The fundamentals of Offshore Wind Energy

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ECN Wind Energy
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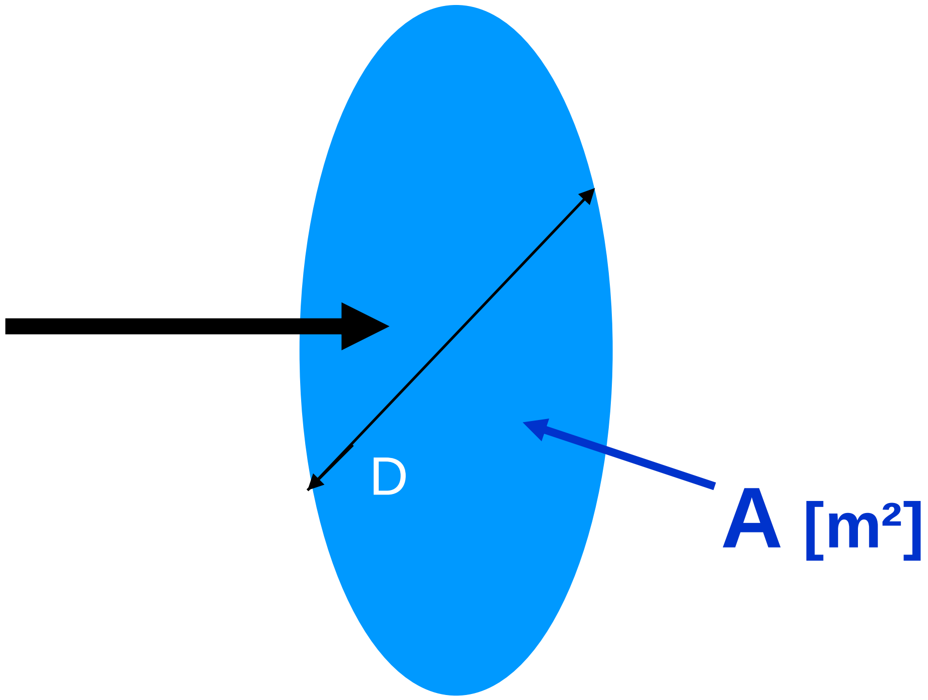
Wind Energy – The Facts
EWEA Offshore 2011, pre-event seminar

Amsterdam, 28 November 2011

$$P_{wind} = \tfrac{1}{2}.\rho.V^3 \; [W/m^2]$$

$$P_{wt} < \tfrac{1}{2}.\rho.\,C_p\,.V^3 \; [W/m^2];\; C_p < 16/27$$ (Lancaster-Betz Limit)

Windsnelheid (m/s)	Windsnelhed (Watt/m²)
3	16
6	130
12	1035



$$A = \pi/4.D^2$$

Energy output is determined by wind speed and rotor swept area and not by generator capacity or rotor configuration !!

Specific Offshore issues

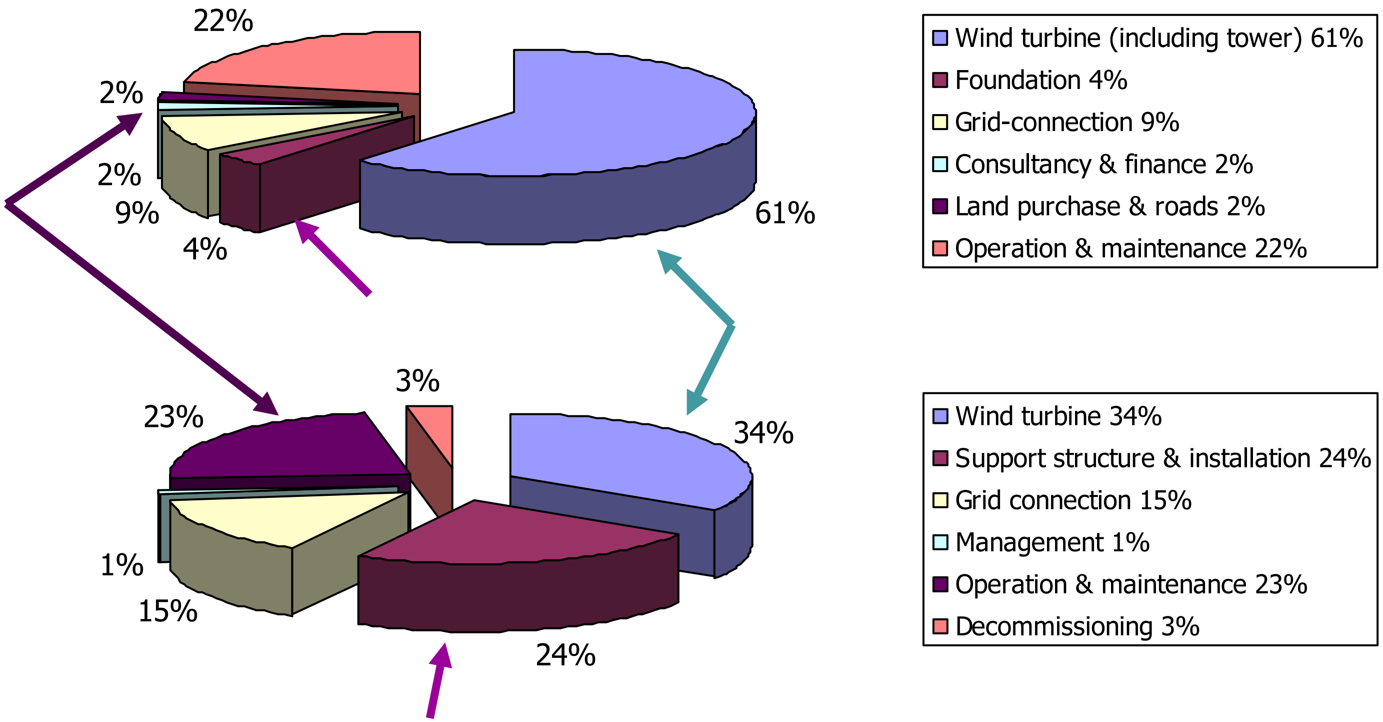
Offshore WE technology:
What makes it different from land based applications?

- Cost breakdown
- External conditions (waves, salt conditions, turbulence, extreme winds, (sea) bottom) (Jørgensen, Beurskens)
- Dedicated & integrated concepts (Beurskens)
- Support structures (Arapogianni)
- Transport and Assembly; Commisioning (ter Horst)
- Operation and Maintenance; Access (Beurskens)
- Grid integration (Morgan)
- Scale & Risk (Guillet)
- Nature issues & Safety (Koulouri)

