Wind farm design

TWIND course
Design and testing of offshore wind turbines and farms

Michiel Zaaijer

Overview

- The design task
- The design process
- From task to solution: some reflections
- Design interactions
- Trends in farm design

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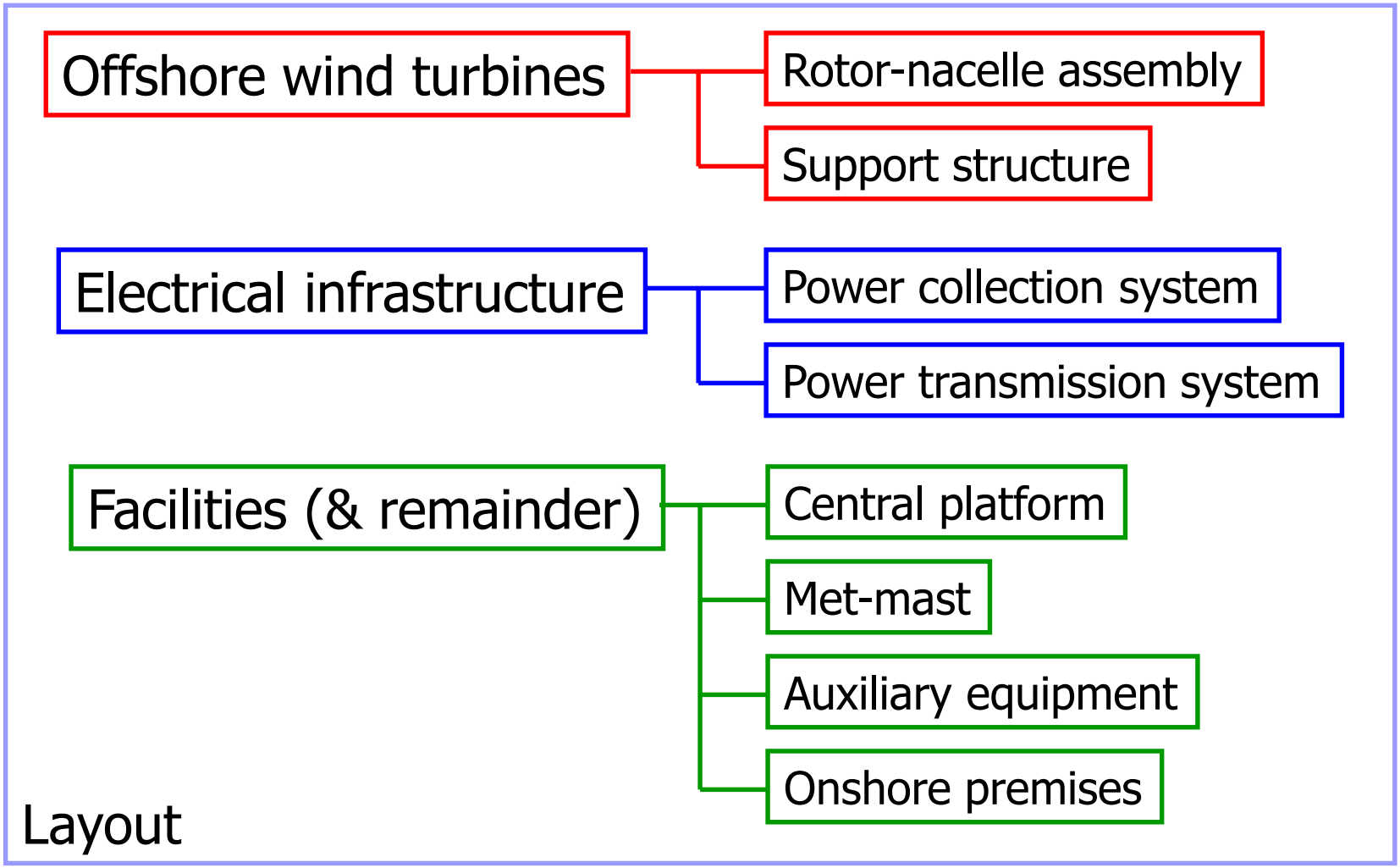
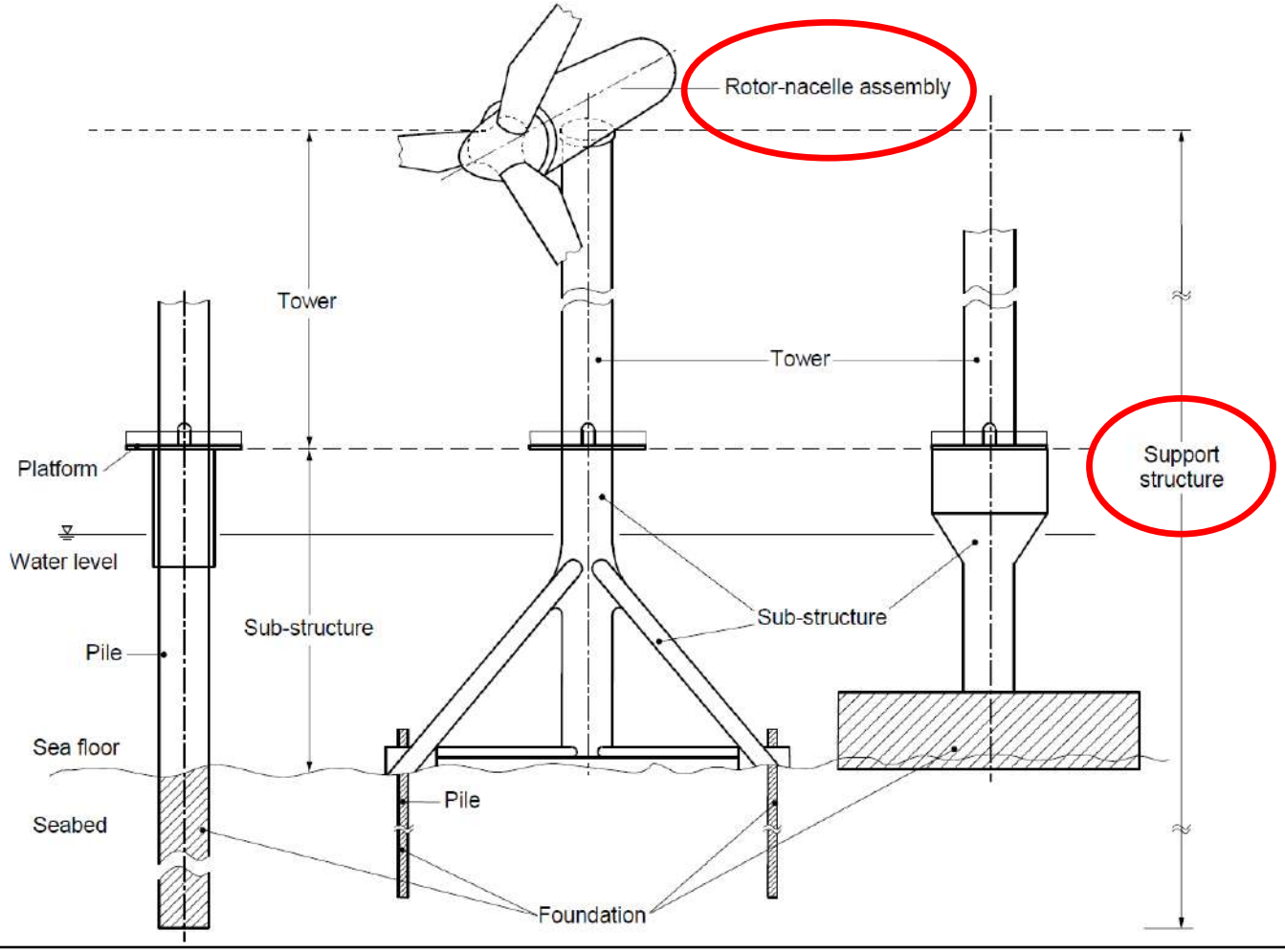
Hardware components



Offshore wind turbine



Rotor-nacelle assembly

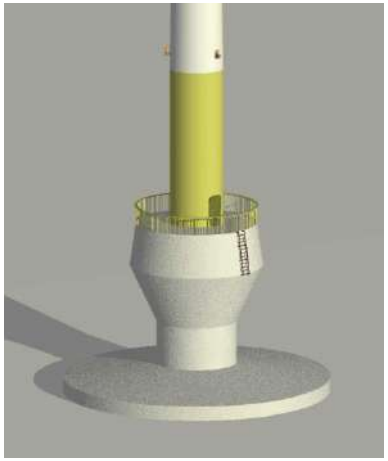
Developments:

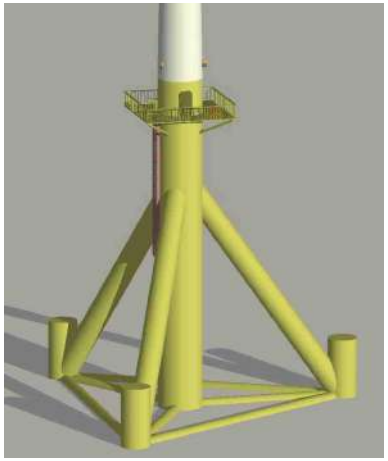
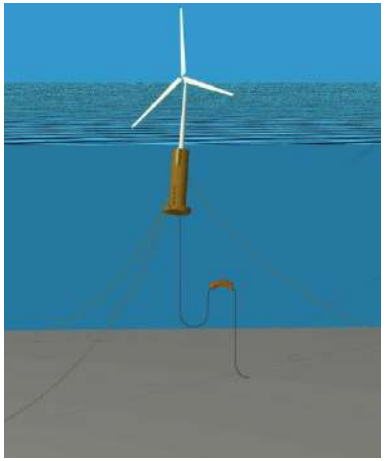
- Upscaling
- Gearbox → Direct drive → 1 or 2 stage gearbox
- 2 blades (or keep 3?)
- More monitoring and remote control
- Helicopter access (or not?)

