVE OFFSHORE WIND CAPACITY IN 2015



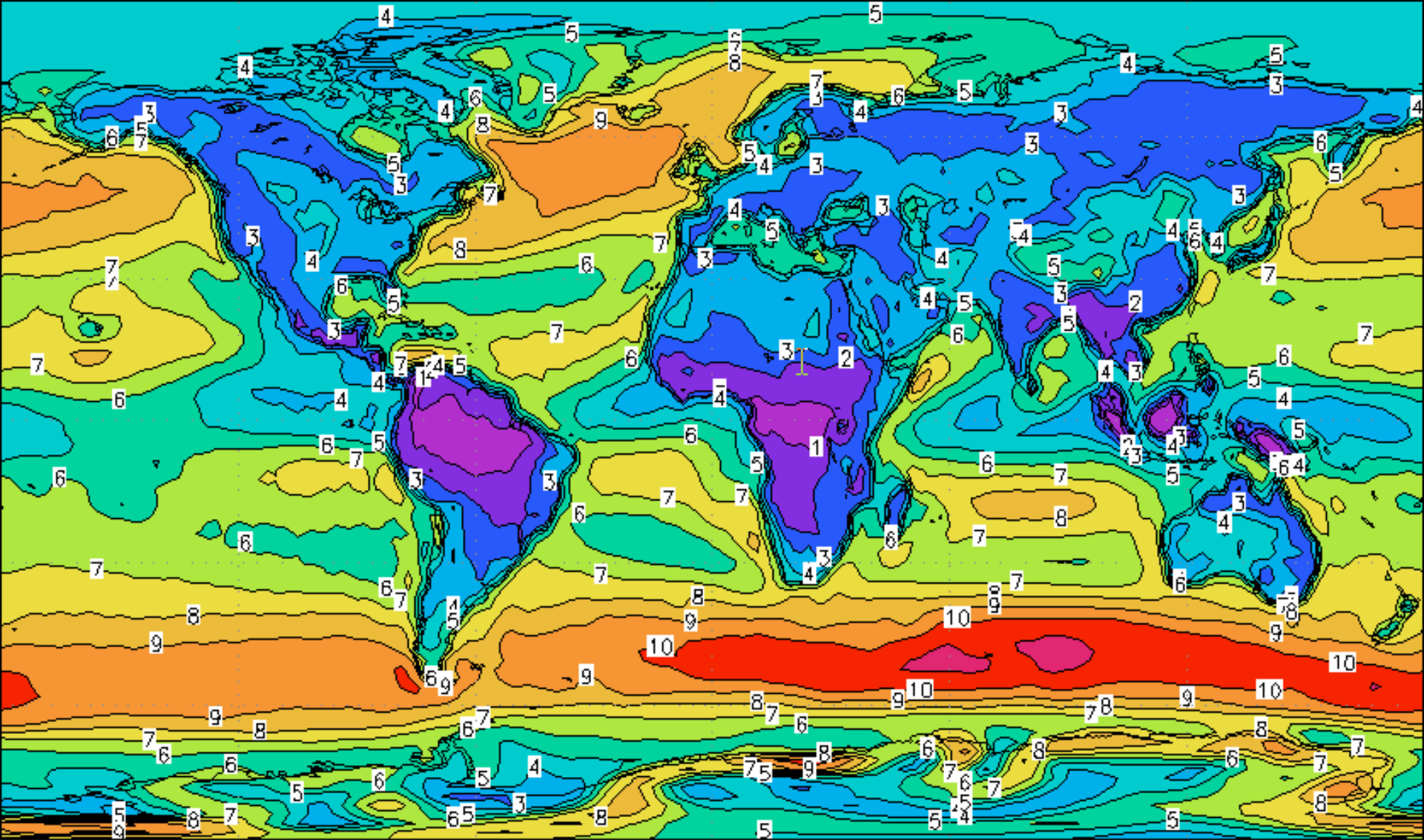
	UK	Germany	Denmark	PR China	Belgium	Netherlands	Sweden	Japan	Finland	Ireland	S Korea	Spain	Norway	Portugal	US	Total
Total 2014	4,500.4	1,012	1,271	654	712	247	212	50	26	25	5	5	2	2	0.02	8,724
New 2015	572.1	2,282.4	0	360.5	0	180	0	3	0	0	0	0	0	0	0	3,398
Total 2015	5,066.5	3,294.6	1,271.3	1,014.7	712.2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



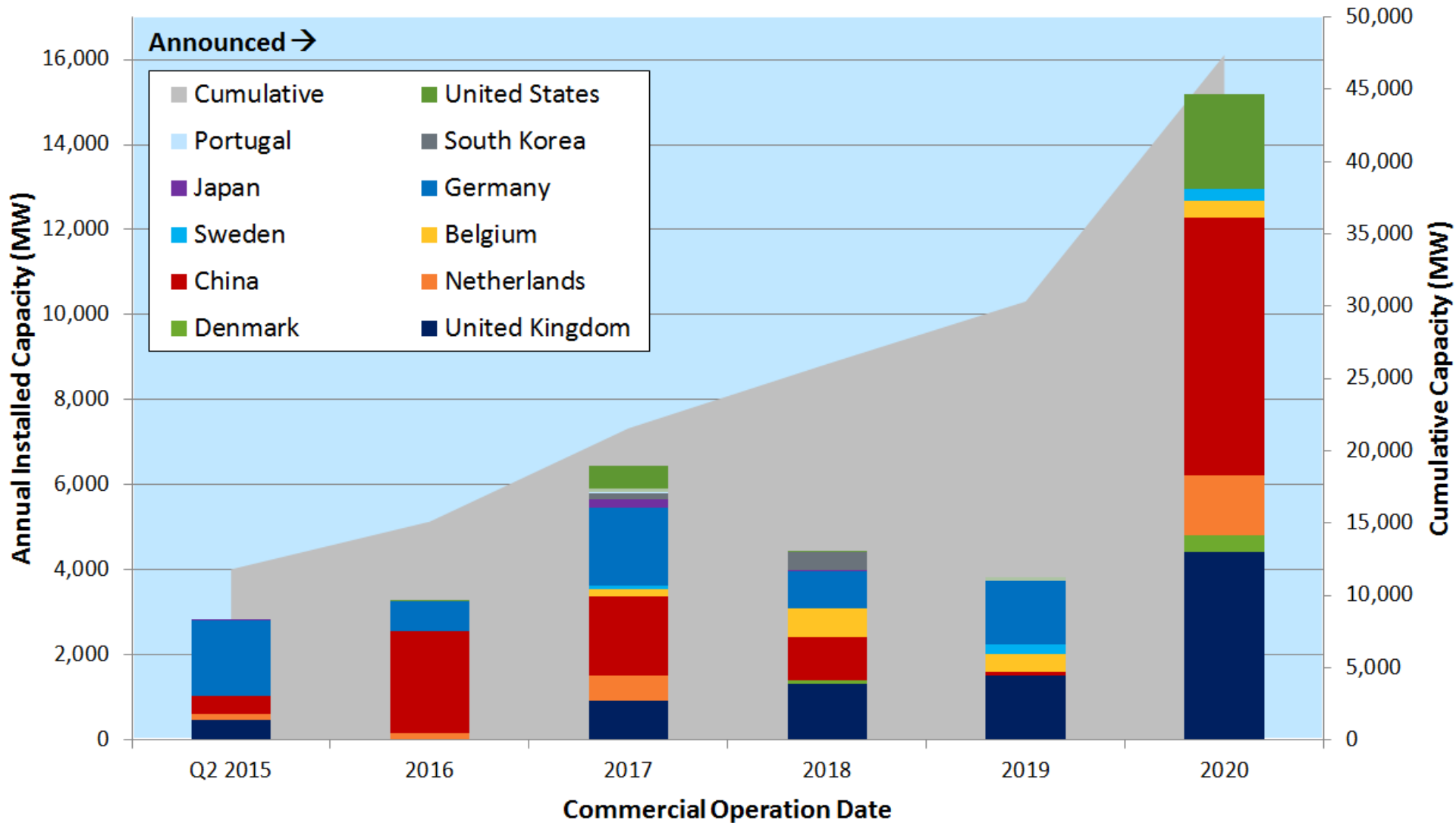
Average wind speed at 10 m between 1976 and 1995 from NCEP