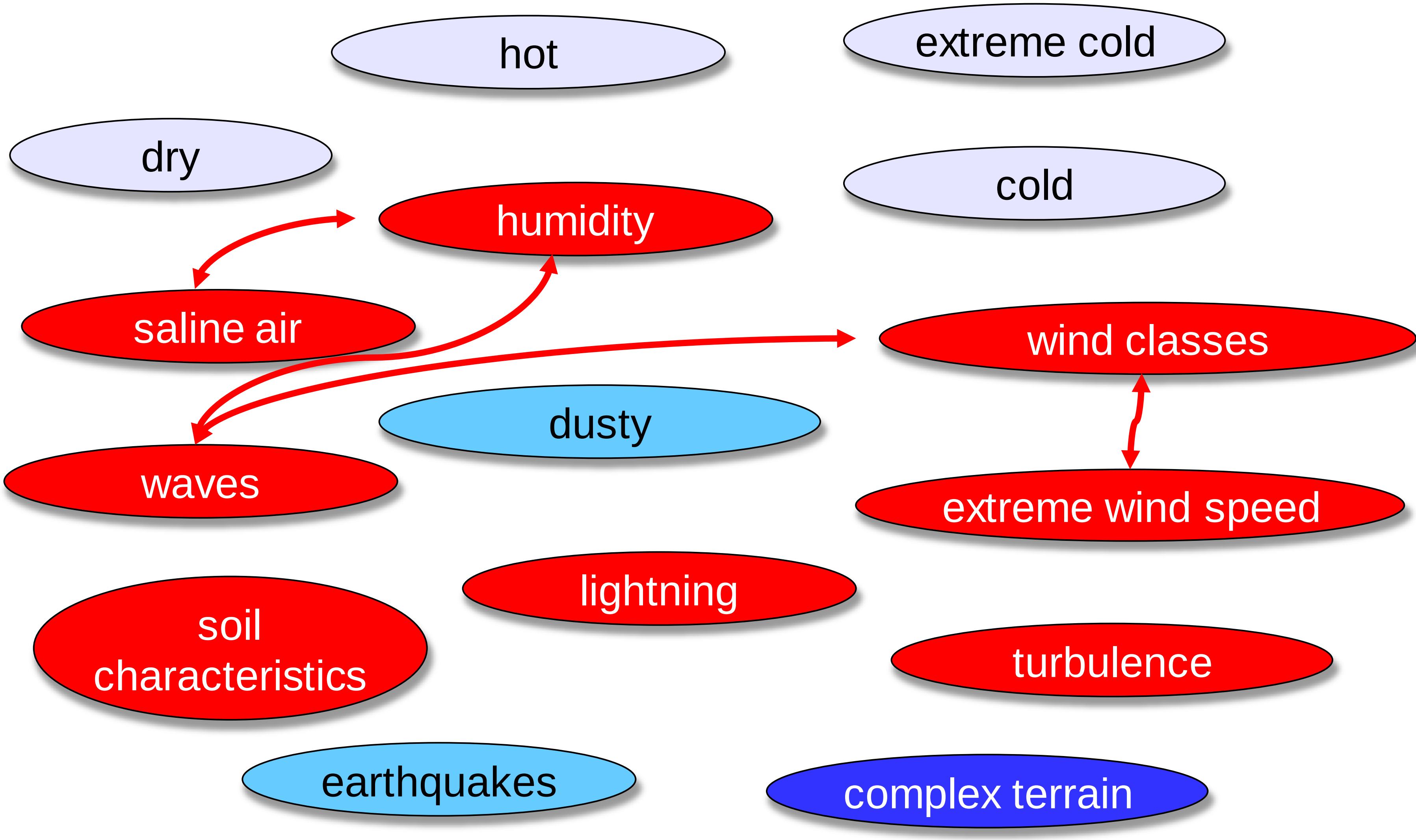
Cost break-down

onshore

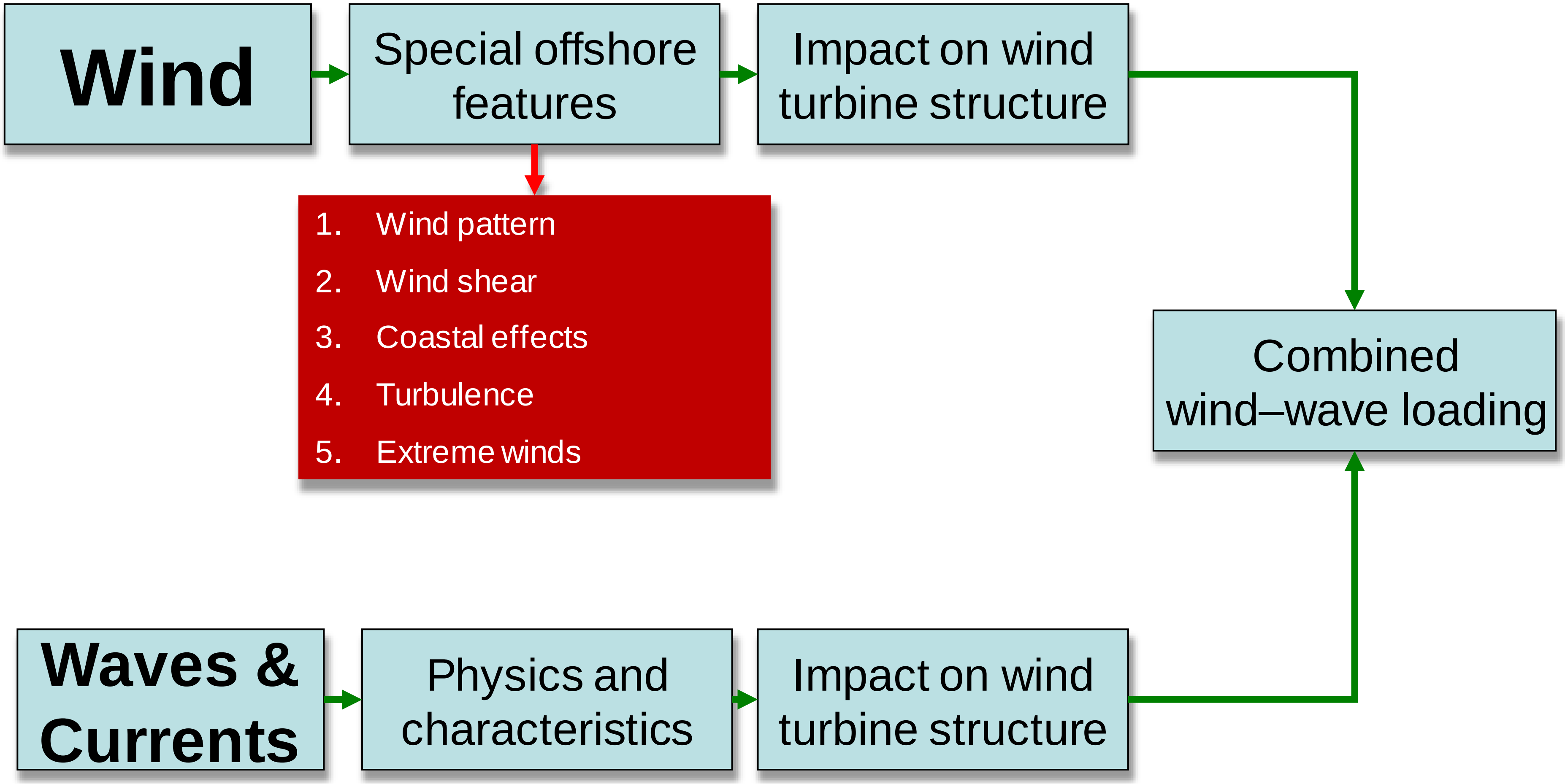
offshore



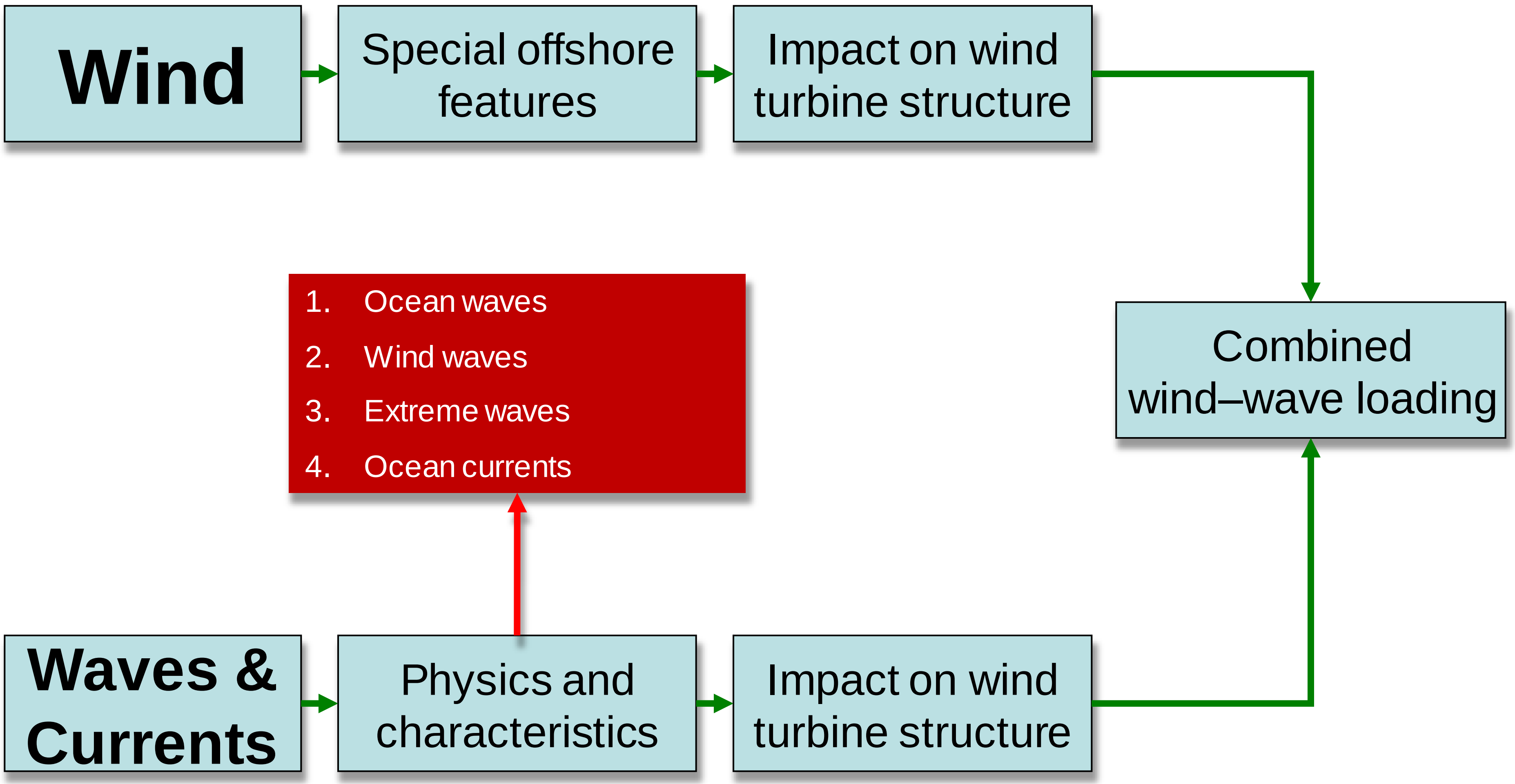
External Conditions



External Conditions



External Conditions



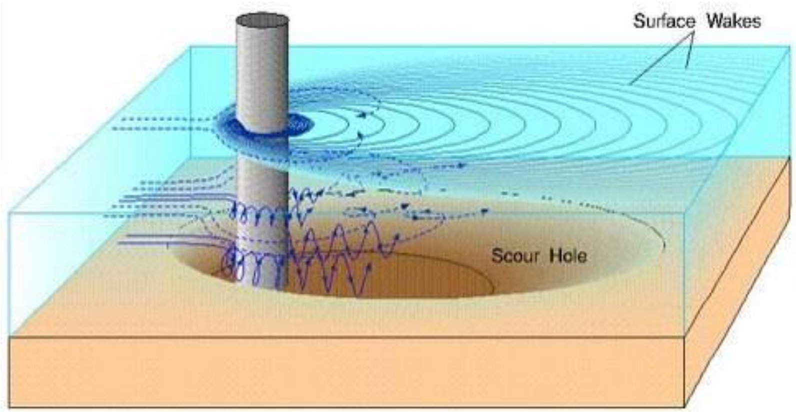
External Conditions; wave & current characteristics

Waves relevant for:

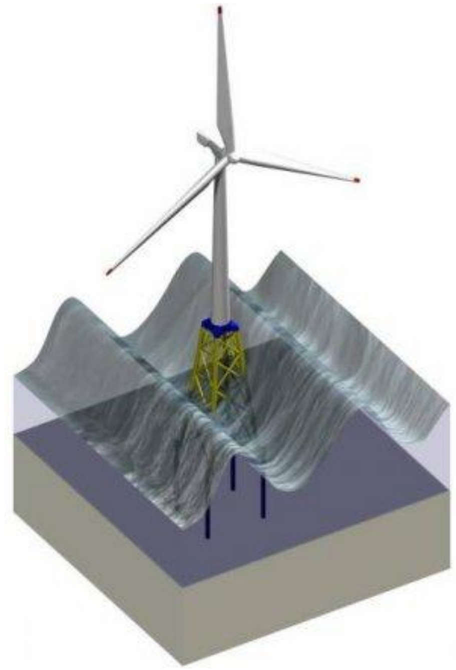
- Access levels
- Extremes
- Fatigue
- Installation & Maintenance

Currents relevant for:

- Loads (Extremes)
- Installation & Maintenance
- Scour



External Conditions; wave & current characteristics

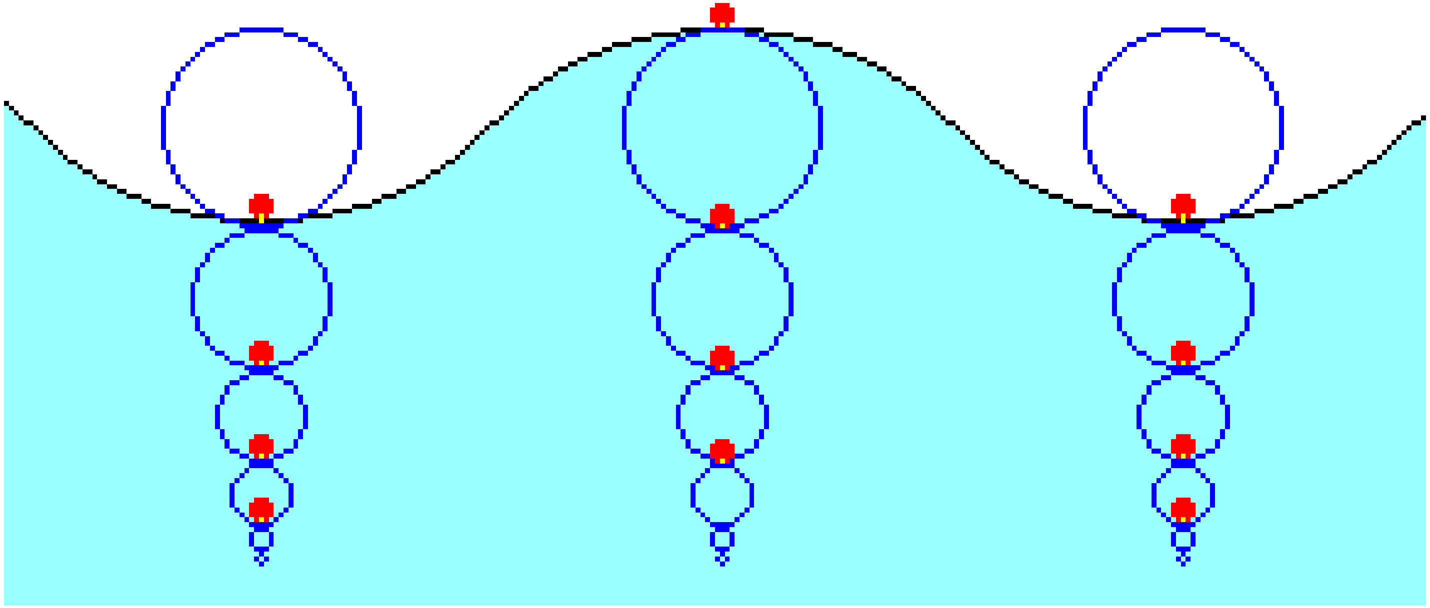


Waves

- Ocean surface waves
- Wind waves

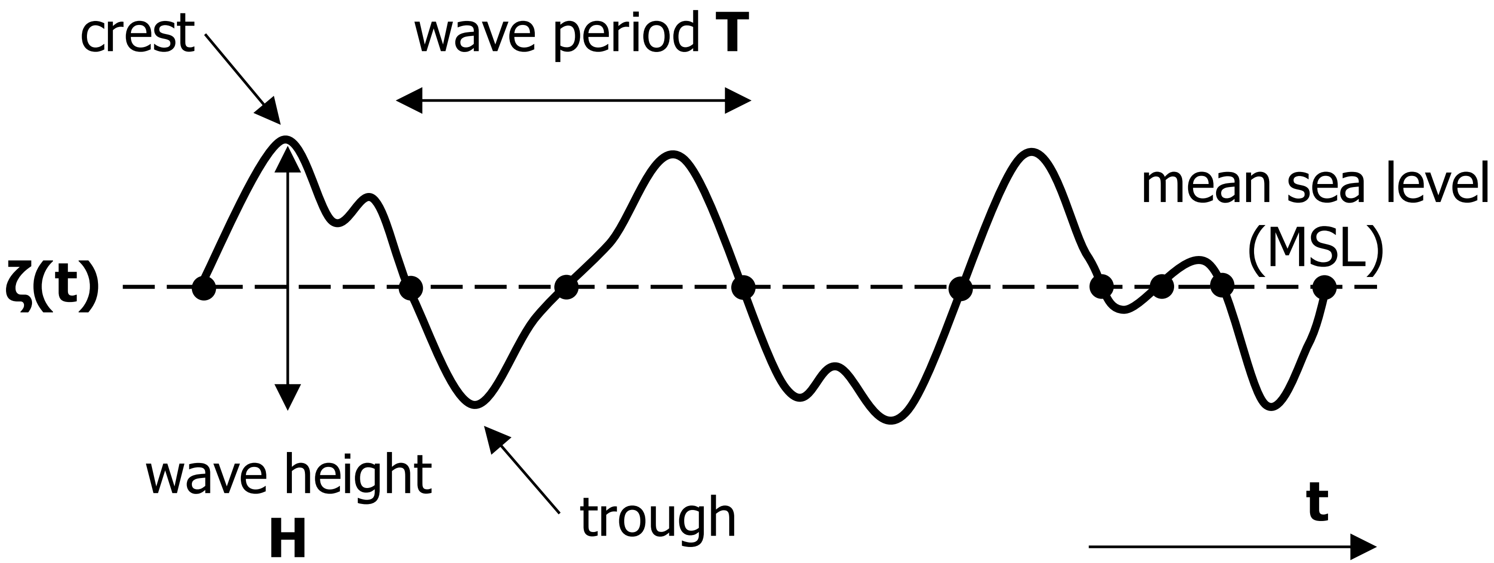
Definition:

"Perturbations that propagate through water"



From TUDelft course. Wybren de Vries

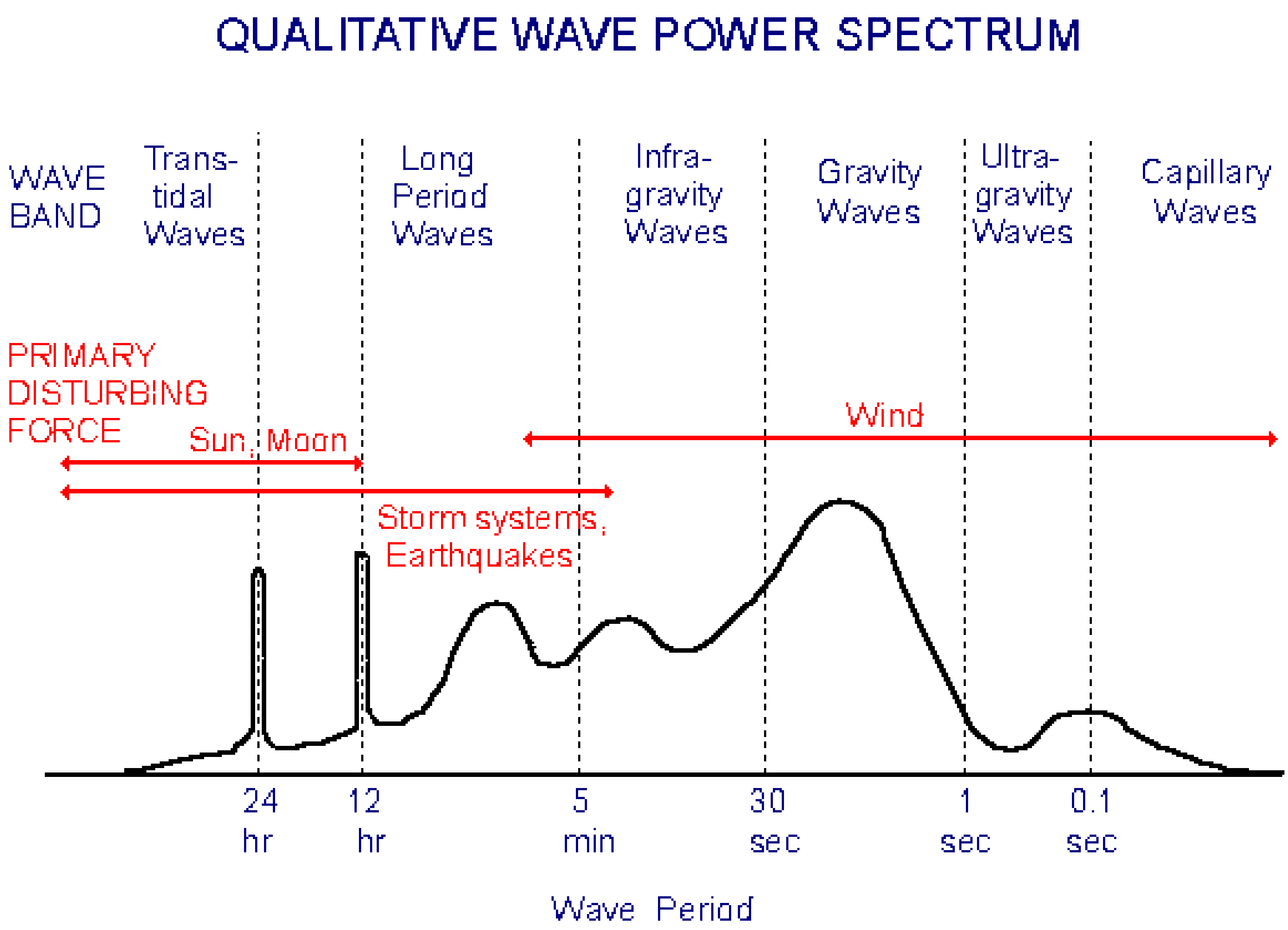
External Conditions; wave parameters



H_s = Significant wave height [m]

"Average of highest 1/3 of the waves in the record."

External Conditions; wave spectrum



Combined wind wave load spectrum analysis

Breaking waves exeriments by ECN & MARIN

Photos: Jos beurskens

External Conditions; currents

Hydrodynamic loads on monopile

Scour

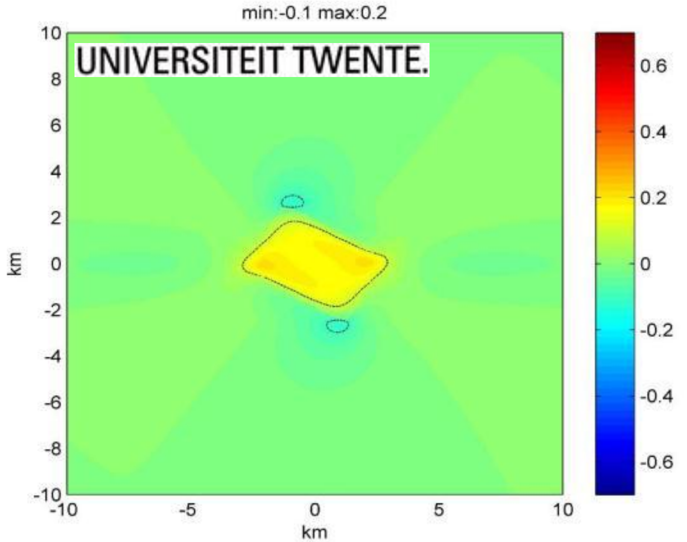
- Caused by current
- Between 1.3 × D and 2.5 × D
- Consider when designing

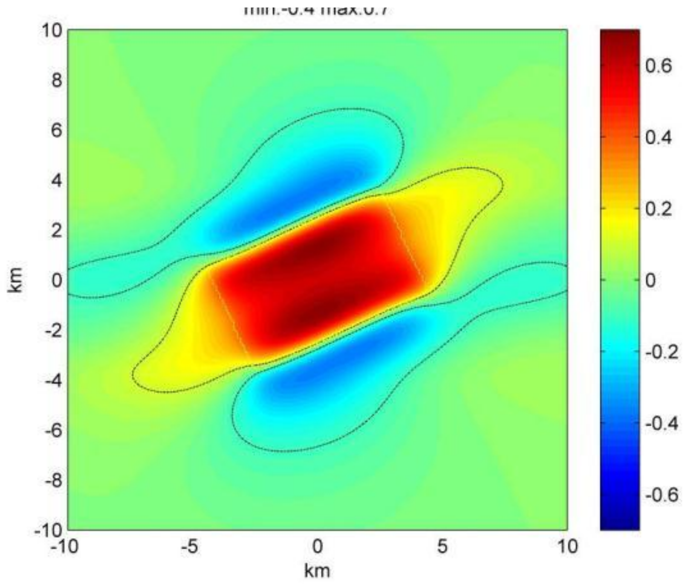
Support structures; seabed condition

sea bed condition

Long term sand transport can be a critical issue. Northe sea: 20 to 70 cm of sand layer removal in 100 years time.