Support structure

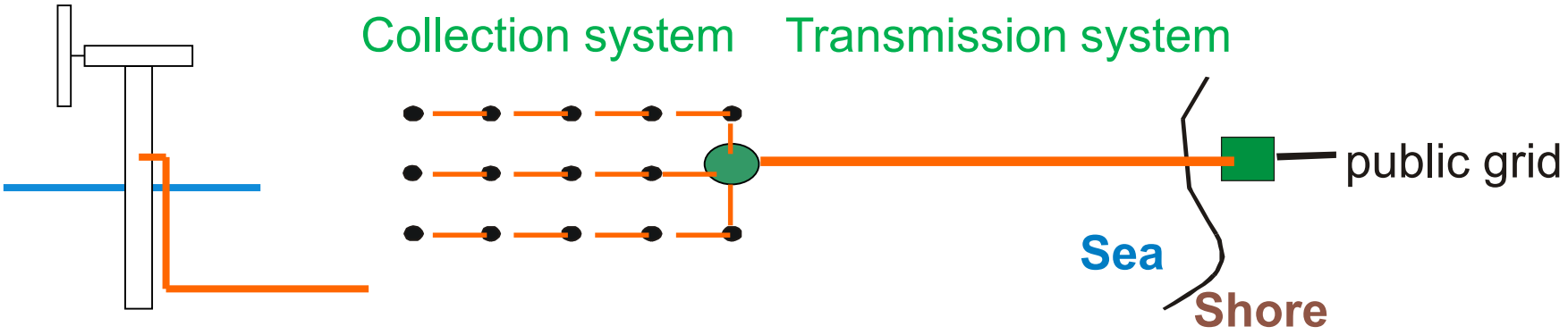
Developments:

- XXL Monopile
- Deeper and deeper water: Monopile → Jacket → Floating structures
- No transition piece
- Designed for installation (suction can, slip-joint, …)



Electrical infrastructure



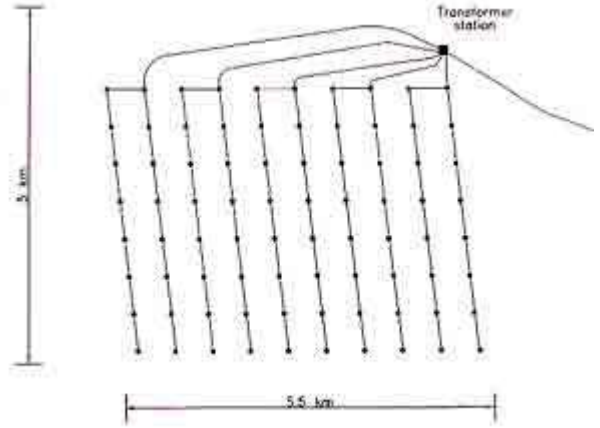
Components:

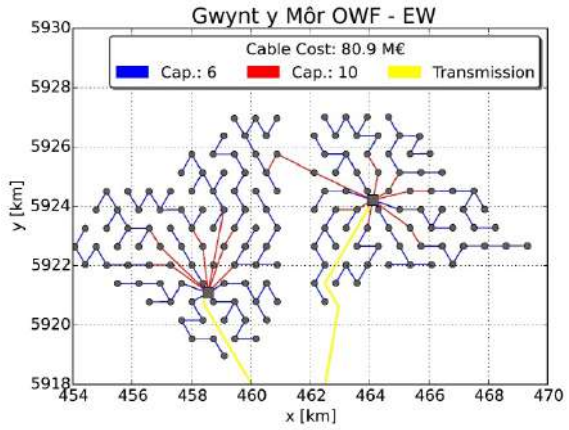
- cables
- transformers for voltage adaptations
- switch gears for protection and redundancy
- offshore connection platform (not always)
- onshore connection point

Power collection system

Developments:

- More complex (optimised) topologies
- Higher voltage (from 33-36 kV to 66 kV)





Power transmission system

Developments:

- AC connections → DC connections
- TSO responsible (instead of farm owner)

Facilities: Central platform

Developments:

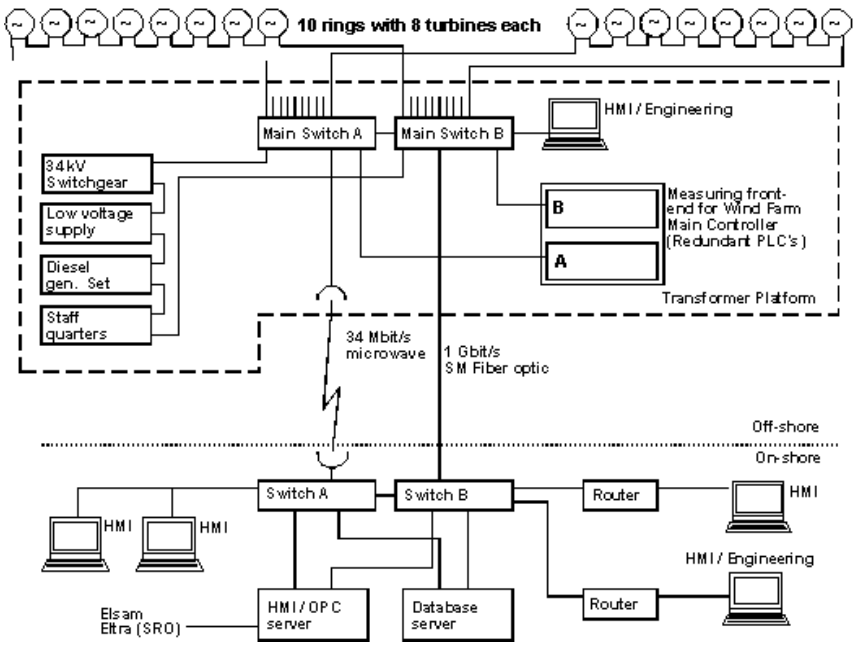
- Lean platform on monopile or at turbine (clustered)
- Include maintenance base
- Energy island (or too expensive?)

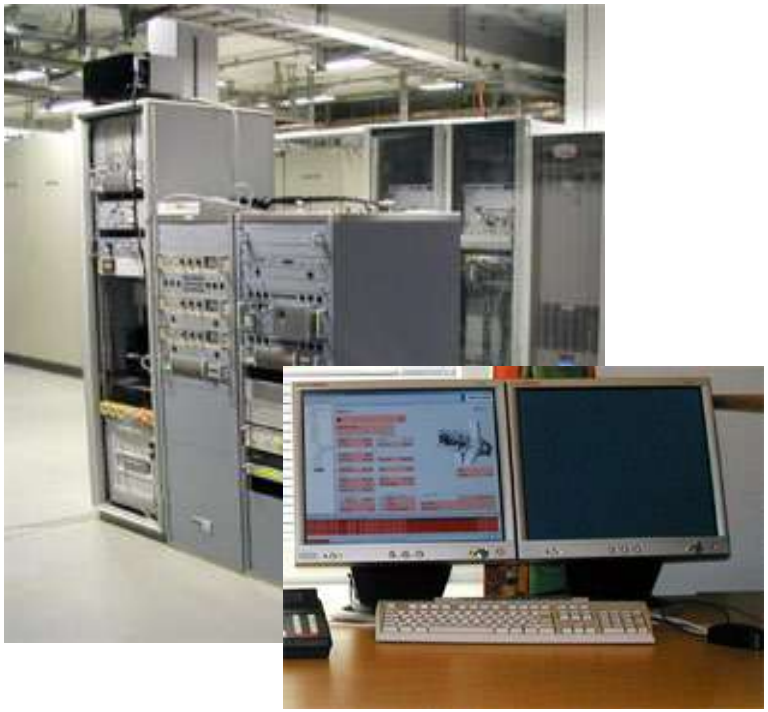
Facilities: Metmast

Issues and developments:

- Often subsidised by government, with public access to data
- (Floating) lidar: cheaper and more mobile
- More use of reanalysis data (hindcast data) and satellite data