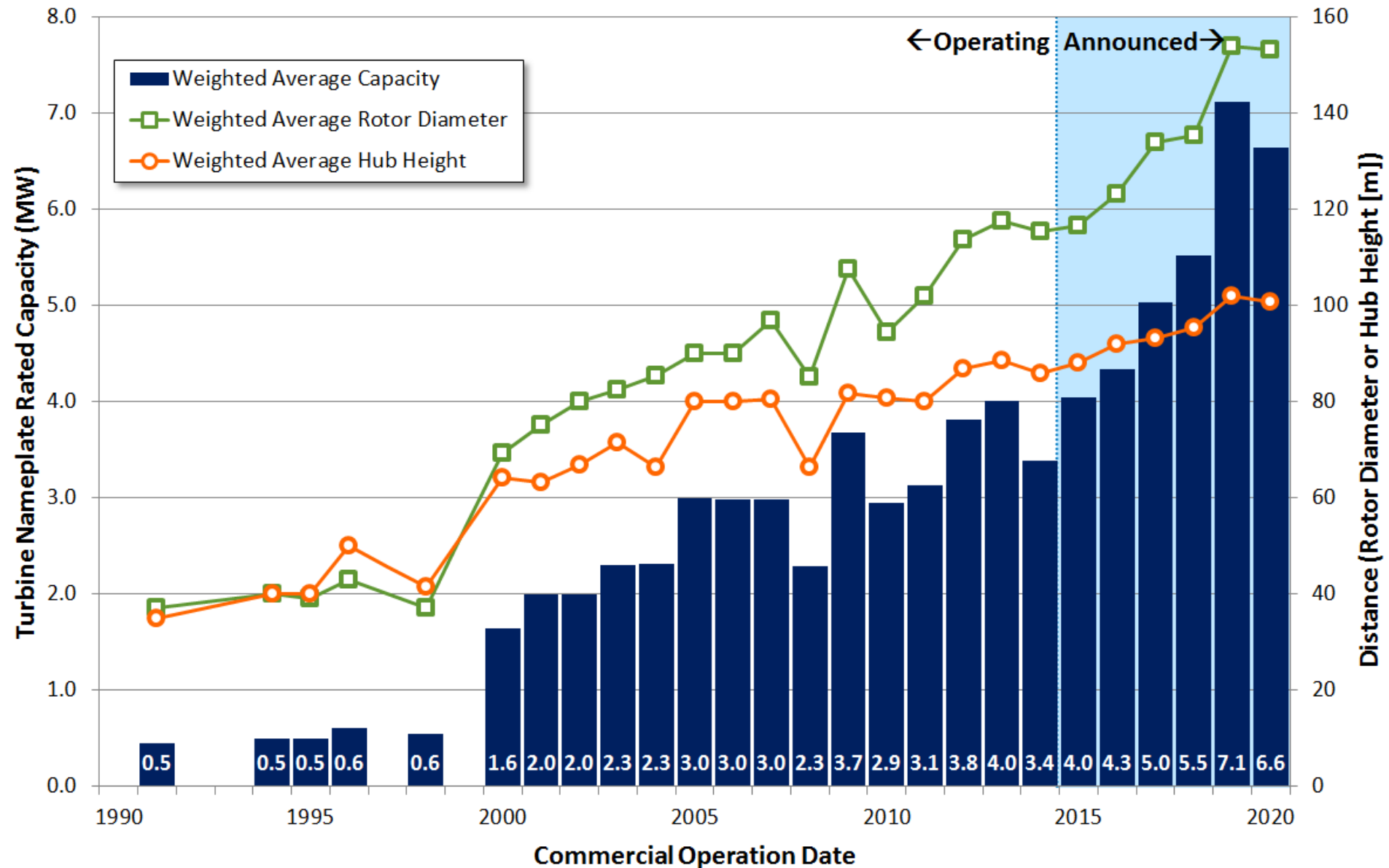
Source: http://www.wasp.dk/DataandTools#wind-atlas__world

45 GW:



42 Mil. homes supplied





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

Rotor diameter: 154 m
Turbine capacity: 6 MW





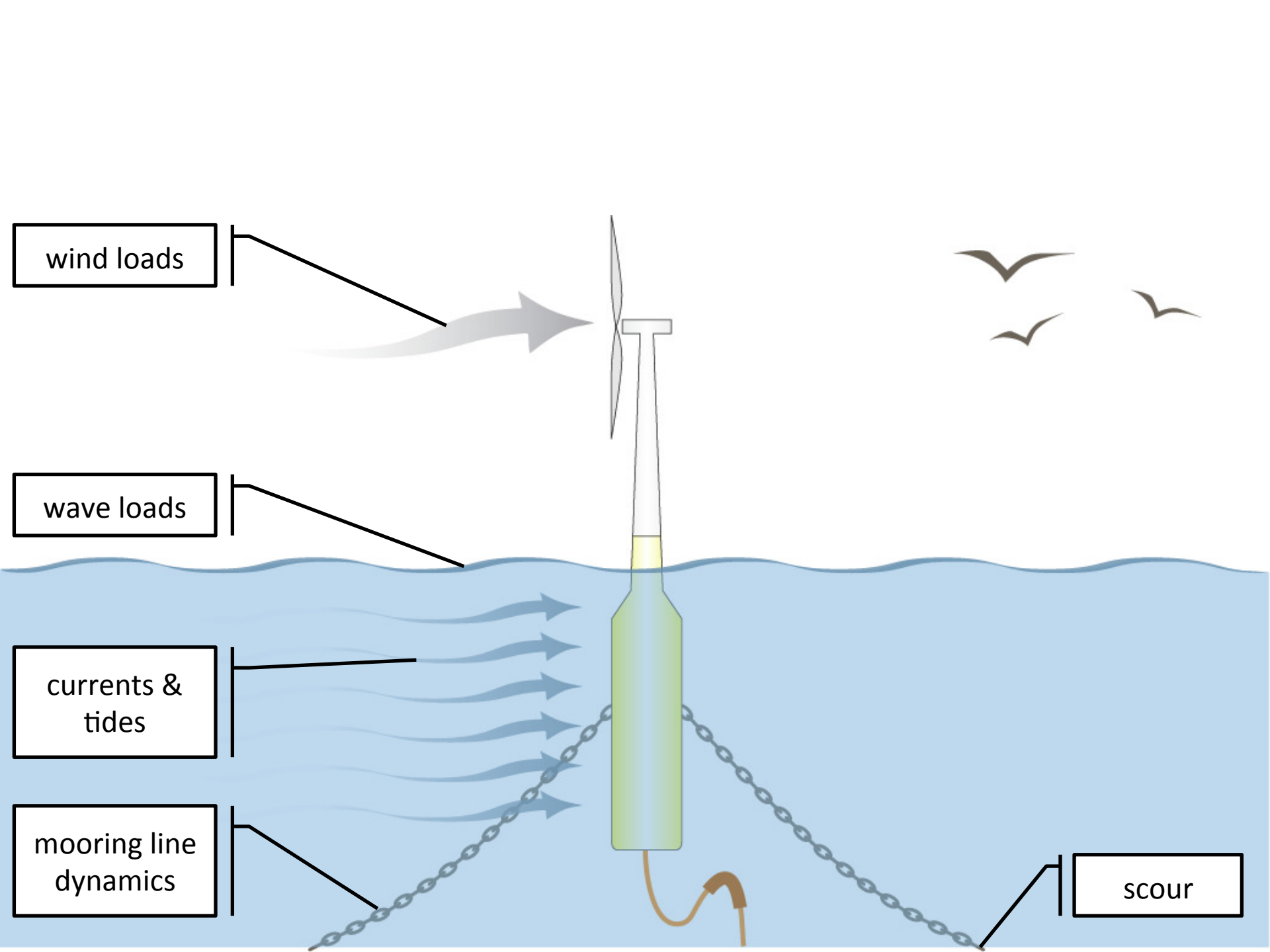
- Why offshore ?
 - Higher wind potential
 - Higher capacity with bigger rotors
- Where are we now ?
 - Global cumulative offshore capacity 2015:
12.107 GW
- Where are we going ?
 - 45.5 GW announce to be operating in 2020 with
bigger rotors