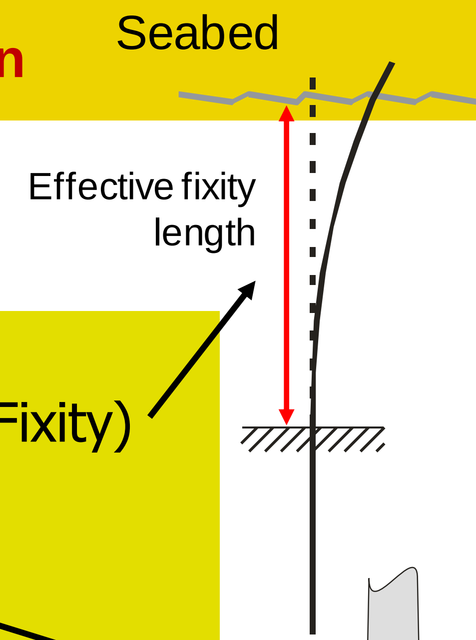
Possible impact on structural dynamics.





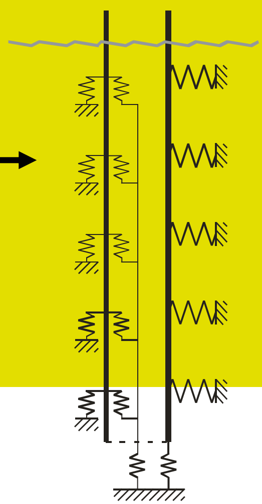
Ref.: We@Sea. Uni. Twente

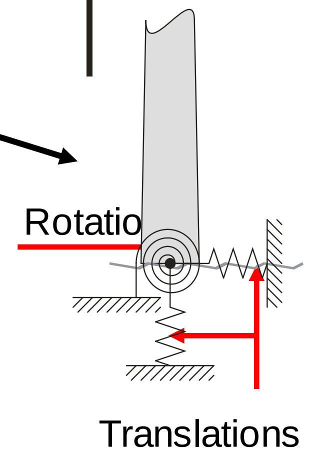
Support structures; seabed condition



Foundation models

- Fixed at some distance below seabed (Effective Fixity)
- (Un)coupled rotational and lateral spring
- Stiffness matrix
- Distributed springs model
- Finite element model of pile-soil structure





Note: soil not homogeneous “soil ≠ soil”

From TUDelft course. Wybren de Vries

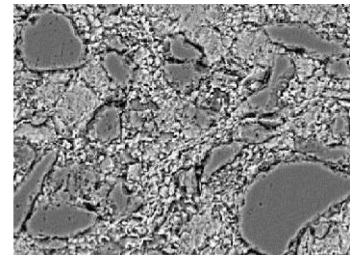
Support structures; seabed condition

Relevant for:

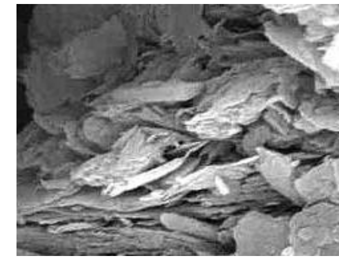
- Support structure dynamics
- Bearing capacity
- Scour
- Installation

Soil Types

Sand



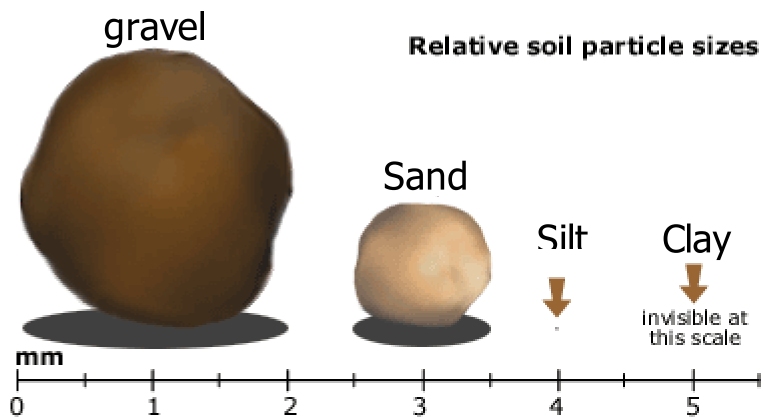
Silt



Clay

Peat

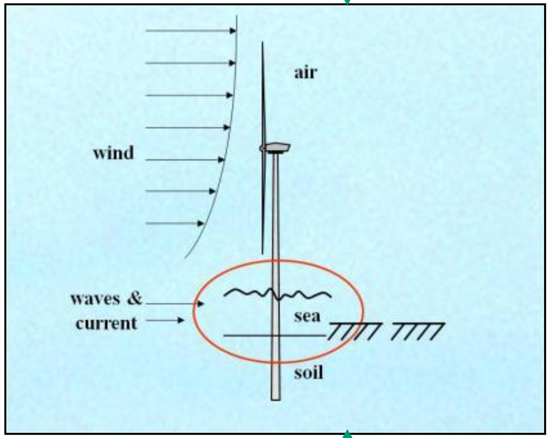
Rock



From TUDelft course. Wybren de Vries

External Conditions; combined loads

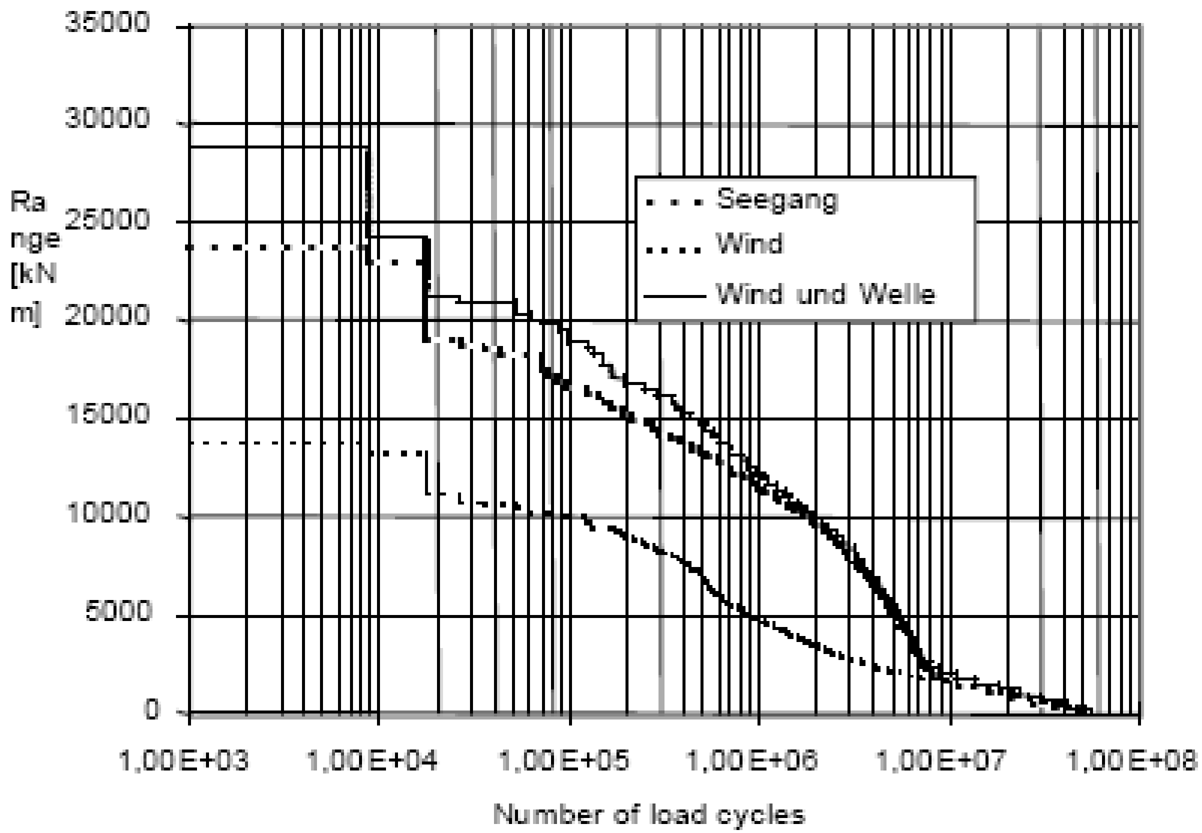
Wind → Special offshore features → Impact on wind turbine structure



Waves → Physics and characteristics → Impact on wind turbine structure

Combined wind–wave loading

External Conditions



Combined wind- wave laoding < wave loads + wind loads

Ref.: S. Schwartz, K. Argyriadis. GH-GL

Cost of support structures are dominant and are relatively insensitive to load carrying capacity

↓

Up scaling is necessary !

Up scaling

For the engineer:

mass ~ (D^3)
cross section ~ (D^2)
stress (= mass/cross section) ~ D

For the economist:

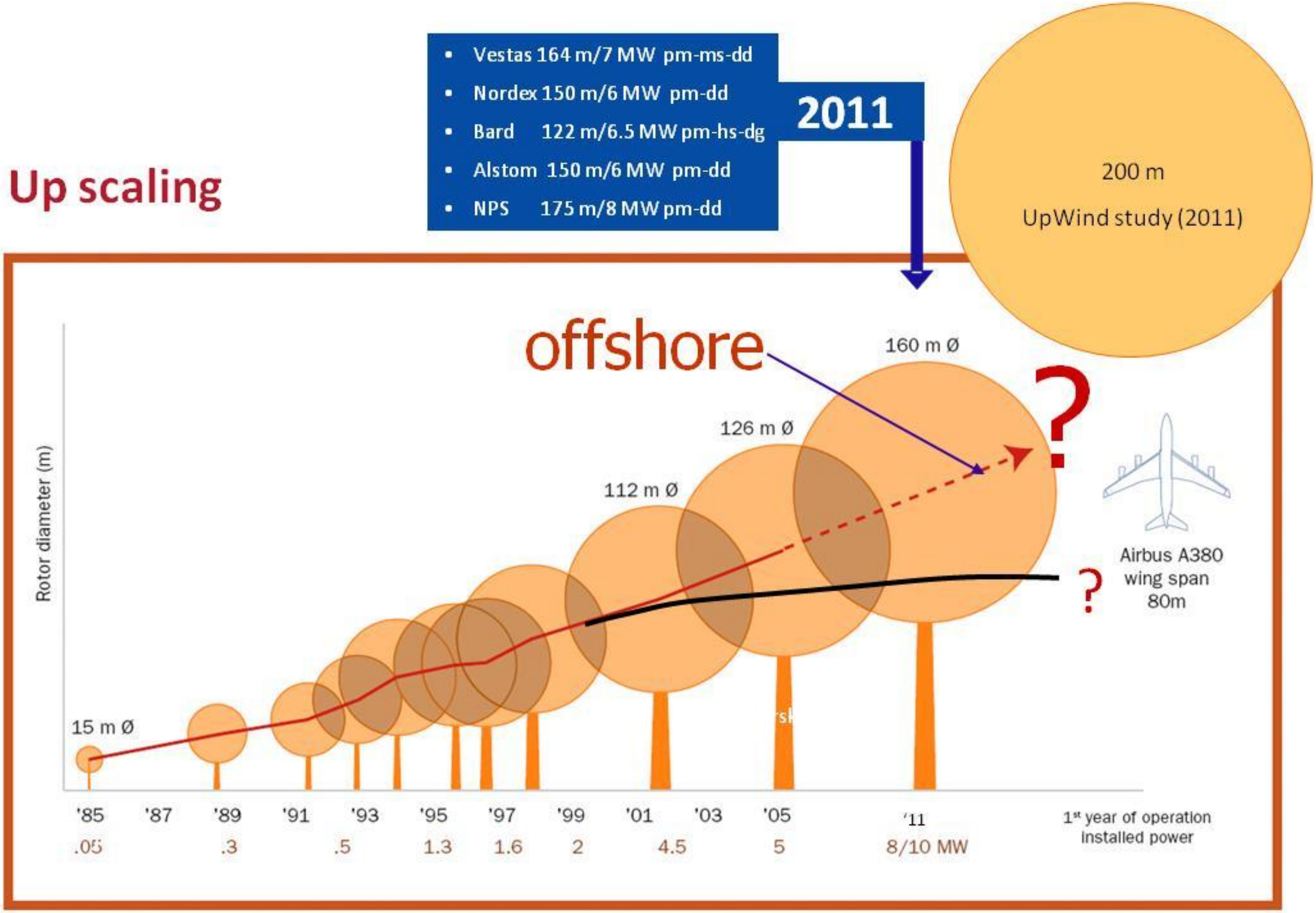
investment cost ~ (D^3)
energy output ~ (D^2)
COE (= inv. cost/energy output) ~ D