Facilities: onshore premises

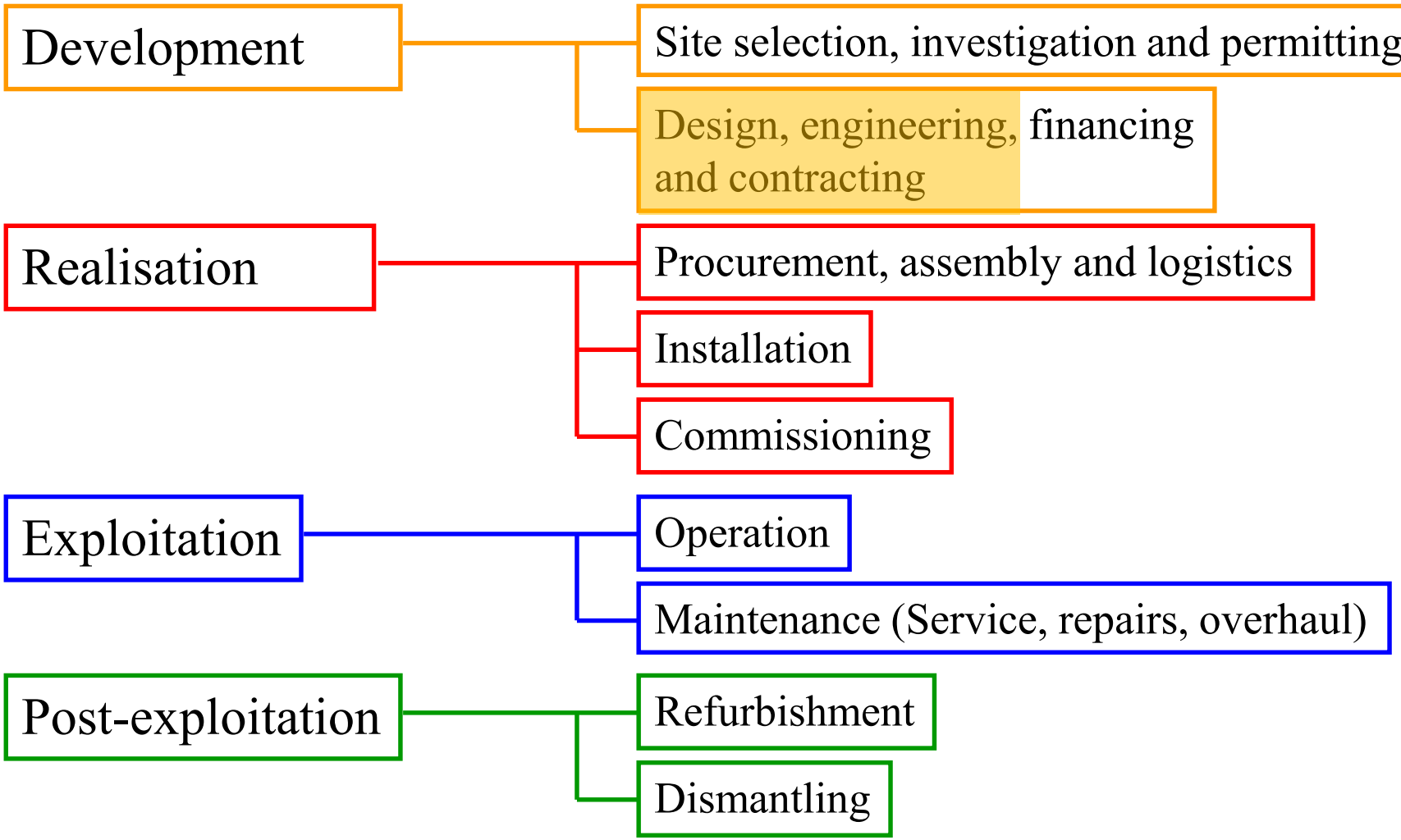




Developments:

- More monitoring and remote control (as in RNA)
- Access to more and better environmental data
- Better predictions of weather (power & workability)

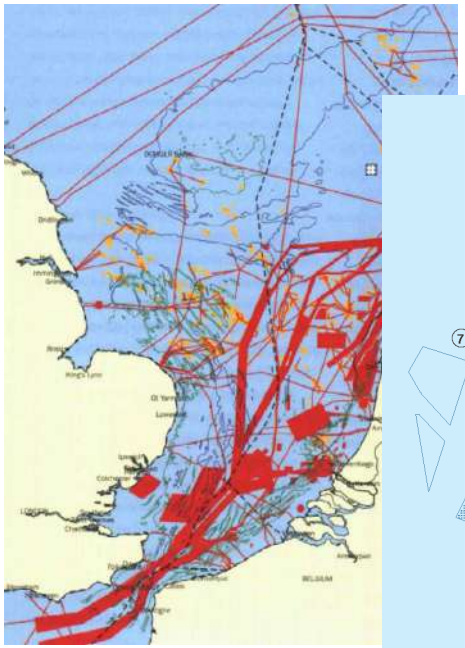
Activities (procedures)



Site selection, investigation and permitting

Developments:

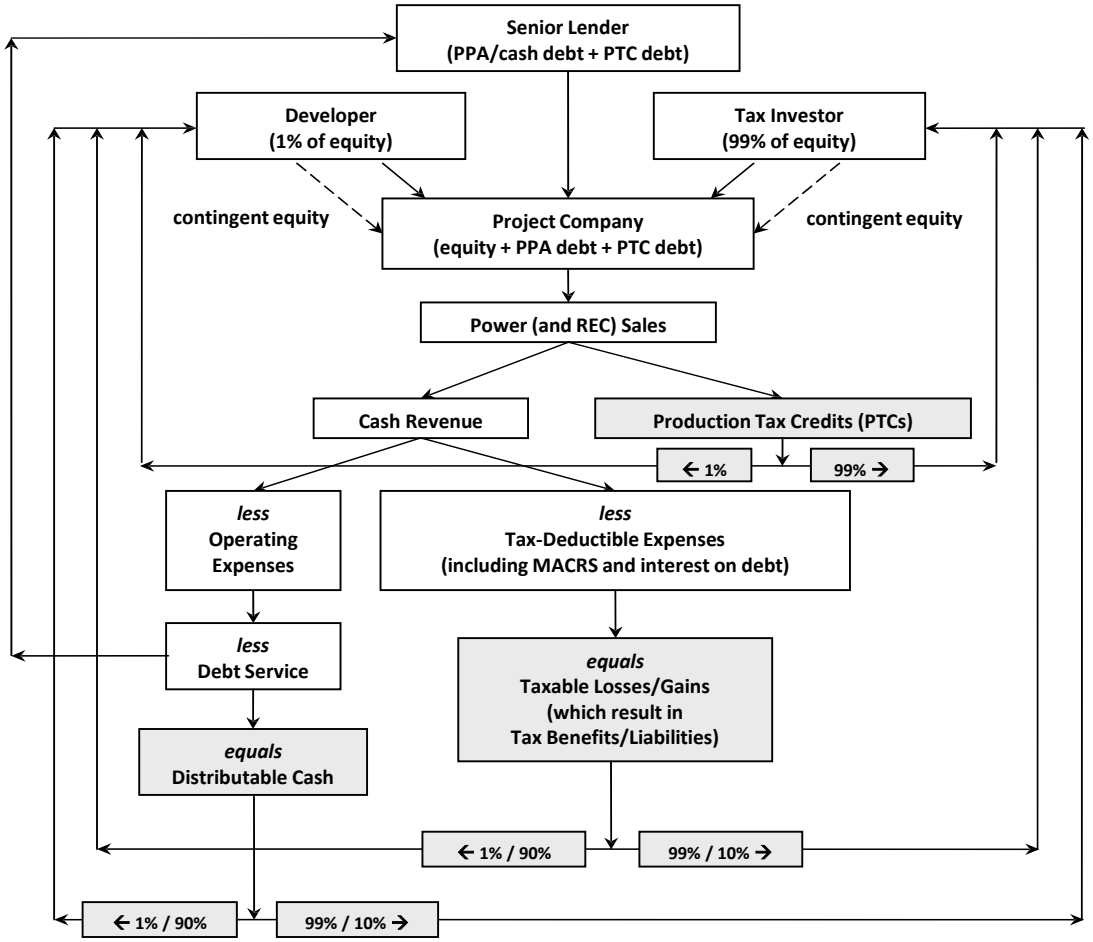
- Developers pick (outside exclusion zones) →
- Governments pick
  - Designated areas
  - Specific wind farm site
- Governments do site investigation



Financing

Developments:

- (complex) mixture of equity and debt
- Optimisations of cash flows (e.g. for tax benefits)
- Investment and risk transfer (after installation)



Procurement and logistics

Developments:

- Transport over water (large components)
- Manufacturing facilities close to sea or waterways

Installation: Monopiles

Developments:

- Larger vessels, anvils and positioning tools
- Pile driving without transition piece
- Noise mitigation (bubble screen or 'quiet seasons')
- New pile driving techniques (vibration, 'blue piling')

Installation: rotor-nacelle assembly

Developments:

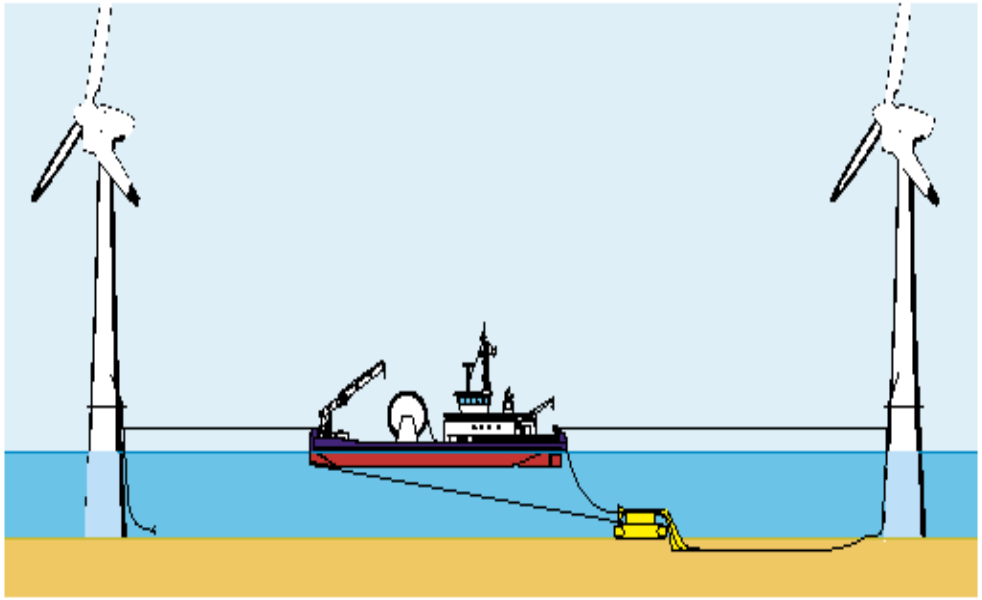
- Dedicated, large wind turbine installation vessels (TIV)
  Self-elevating (jack-up), self-propelled
- Pre-assembly in harbour versus offshore assembly

Installation: Floating wind turbines

Developments/opportunities:

- Complete pre-assembly in sheltered place
- Tow to place with tugboats

Installation: cables



Developments:

- Easier trenching / cable protection, with less damage
- Use of remotely operated underwater vehicles (ROV)
  less/no diver operations: safer

Installation: Transformer platform

Developments:

- Mostly 'Business as usual' (for oil & gas industry)
- Platform on monopile or at turbine: no extra equipment

Maintenance: Access/logistics 1

Developments:

- Short-term decision support
- Crew comfort during transfer
- Safety

Maintenance: Access/logistics 2

Development of gangways for high and safe accessibility

Maintenance: Replacement large components

Issues and developments:

- (Expensive) Lifting equipment needs to be mobilised
- Built-in cranes to lower components to platform
- Modular versus integrated drive train designs (maintainability)

Dismantling

Issues and developments:

- Similar to installation (but less sensitive)
- Recycling of blades?
- Complete removal of piles?
- Leave foundations as artificial reefs?

Sources of information

https://www.4coffshore.com

https://sea-impact.com

- Wind farms (existing and planned)
- Turbines
- Support structures
- Substations
- Cables
- Vessels
- …

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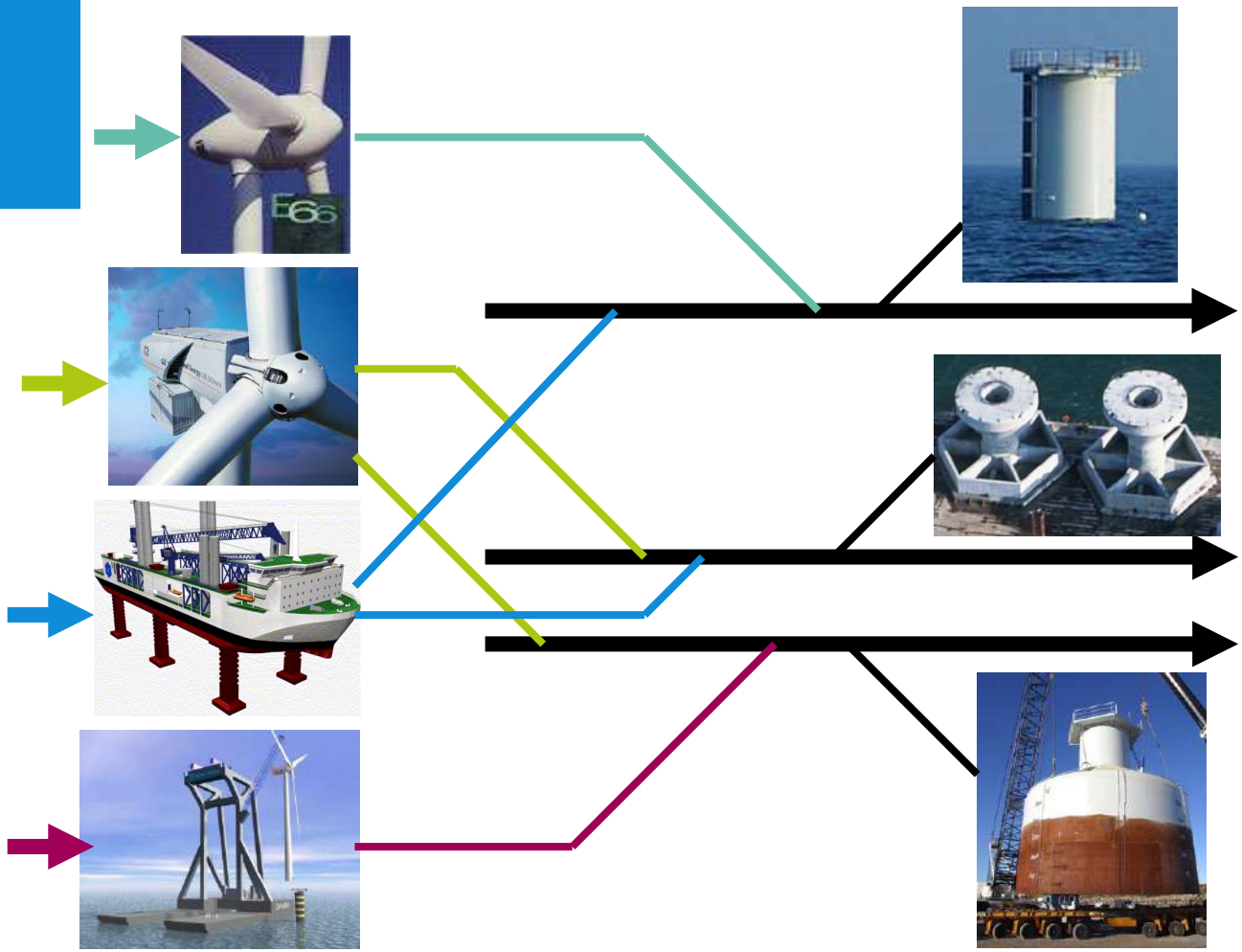
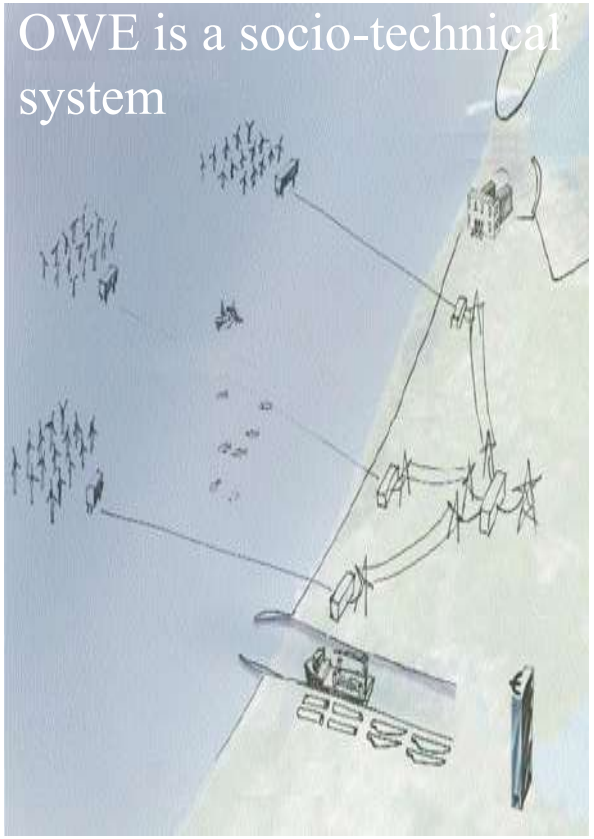
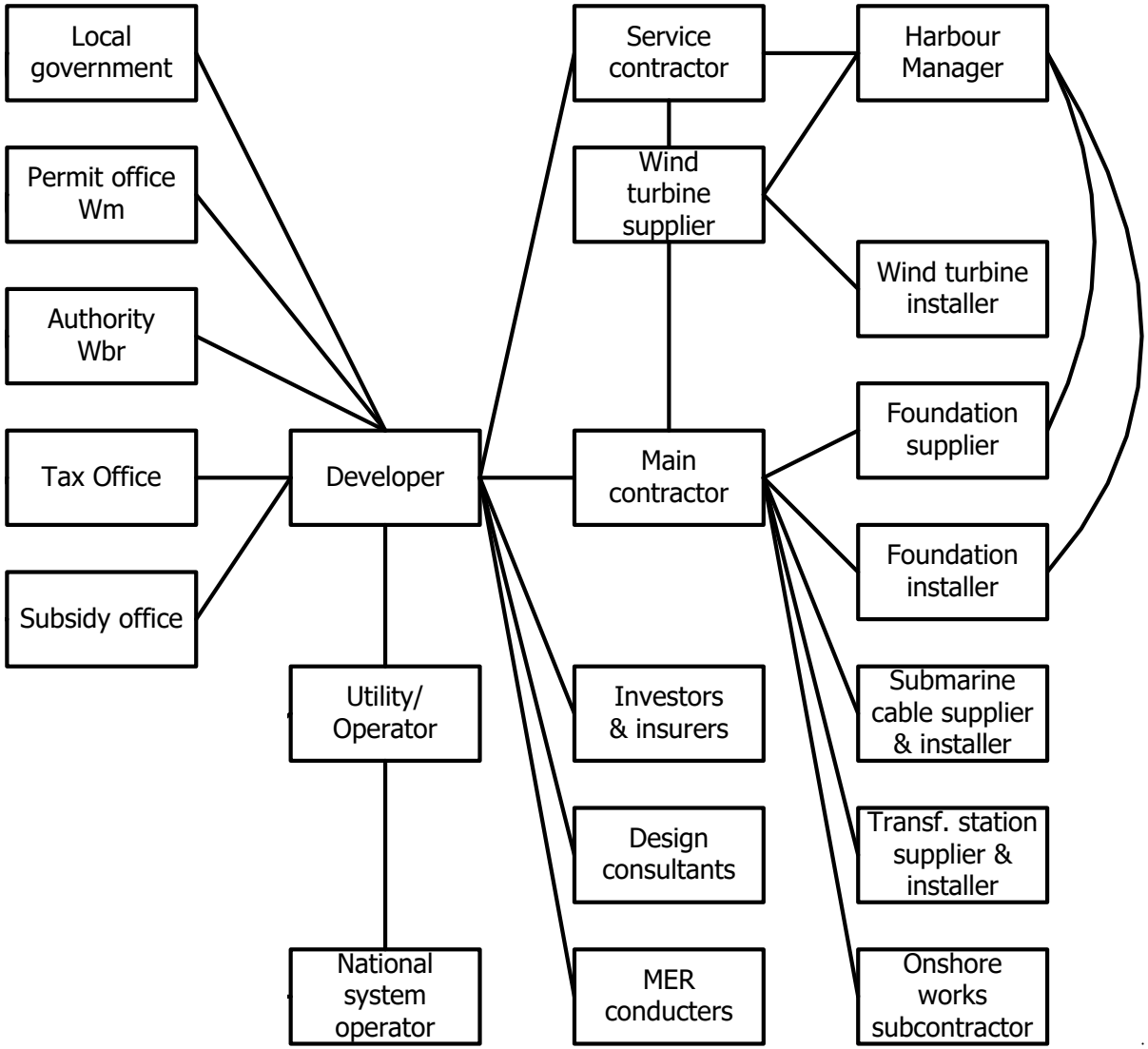
Design as part of OWE development