A wide-angle photograph of an offshore wind farm. The sea is a deep blue-grey, and the sky is filled with heavy, dark grey clouds. A long line of wind turbines stretches across the horizon. The word "Challenges" is written in a white, hand-drawn, pixelated font across the middle of the image.

Challenges



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



wind loads

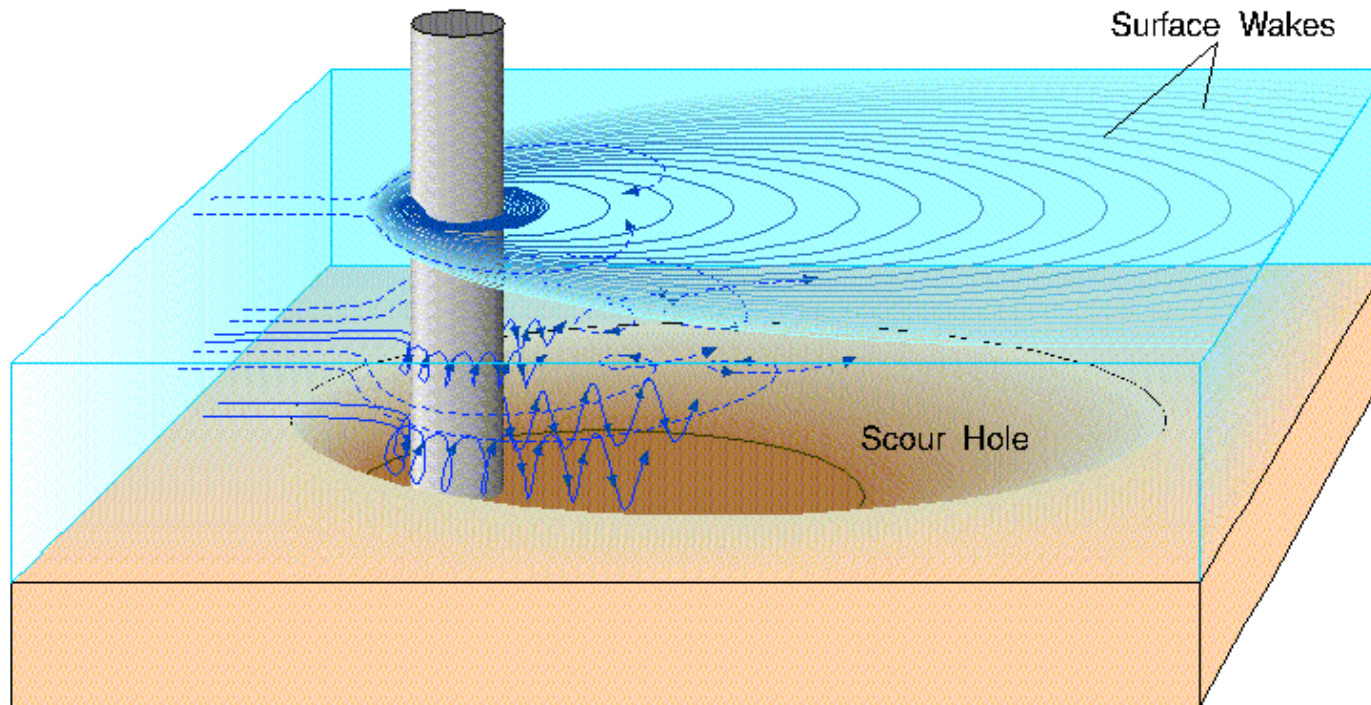
wave loads

currents &
tides

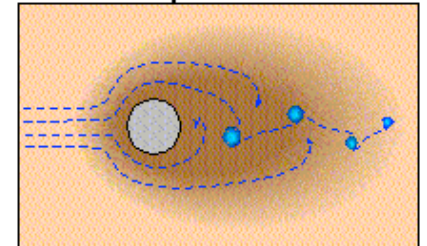
mooring line
dynamics

scour

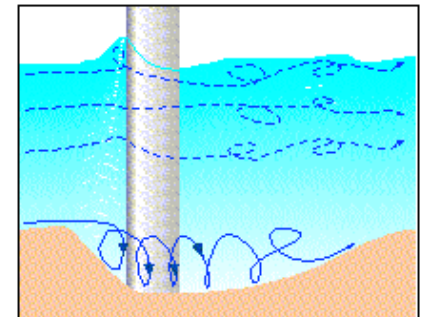
Horseshoe and Wake Vortices around a Cylindrical Element