Development of advanced materials with a higher strenth to mass ratio

Up scaling

- Vestas 164 m/7 MW pm-ms-dd
- Nordex 150 m/6 MW pm-dd
- Bard 122 m/6.5 MW pm-hs-dg
- Alstom 150 m/6 MW pm-dd
- NPS 175 m/8 MW pm-dd

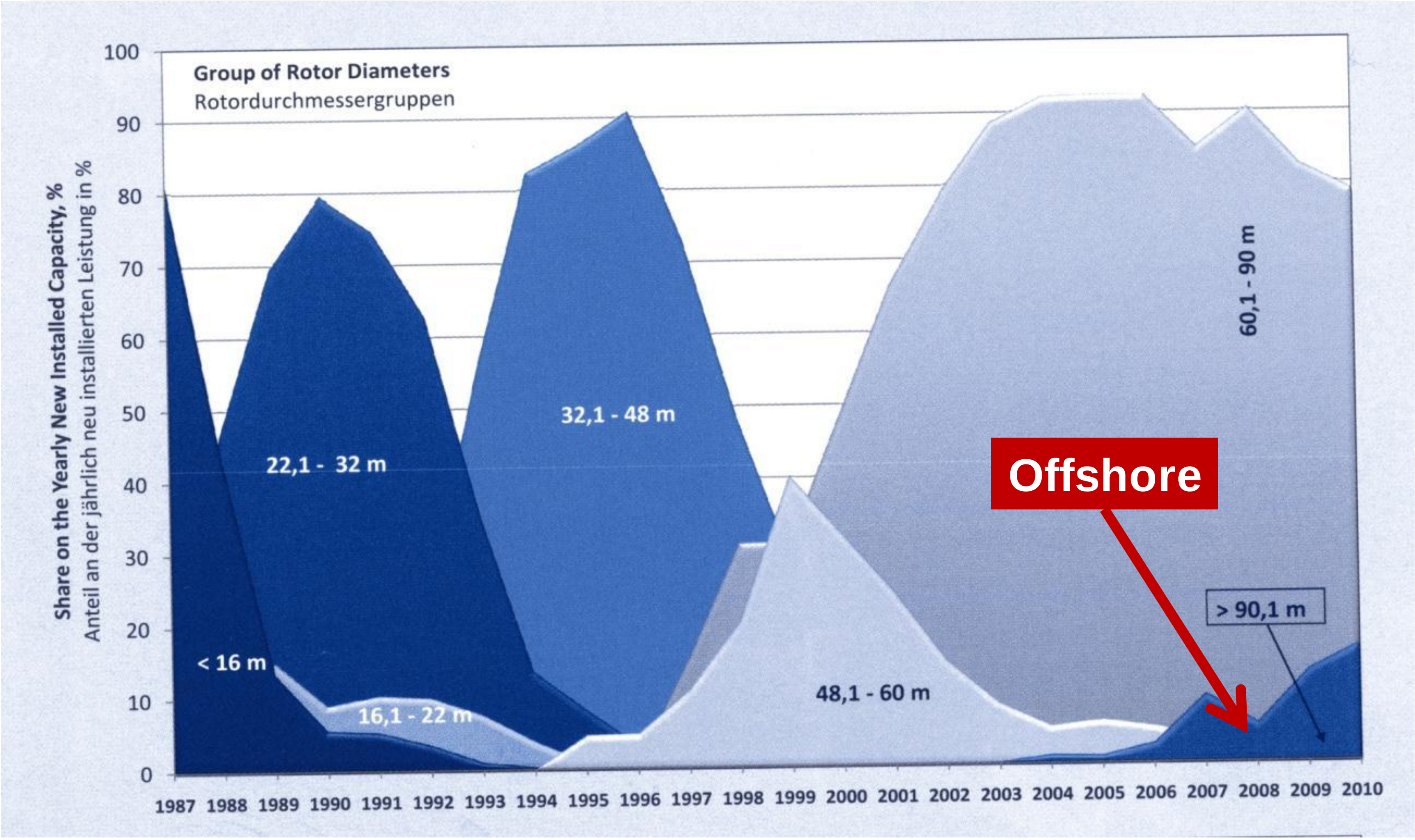
2011



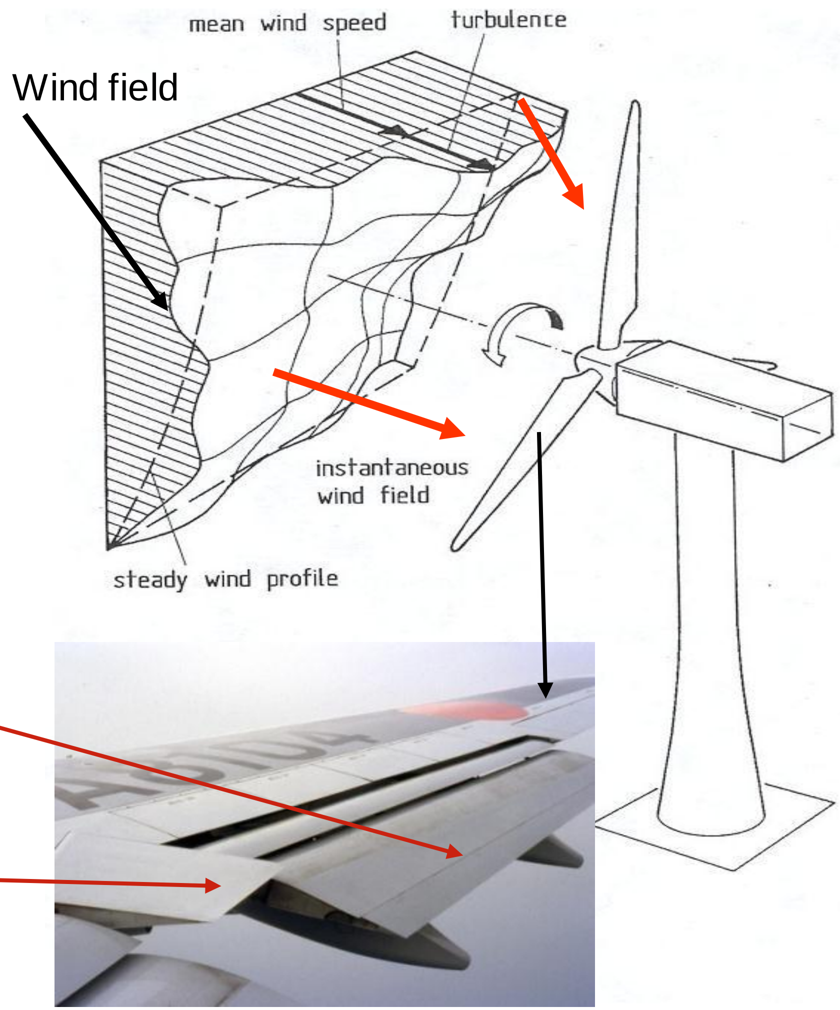
Jos Beurskens

Wind turbines

Product cycle wind turbine according to capacity



Distributed blade control necessary



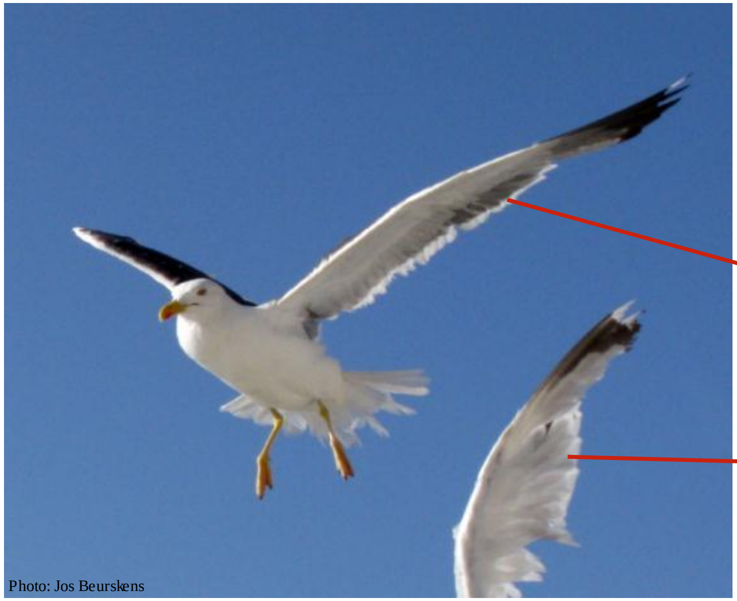
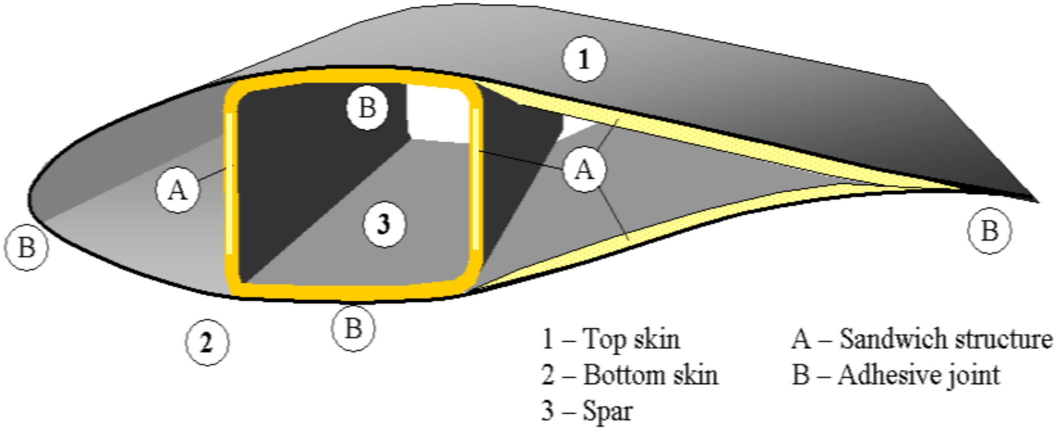