Select existing products – Modify equipment – Use existing concepts

Organisational setting OWF design



Contractual arrangements

Examples 'EPC' contract

- North Hoyle
- Scroby Sands
- Arklow
- Barrow
- Kentish Flats
- OWEZ

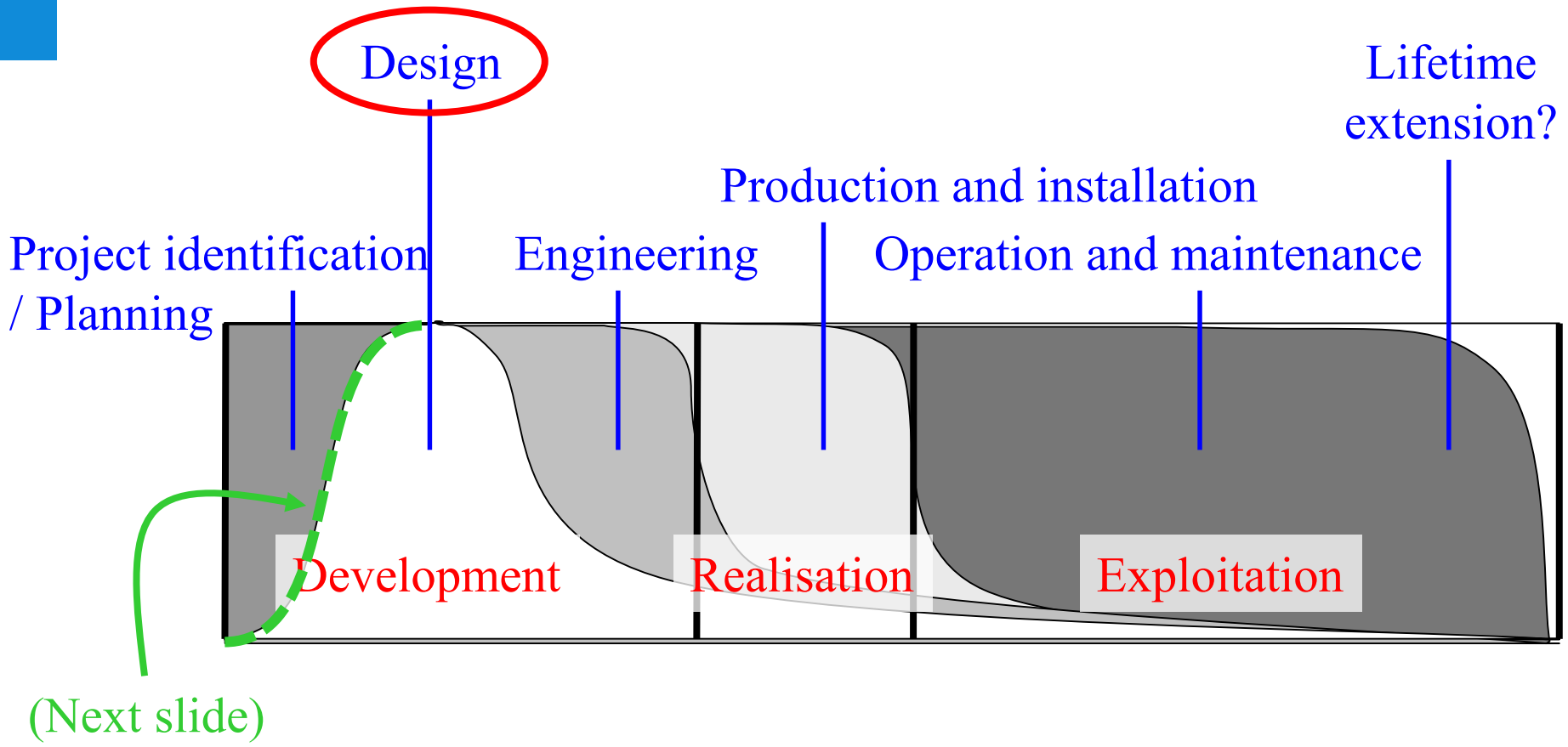
Examples Multi-contracting

- Horns Rev I and II
- Rhyl Flats
- Thornton Bank
- Gunfleet Sands
- Sheringham Shoal
- London Array