Top View

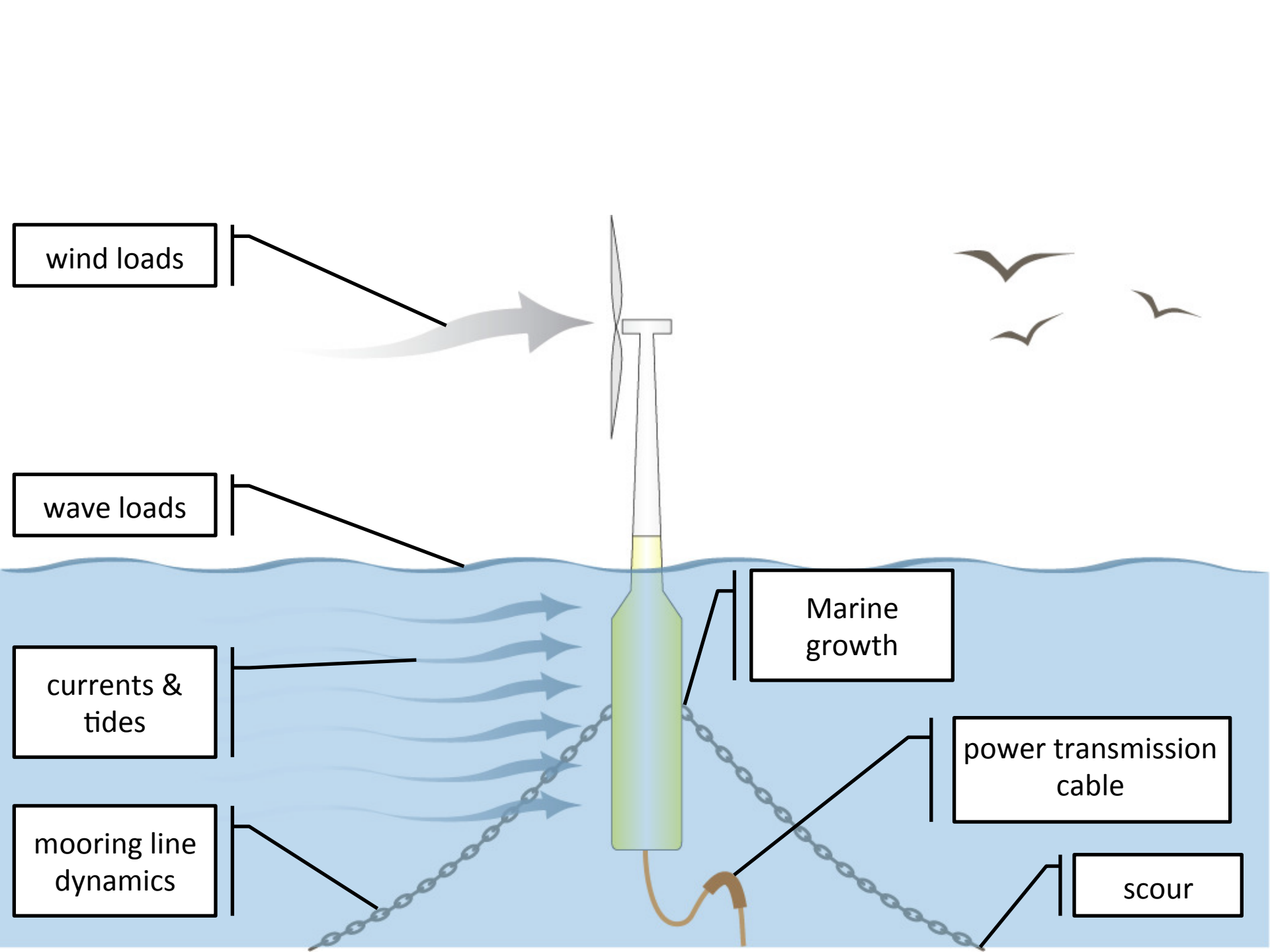


Side View



—→ Horseshoe Vortex

- - -→ Wake Vortex



wind loads

wave loads

currents &
tides

mooring line
dynamics

Marine
growth

power transmission
cable

scour

Cable damage at British offshore wind farms



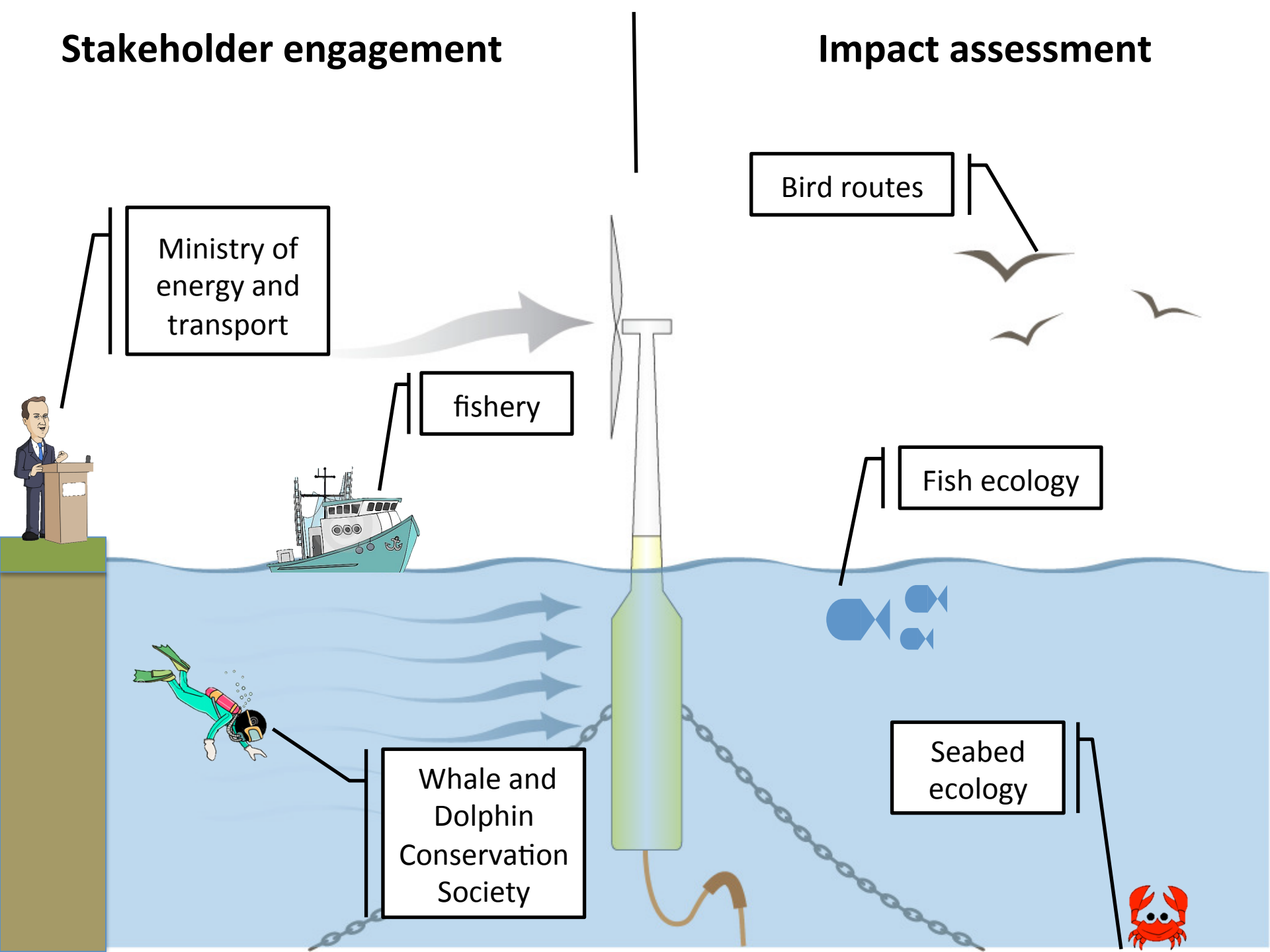
The offshore wind farm London Array has been fighting with problems with its export cables. (Photo: London Array)