Photo: Jos Beurskens



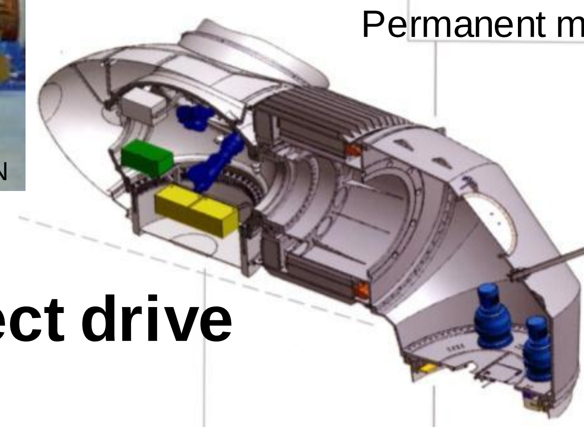
UpWind

Thermoplastic blades

Wind turbine

Classical drive train

Jos Beurskens



Direct drive

HTS (high temperature super conductivity)

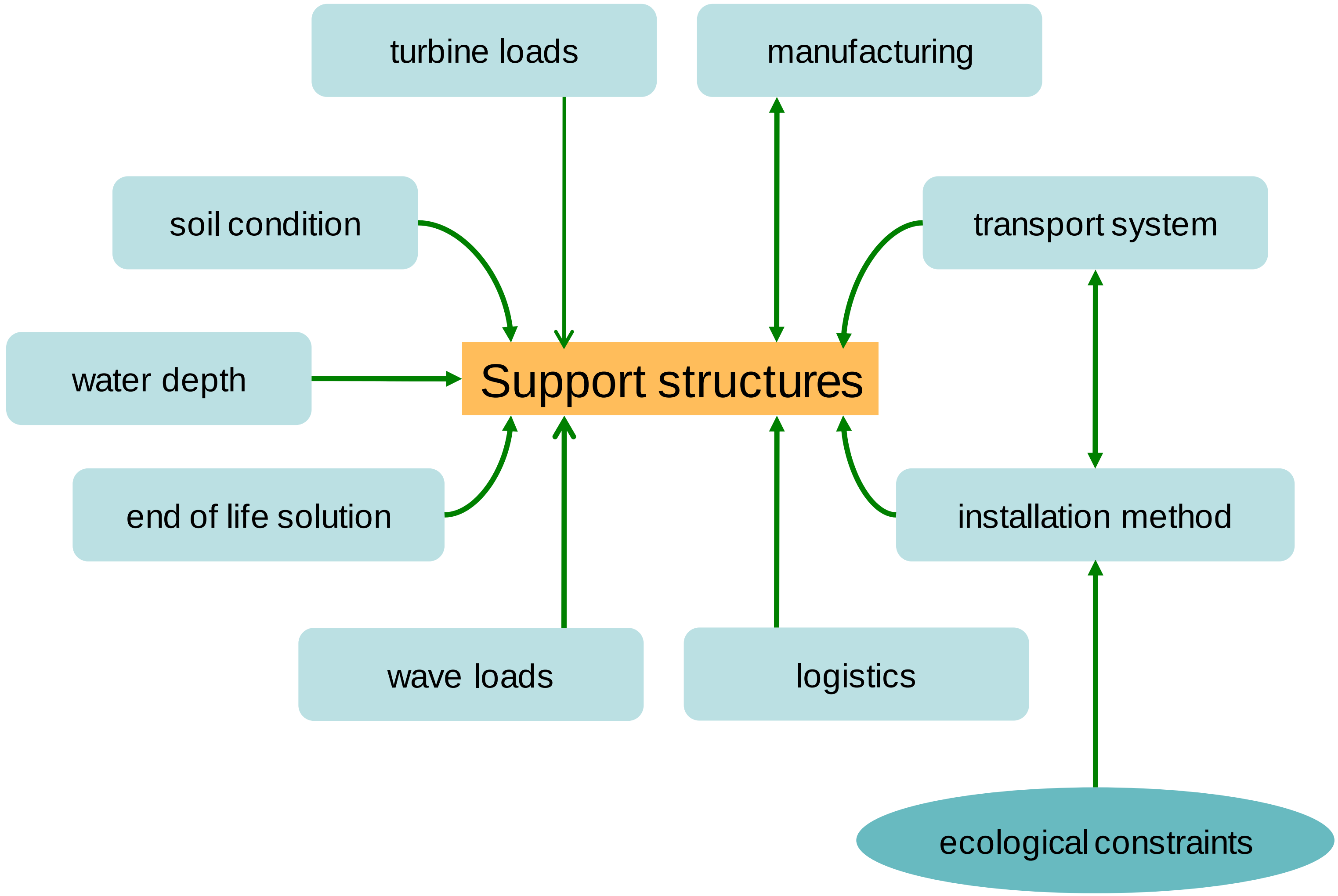
Towards dedicated (radical) designs

Difference between wind energy and oil & gas

Oil & Gas	Topic	Wind energy
Vertical loading	Loads	Mainly horizontal loading
One of a kind	manufacturing	Series & automated
< 500 m	Water depth	<50 m (ground based)
Design driven	Design	Large flexibility
Marginal effect on COE	Cost break down	Large effects on COE

Towards dedicated (radical) designs

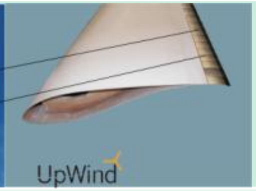
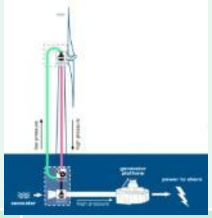
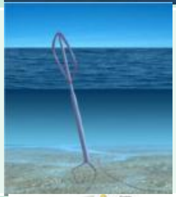
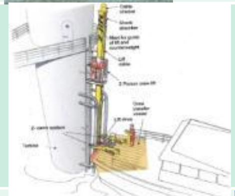
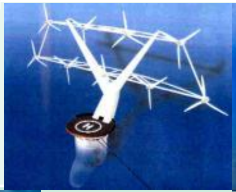
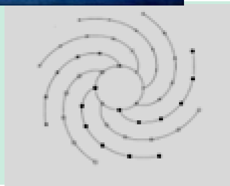
Requirements prescribe the concept to a large extent



Full integration of

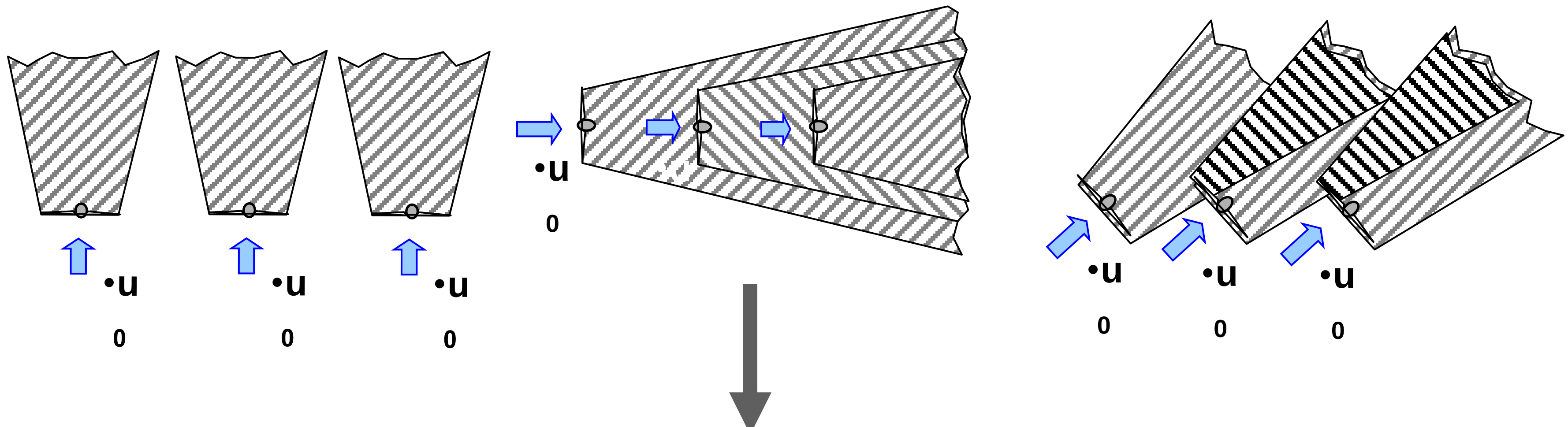
* wind turbine
* support structure
* transport and installation, commisioning
* O&M
* decommisioning,

will lead to radical design changes

Requirement	Solution	Concepts
Up scaling (Full blade pitch becomes ineffective due to large variations in the wind field in the rotor plane)	Distributed blade control with advanced (LIDAR based) control systems	  
Reliability	Reduced number of components (central conversion unit in wind farm, direct drive generators, passive yawing)	 DOT Hydraulic conversion  Lagerwey
Weight reduction	Two bladed rotor (reduces rotor weight and increases rotor speed, which leeds to reduced drive train weight)	 2B-Energy  Stork Ultimate turbine
Integrated operations and design	Transport of floating components. Self erecting and installing systems	 Deep Wind  Sway  Selsam-Sea
Servicebility	Access technology	 Z Technologies  Ampelmann
Maintainability	Floating cantilever structures	  Lagerwey
Wind farm efficiency	Movable foundations Non conventional wind farm lay outs	 Ideol (movable foundations)  Topfarm

Some key figures (per 12-2010)

• Total installed offshore wind power:	3554 MW
• Total number of projects:	43
• Average power per project:	83 MW/project
• Average power of 10 smallest projects:	8.1 MW/project
• Average power of 10 largest projects:	198 MW/project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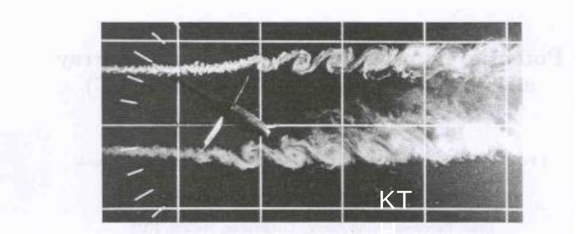
Wind farms

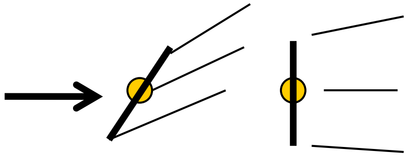
Improving output & decreasing variability by:

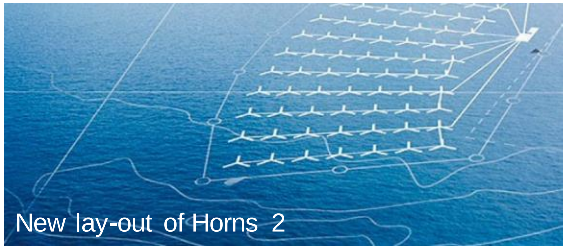
- Wind turbine control
- Different lay out of arrays

Effects depend on:

- Stability of atmosphere
- Stability of wakes (meandering, turbulence)
- Turbulence intensity