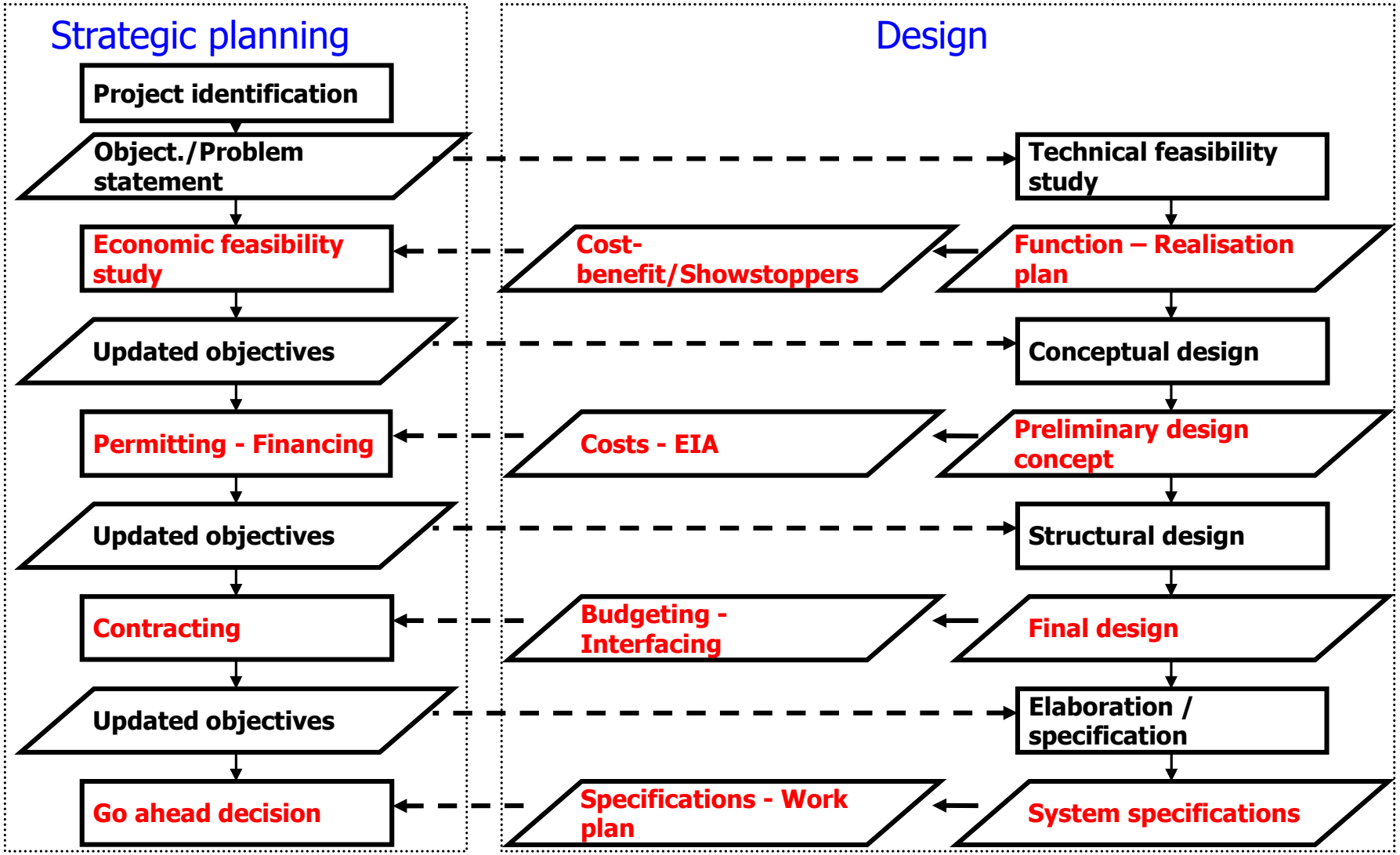
More cooperative: consortia & alliances

Contract structure & supply chain integration influence responsibilities, risk distribution and design integration

Design as part of project lifecycle



Interaction design and planning



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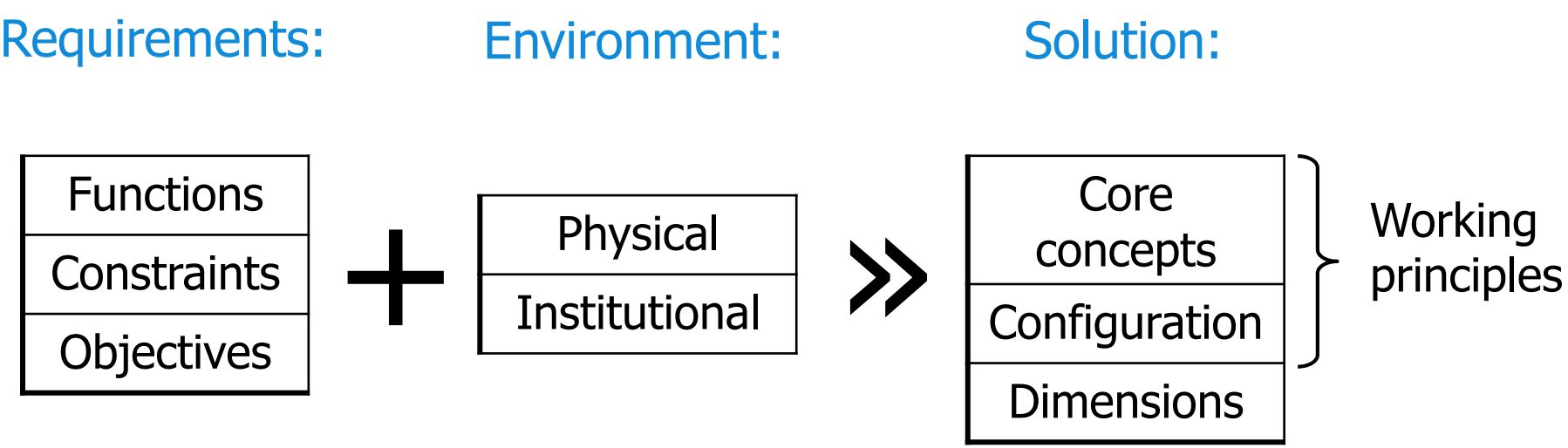
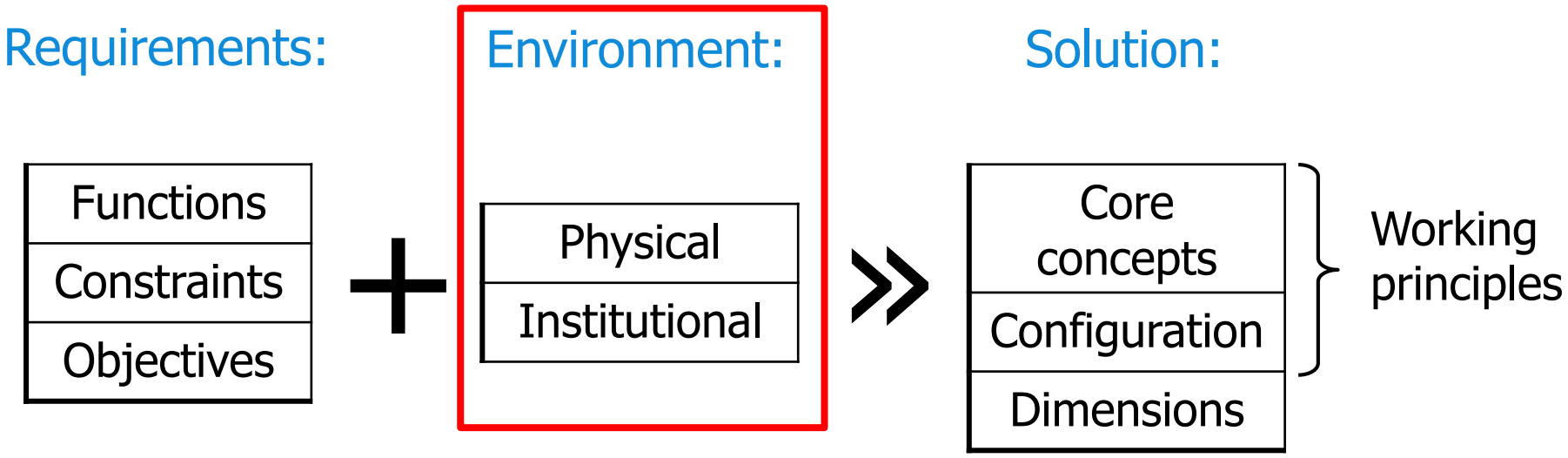
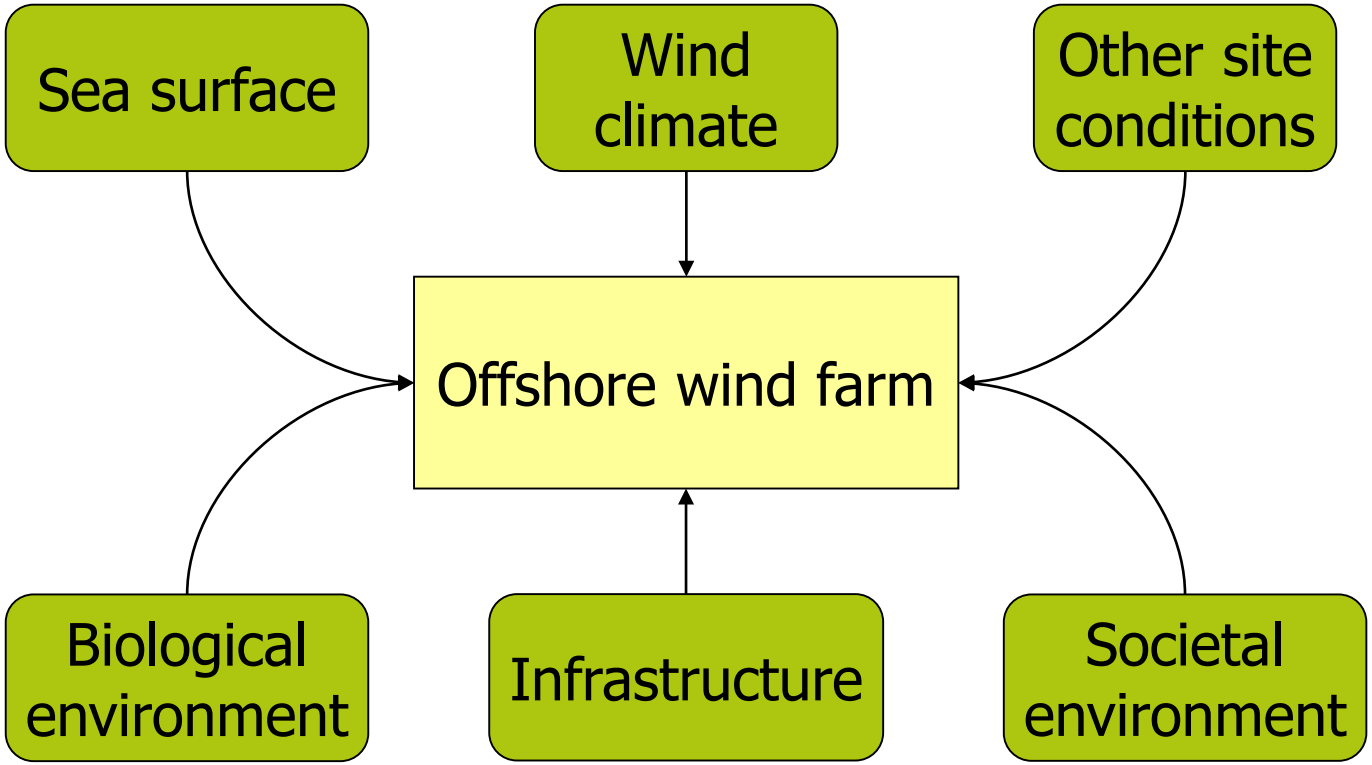
Objective of the design task