- System dynamics
- Environment

Stakeholder engagement

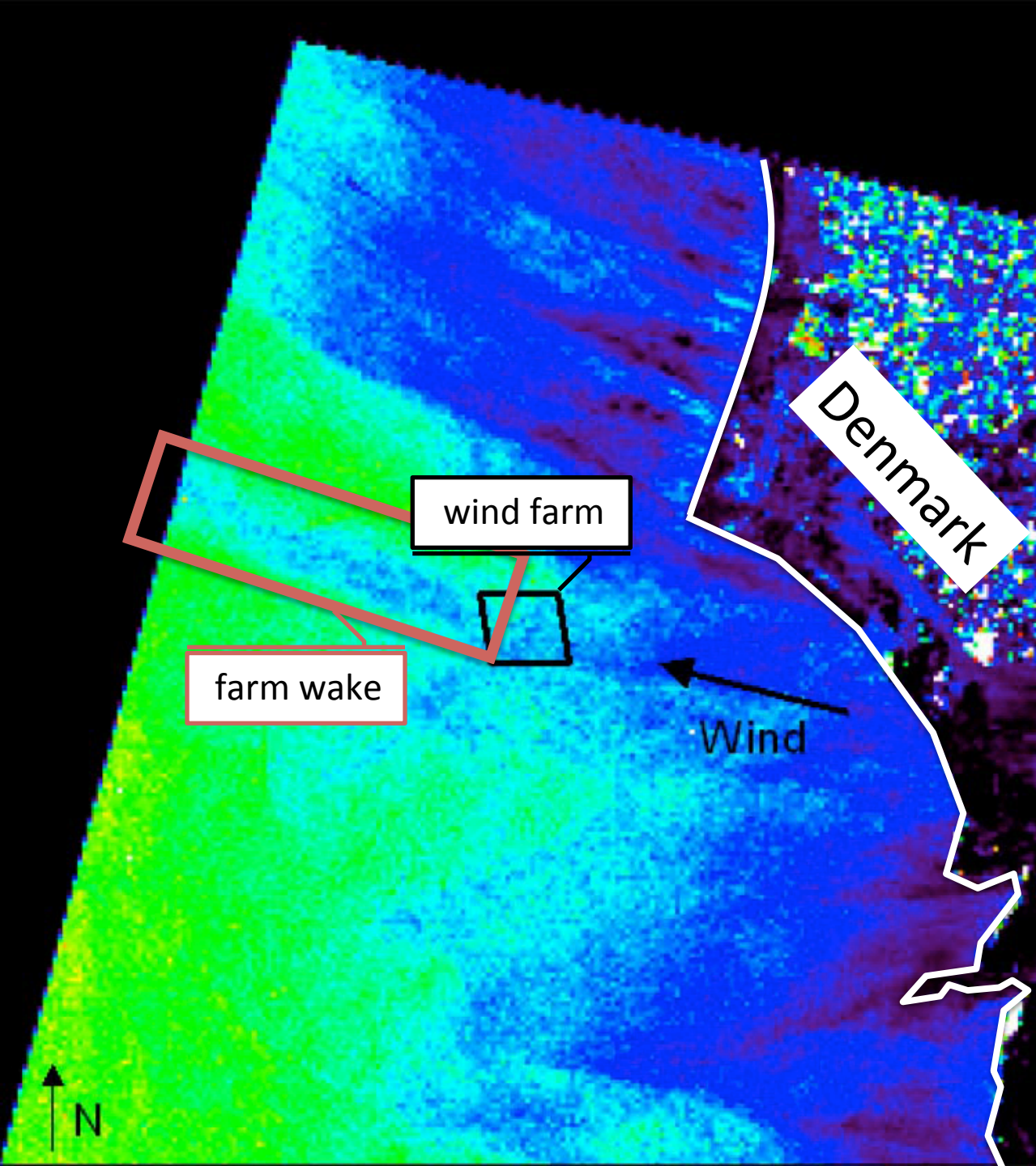
Impact assessment





- System dynamics
- Environment
- **Turbine & Farm Wakes**

Satellite image of surface wind speed



Low wind speed

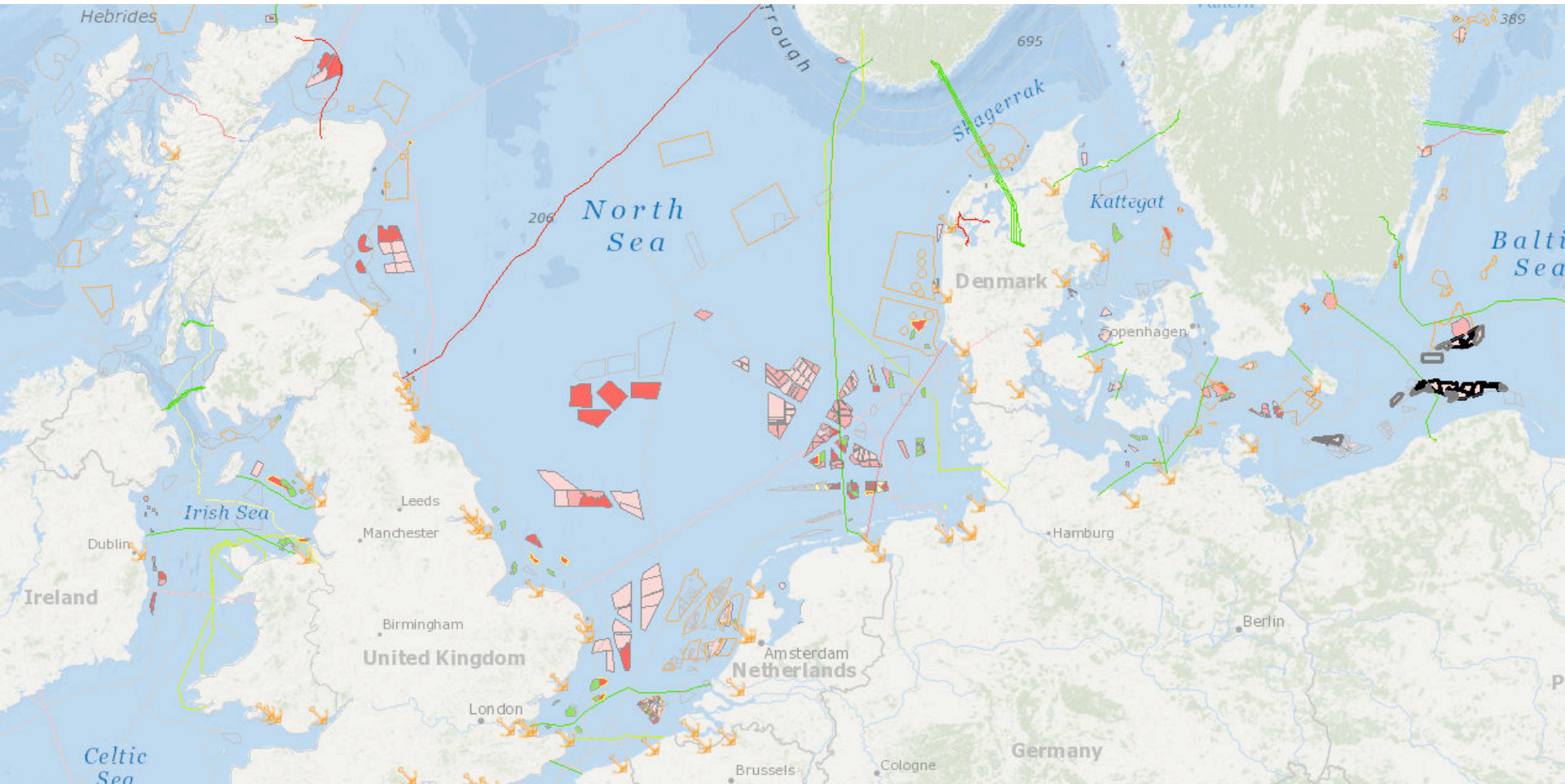


high wind speed



land

Wind farm wakes in site assessment



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



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

This poster gives an overview of the key offshore wind operations and maintenance activity covered by this guide. Activity is centered on the seven categories which are colour-coded and used throughout the guide.