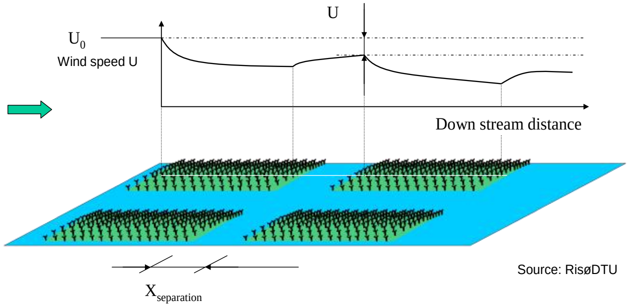





New lay-out of Horns 2

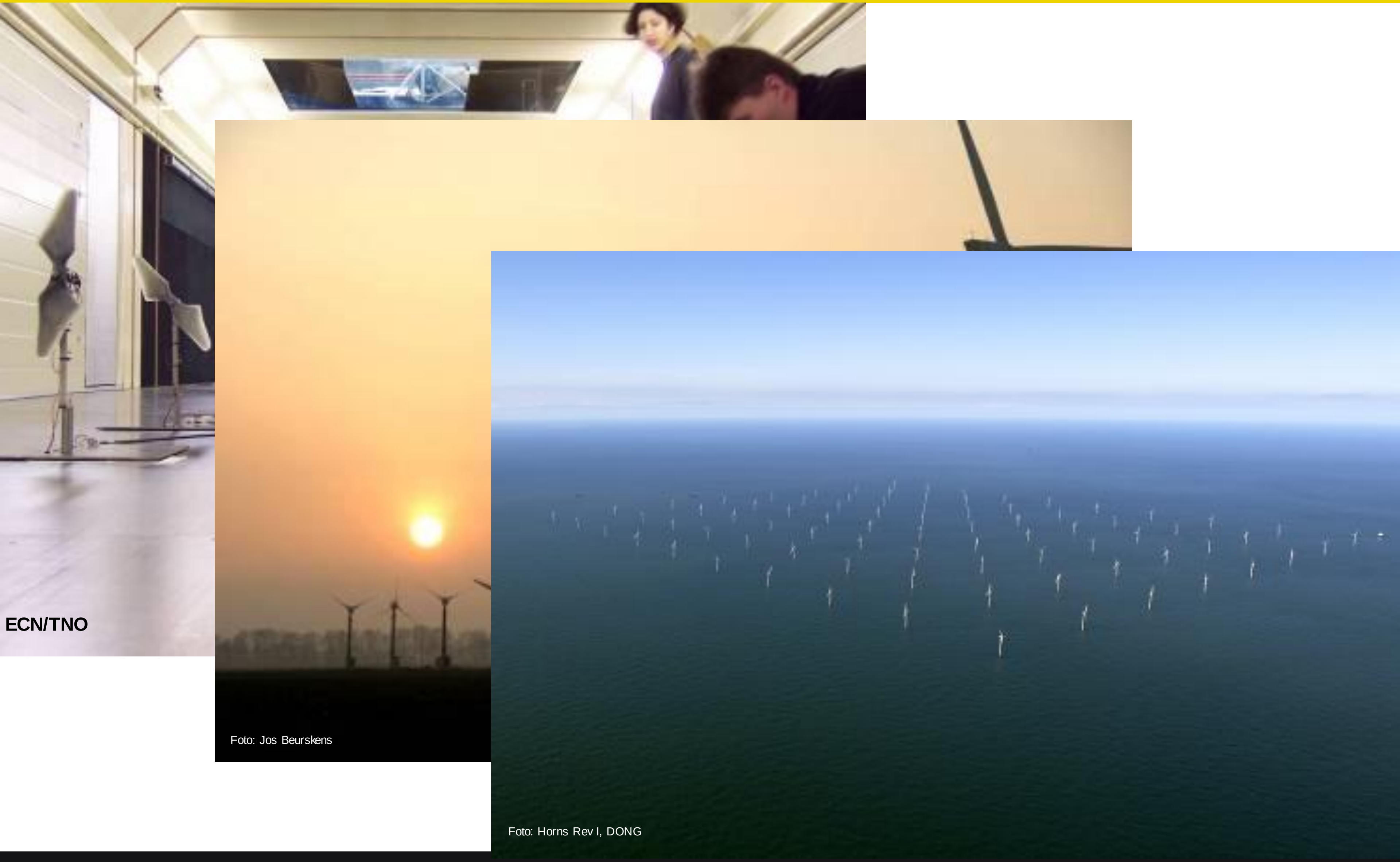
Interaction between wind farms:

- Consequences for WE resource & spatial planning
- Impact on macro climate



Source: RisøDTU

Wind farms



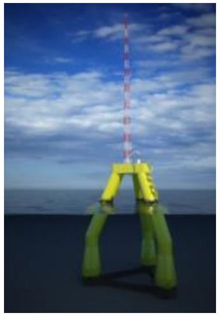
ECN/TNO

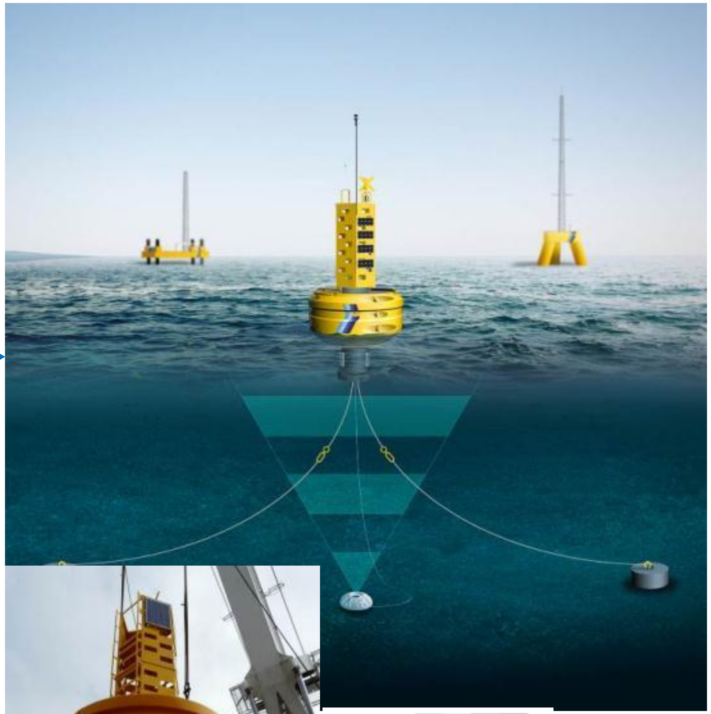
Foto: Jos Beurskens

Foto: Horns Rev I, DONG

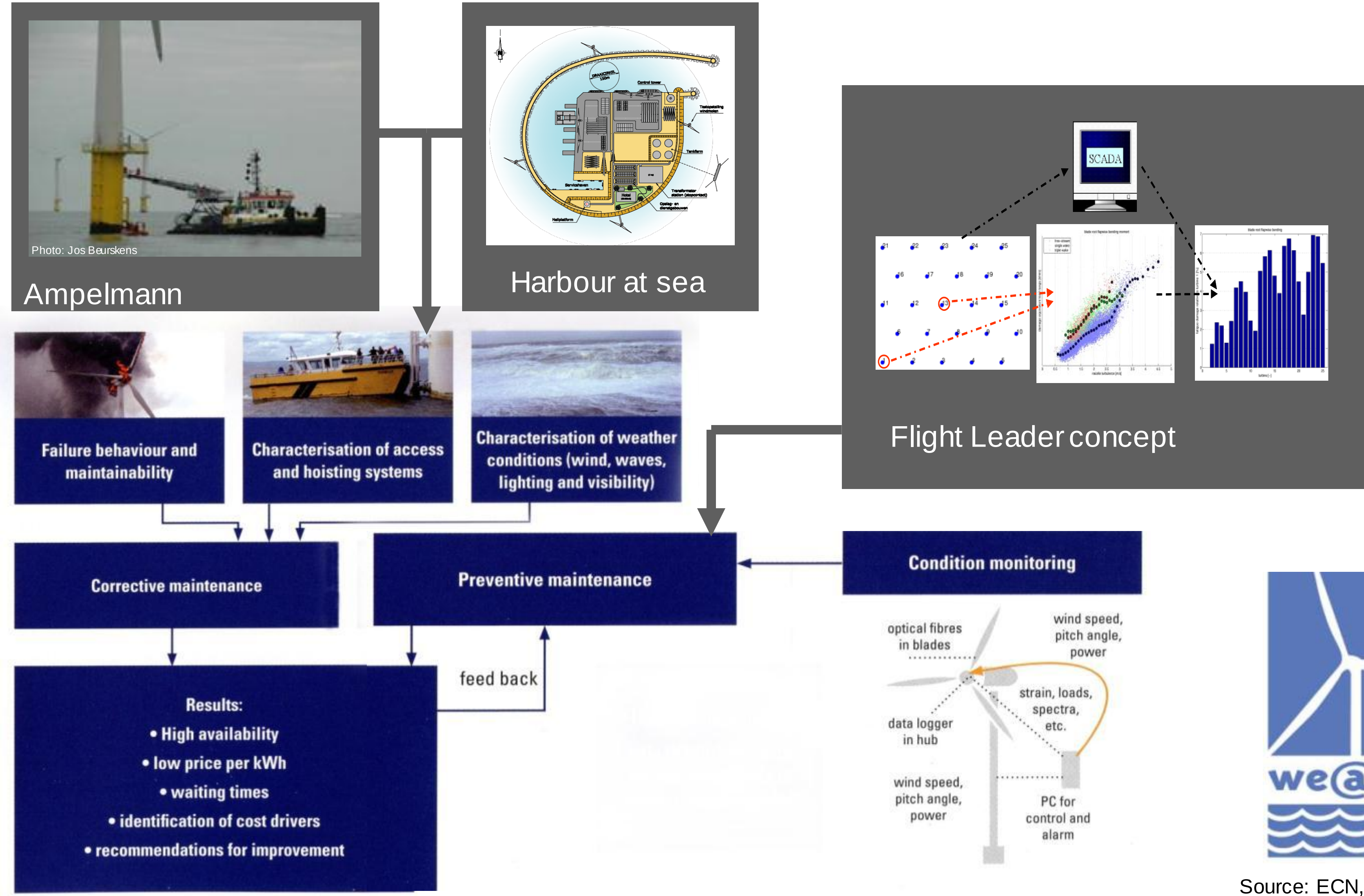
Wind farms

Measuring for verification is a problem; mobile measuring stations





Operation & Maintenance (O&M)