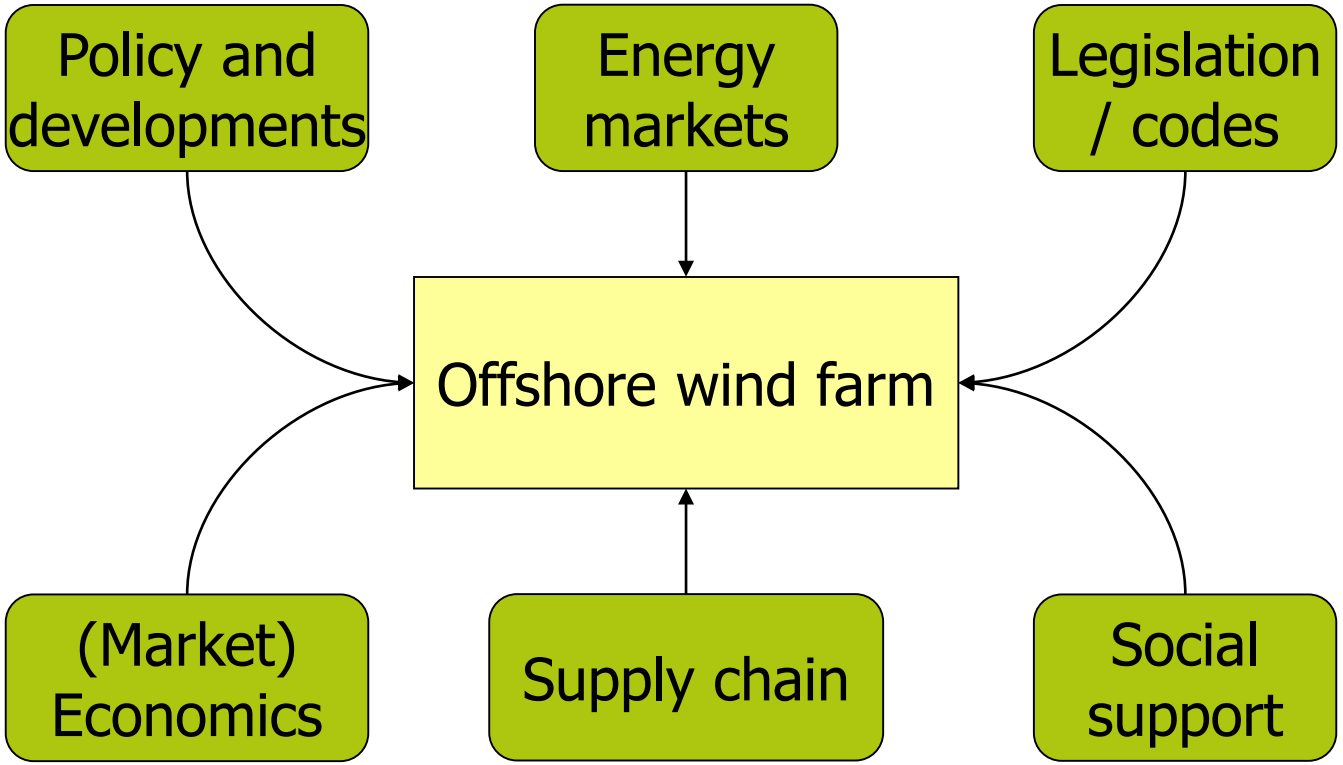
Characterisation of the offshore environment



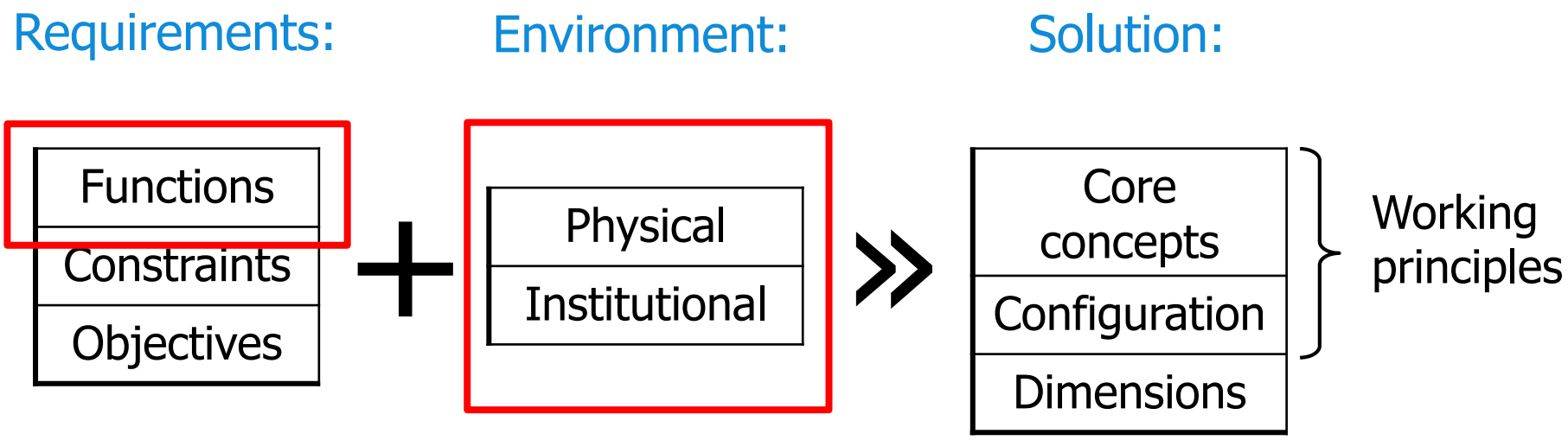
Relevant physical factors



Relevant institutional factors



Differences w.r.t. onshore wind regarding functions



Functions

Function of the primary process: the energy chain

- Energy conversion
- Energy collection
- Energy transmission

Same working principles as for onshore wind possible

Examples of design solutions

"Classical" turbine concept and (AC) connections

Functions

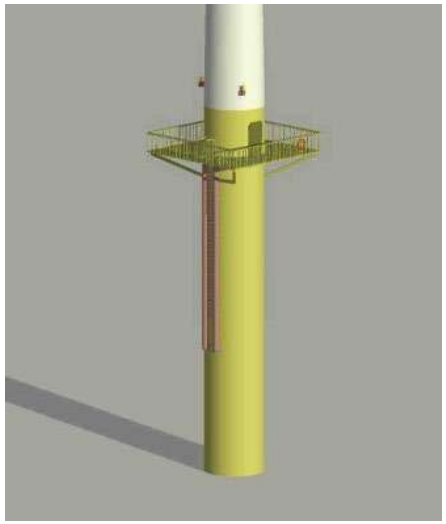
Support structure functions:

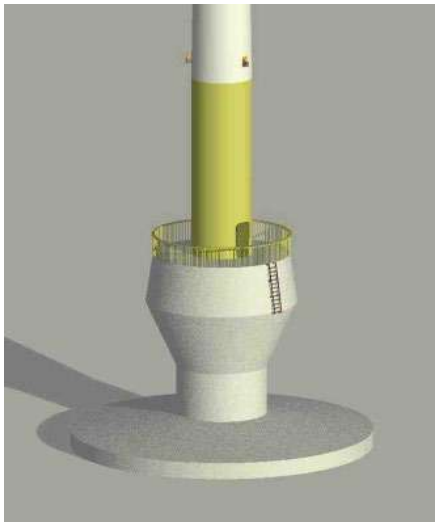
- Keep nacelle in place
- Provide access to nacelle

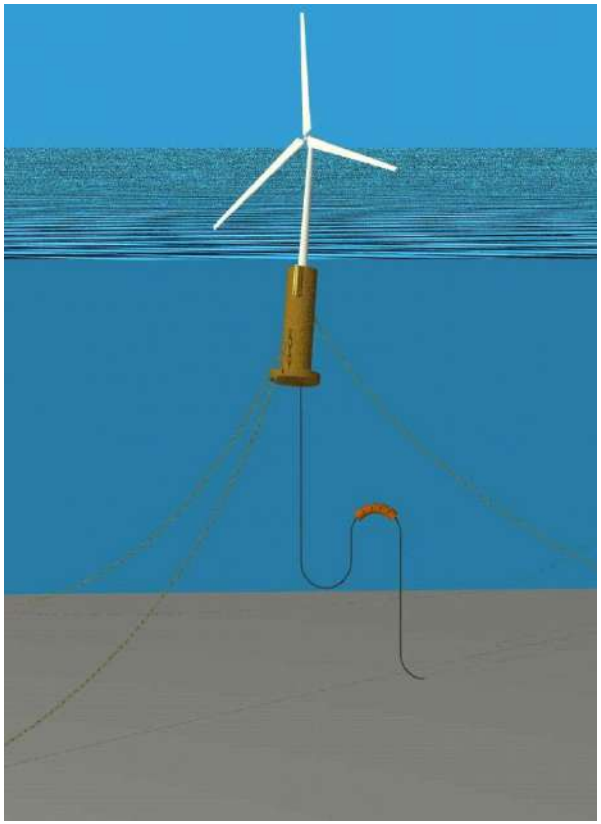
Other working principles possible than for onshore wind