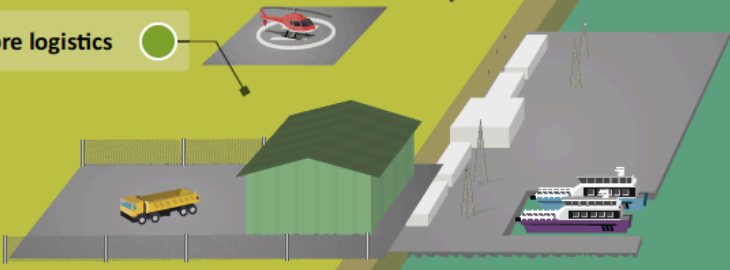
Offshore logistics



Back office, administration and operations



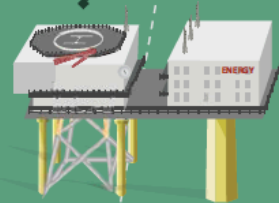
Onshore logistics



~12NM

~40NM

Export cable and grid connection



Turbine maintenance



Array cable maintenance



Foundation maintenance



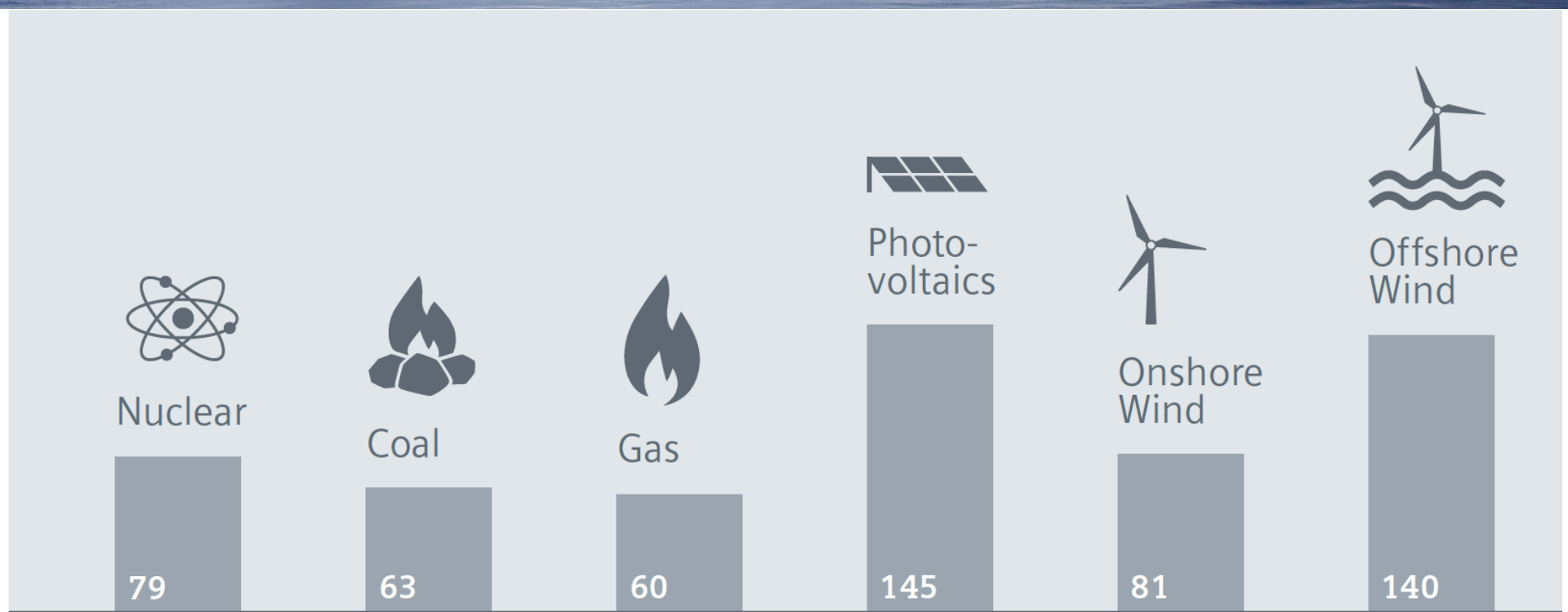
O&M
downtime

WORKBOATS WITH HELICOPTER SUPPORT

OFFSHORE BASE



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