Source: ECN, HEDEN

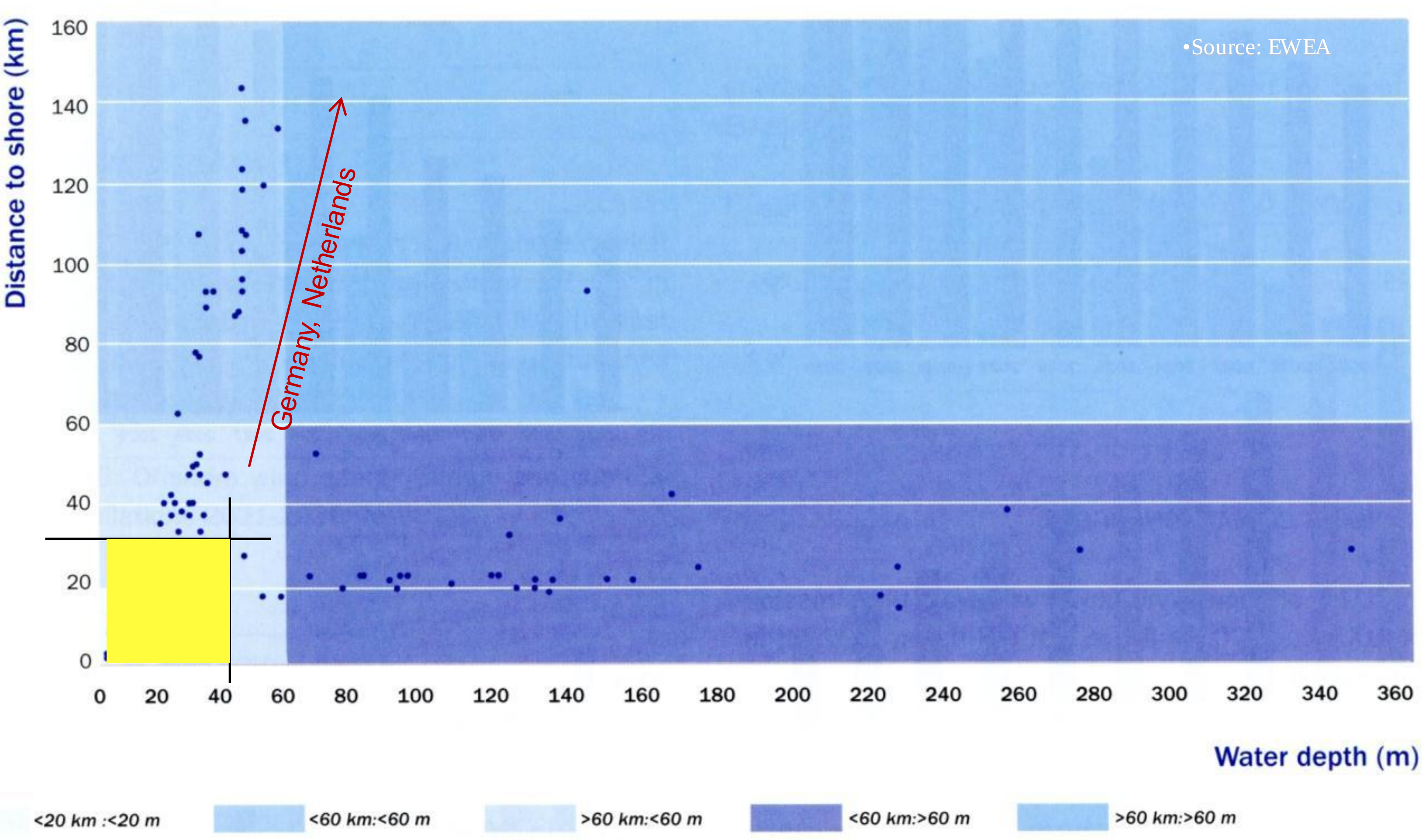
O&M: Access technology

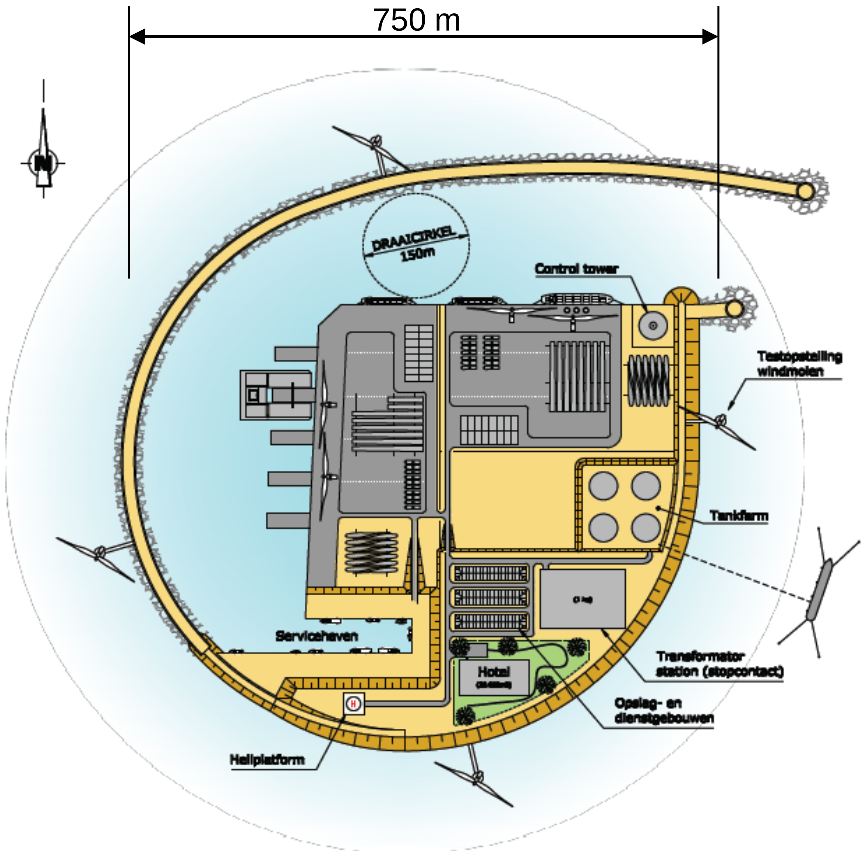
Ampelmann concept
(spin off TU Delft)

OAS concept

O&M: Logistics

FIGURE 10: **Development of the offshore wind industry in terms of water depth (m) and distance to shore (km)**





Harbour at sea

750 M€
Capacity 1000 MW/year
T = 5 to 7 years

Lievense, R. Prins

O&M: Logistics

For WE:

1. Station for transport, assembling, maintenance
2. Accommodation for personnel
3. Spare parts storage
4. Workshops
5. Commissioning facilities for entire wind turbines
6. Test sites
7. Transformer station for wind farm
8. Electrical sub-station for land connection
   and offshore circuit

Other functions:

1. Aquaculture for feedstock materials and food
2. Emergency shelter
3. Marina
4. Gas-to-wire units
5. Logistics centre for fishery
6. Coast gard station
7. Life boat service

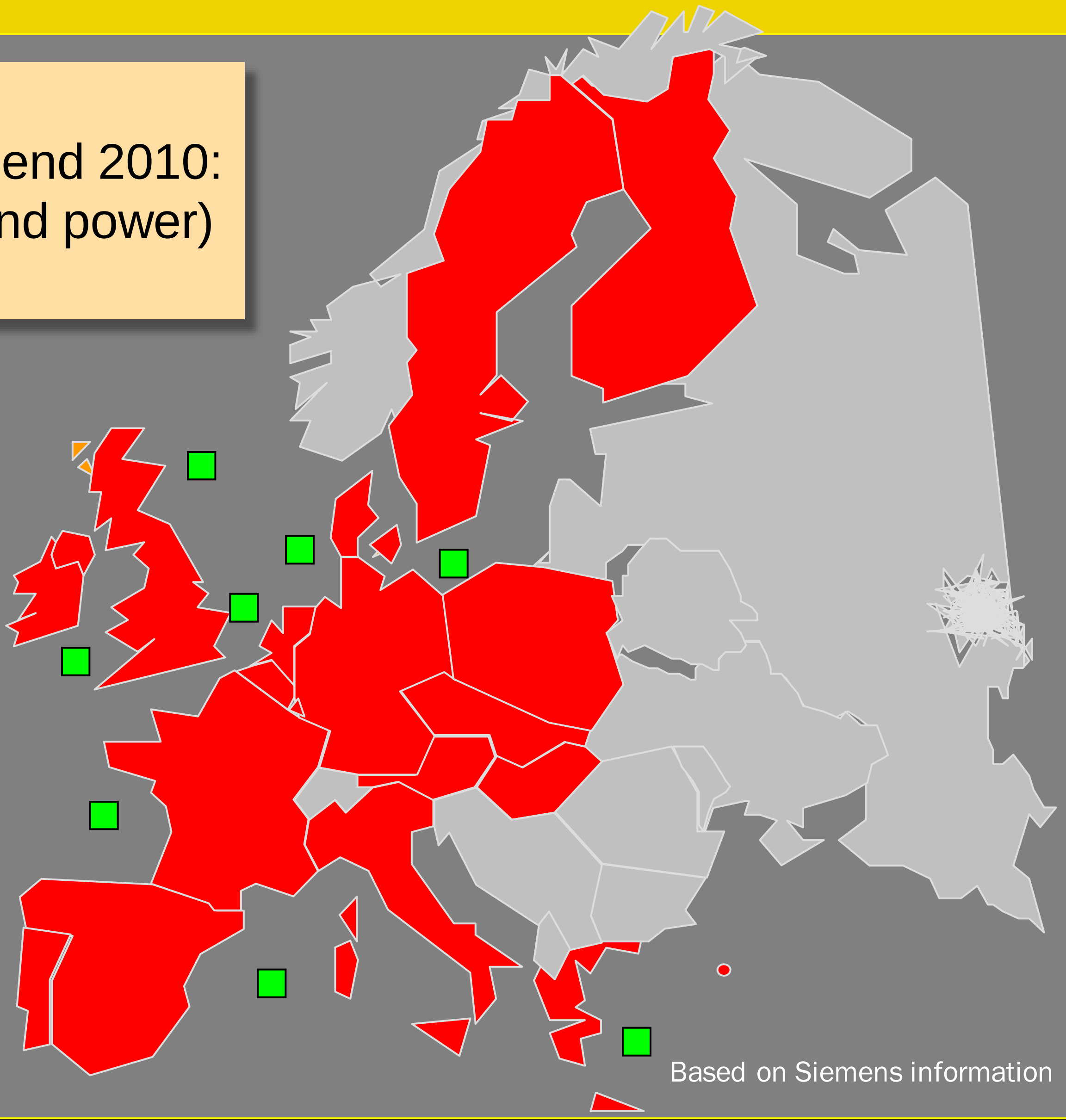
Functions of Harbour at Sea

Conclusions: R&D priorities

- Wind farm optimisation & effects on WE resource
- Design conditions (wind, waves, soil, extremes, etc.)
- Radical dedicated/integrated wind turbine systems
- Associated transport, installation and decommissioning
- Cost reduction support structures
- Electrical infrastructure offshore and on land
- Operation & Maintenance
- Significant reduction of uncertainties along entire design chain

Conclusions: still a long way to go

Installed offshore wind power end 2010:
3,554 MW (= 1,2 % of total wind power)



Eight 100x100 km offshore wind farms could produce 3,000 TWh – equivalent to EU electricity demand

Based on Siemens information

ECN

we@sea

Thank you for your attention !

Will be presented on:

December 1, during press conference, after session ‘Next generation of Demonstration sites’, 10:30.