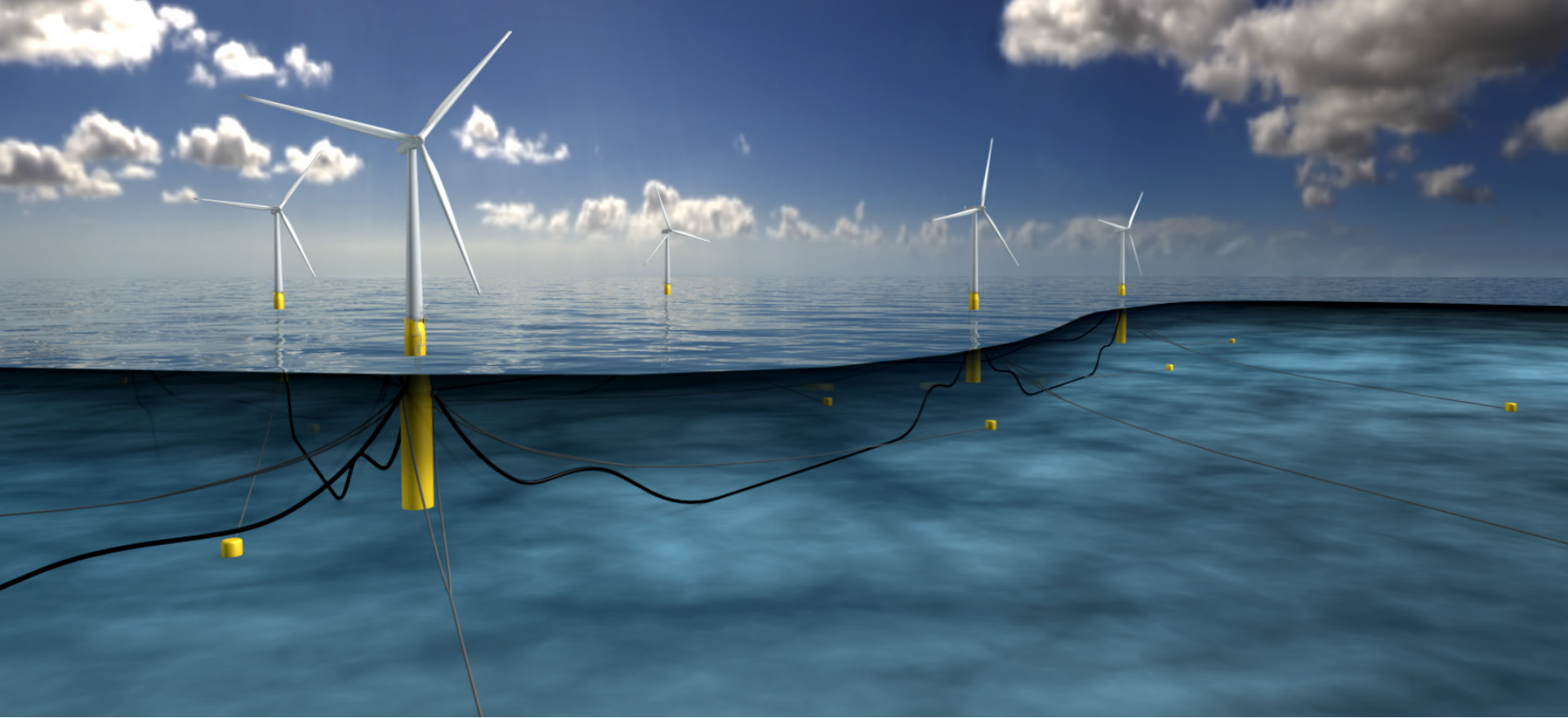


Levelized cost of energy (LCOE) for all primary energy sources in UK for 2013 in €/MWh

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

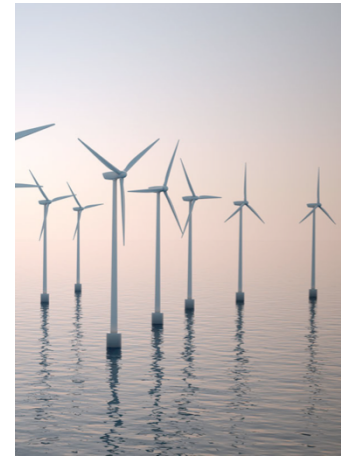
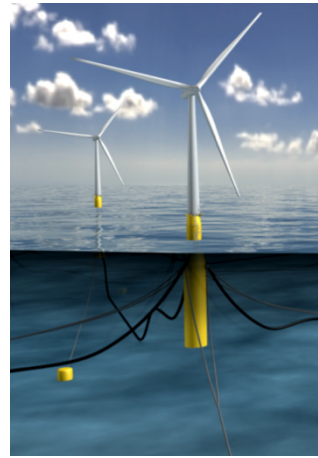
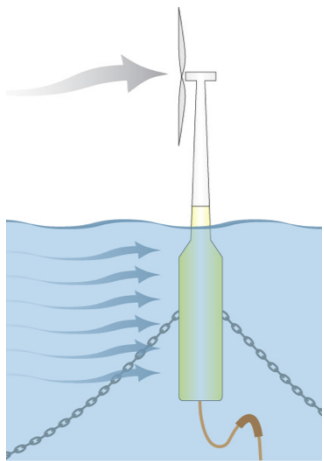


Hywind Scotland



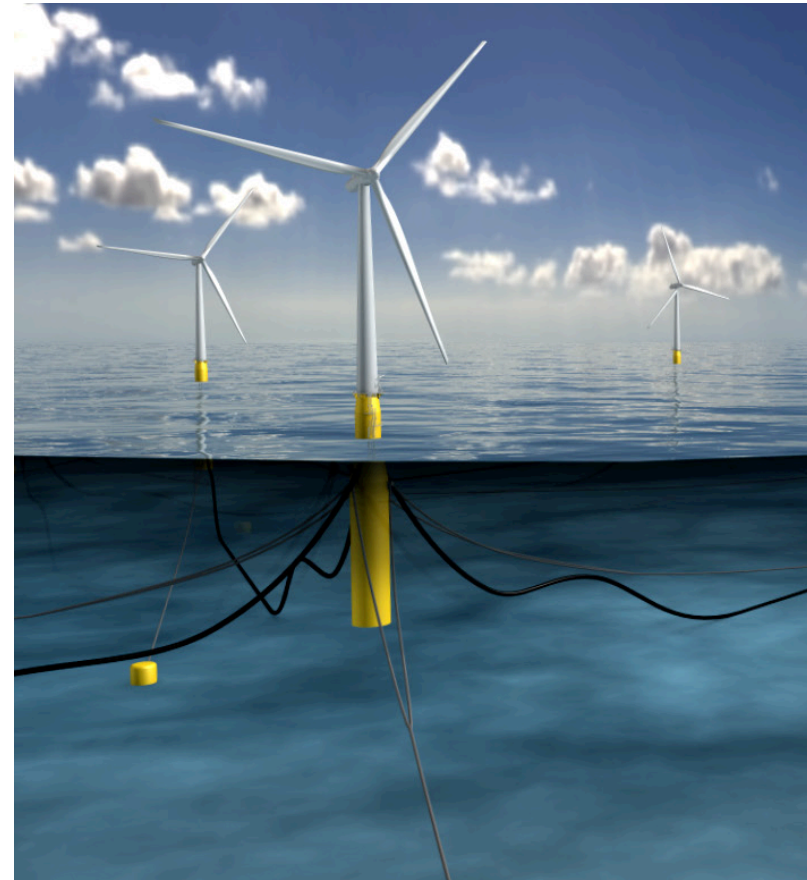
- World's first offshore floating wind park
- [The Hywind Project](#)
- Timescale & Challenges on the Way

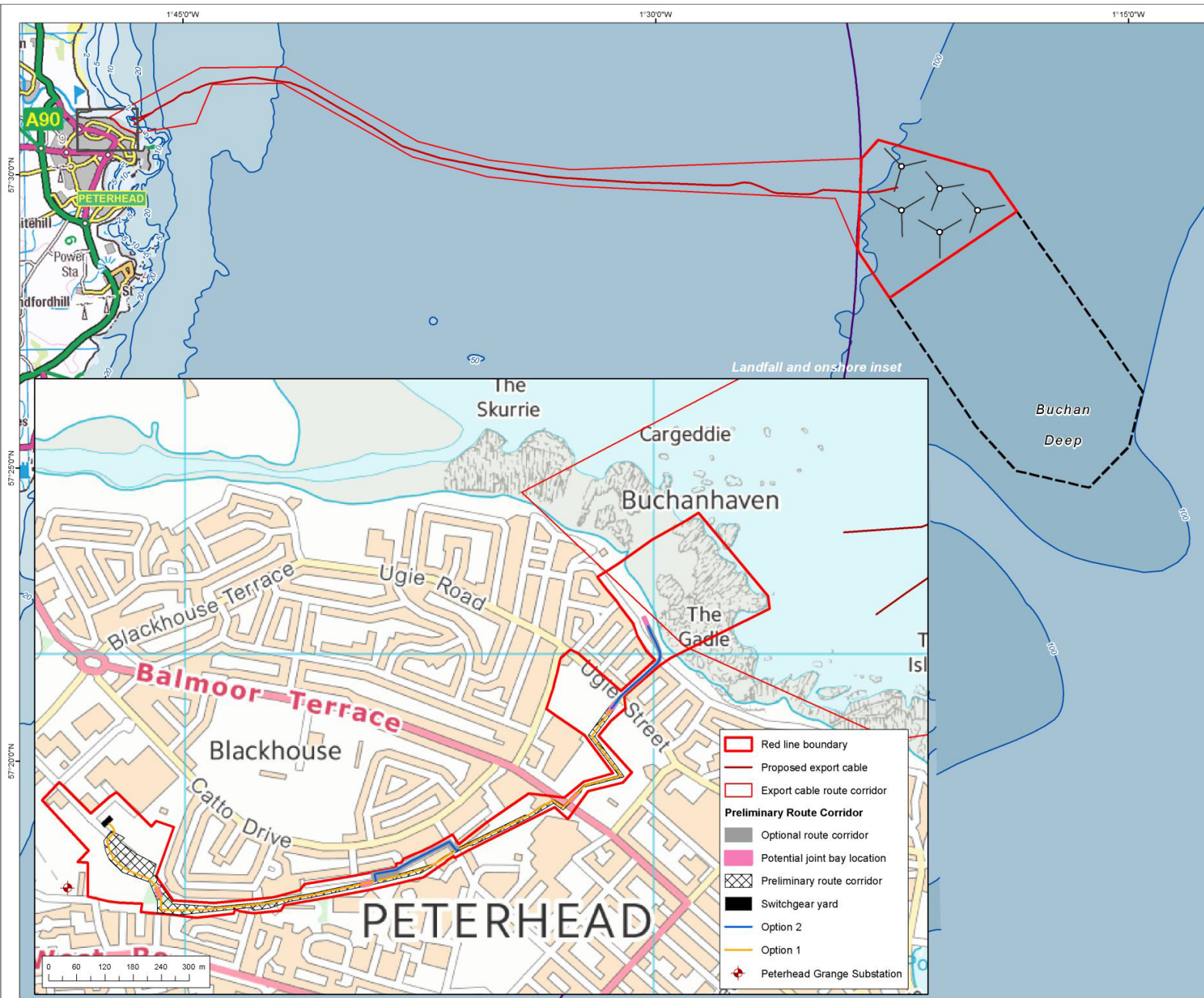
Overview Technology Facts Challenges Hywind Scotland



Hywind Scotland

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



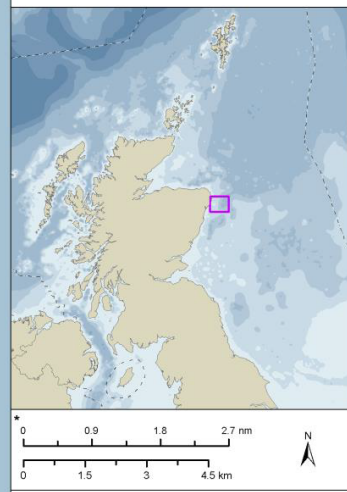


KEY:

- Proposed offshore turbine deployment area
- Buchan Deep demonstration site AfL
- Proposed export cable
- Export cable route corridor
- Wind turbine generator
- Wind turbine generator mooring lines
- 12 nautical mile limit

Bathymetry (m)

- 0 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200



TITLE:

Location Plan

CLIENT:

Statoil

DATE: 16/05/2014	SCALE: 1:119,766	PROJECT: A100142	A3
DRAWN: JHGJ	CHECKED: SE	APPROVED: LF	

DRAWING: A100142_S00_LocationPlan.mxd

SOURCE: © Crown Copyright, 2014. All rights reserved. License No: EK001-0753-MF0200 Not for Navigation. Contains Ordnance Survey data © Crown copyright and database right 2014. UK DEAL

COORDINATE SYSTEM: WGS 1984 UTM Zone 30N



- 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

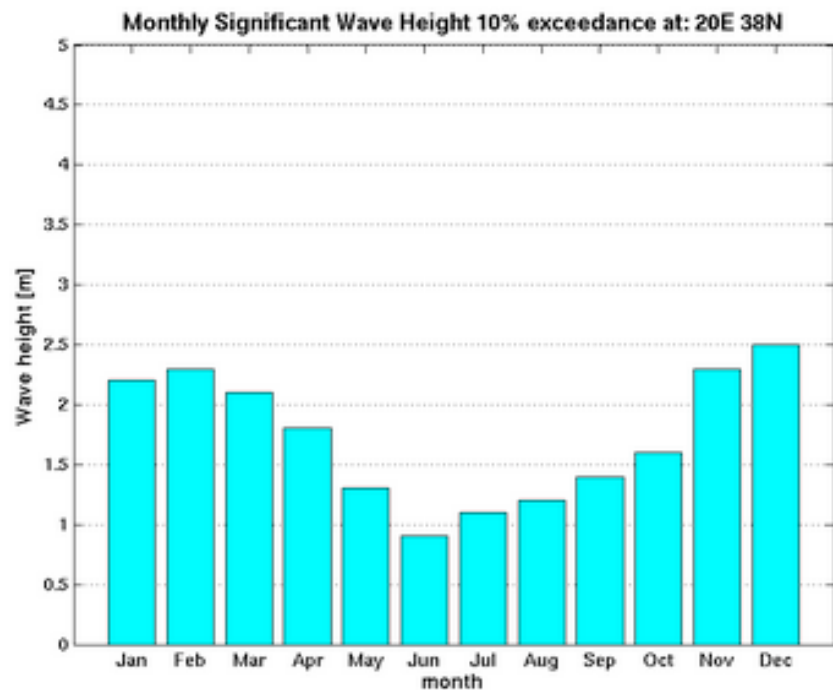
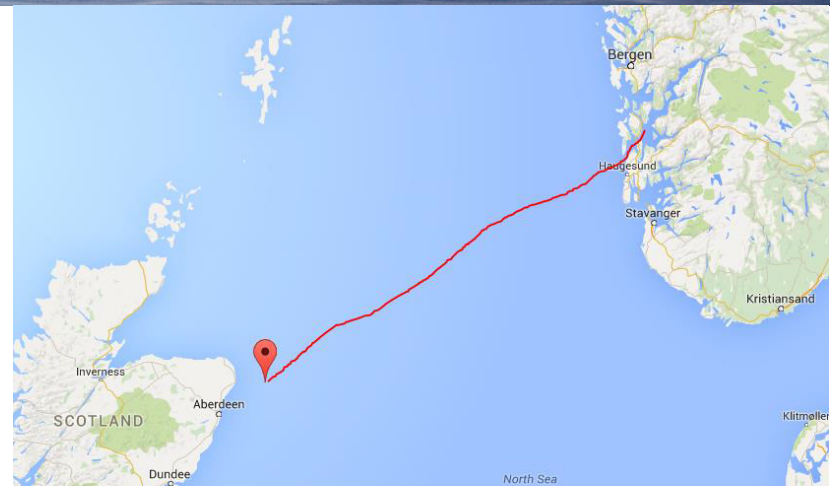
Hywind Demo

Cost  Cost 



- 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



- 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?





Thank you for your
attention!

Offshore Wind Energy

Potential, Challenges and Limitations

Trial Lecture
Valerie-M. Kumer
26. August 2016