Working principles can be similar to those used in Oil & Gas

Examples of design solutions







- Adapted offshore monopile and GBS
- Floating structures

Functions

Logistics functions:

- Transporting equipment
- Transporting people
- Enabling installation

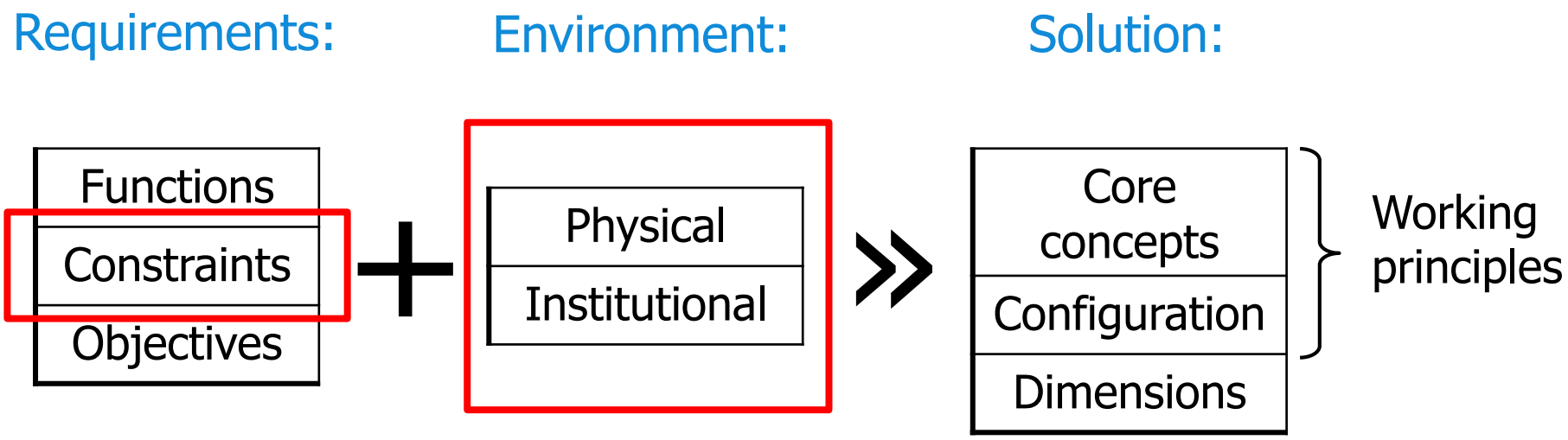
Other working principles needed than for onshore wind

Working principles can be similar to those used in Oil & Gas

Examples of design solutions

- Classical (onshore) O&M / installation procedures
- Adapted offshore installation equipment
- Adapted offshore access equipment

Differences w.r.t. onshore wind regarding constraints



Constraints

Changes in constraints w.r.t. onshore wind:

- Noise restriction
- Visual impact restriction

More severe onshore

More severe offshore

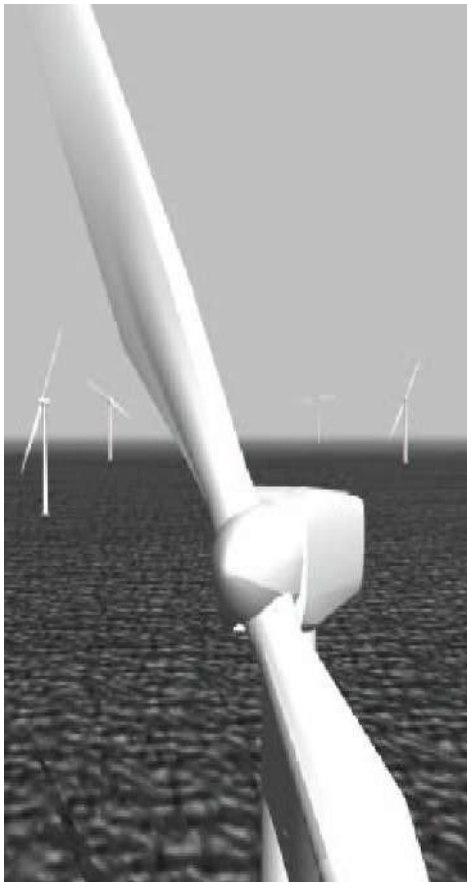
- Space restriction
- Logistics
- Material deterioration
- Hydrodynamic loading
- Wind loading
- Ice loading
- Effects on nature (e.g. bird migration)

Examples of design solutions

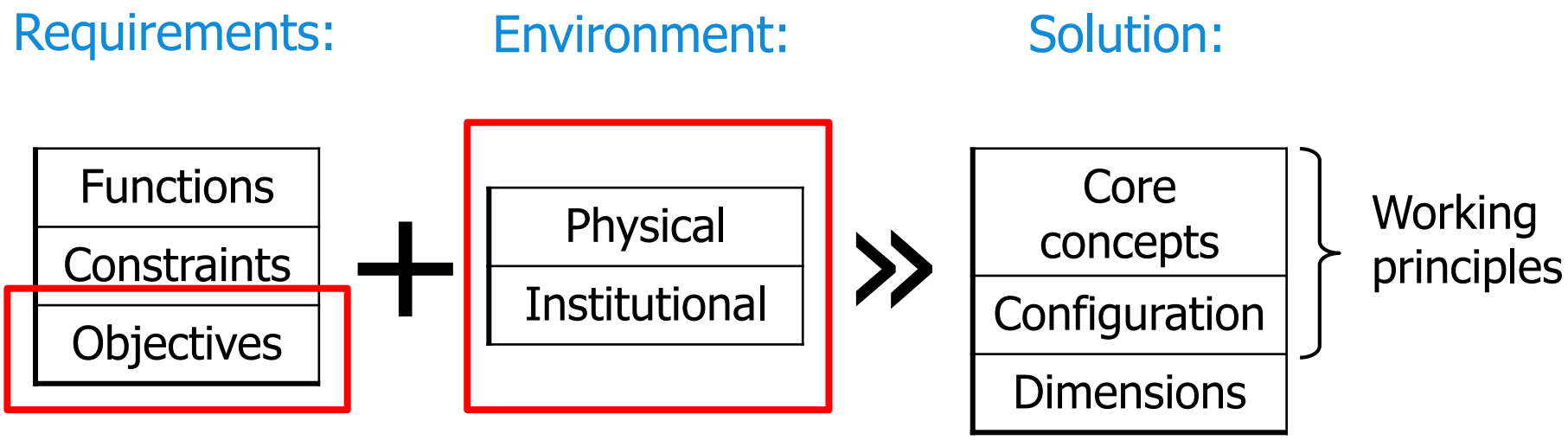
Design	Power [kW]	Tip speed [m/s]	Ratio (offshore/land)
Vestas V66 (land)	1650	66	1.21
Vestas V80 (offshore)	2000	80	
Nordex N60	1300	60	1.33
Nordex N80 (offshore)	2000	80	
Bonus 1300 (land)	1300	62	1.1
Bonus 2000 (offshore)	2000	68	
NEG Micon 1000/60 (land)	1000	57	1.19
NEG Micon 2000/72 (offshore)	2000	68	

Reduced noise constraint:
Higher tip speeds

Reduced visual impact:
Renewed interest
in 2-bladed turbines

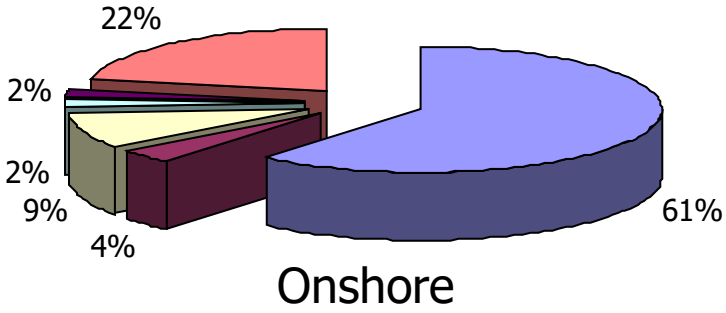


Differences w.r.t. onshore wind regarding objectives



Objectives

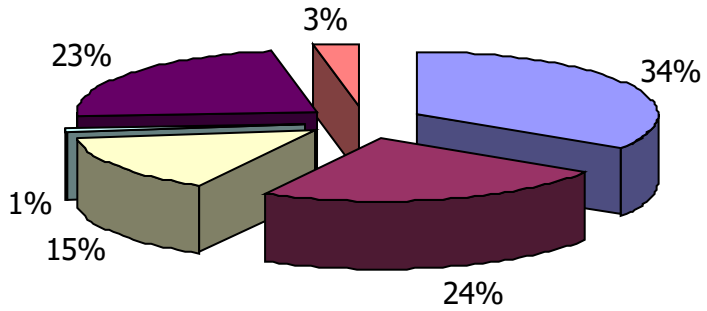
Same objective as for onshore wind, but other relative contributions Note: more 'value', instead of (only) on 'costs'



Onshore

- Wind turbine (including tower) 61%
- Foundation 4%
- Grid-connection 9%
- Consultancy & finance 2%
- Land purchase & roads 2%
- Operation & maintenance 22%

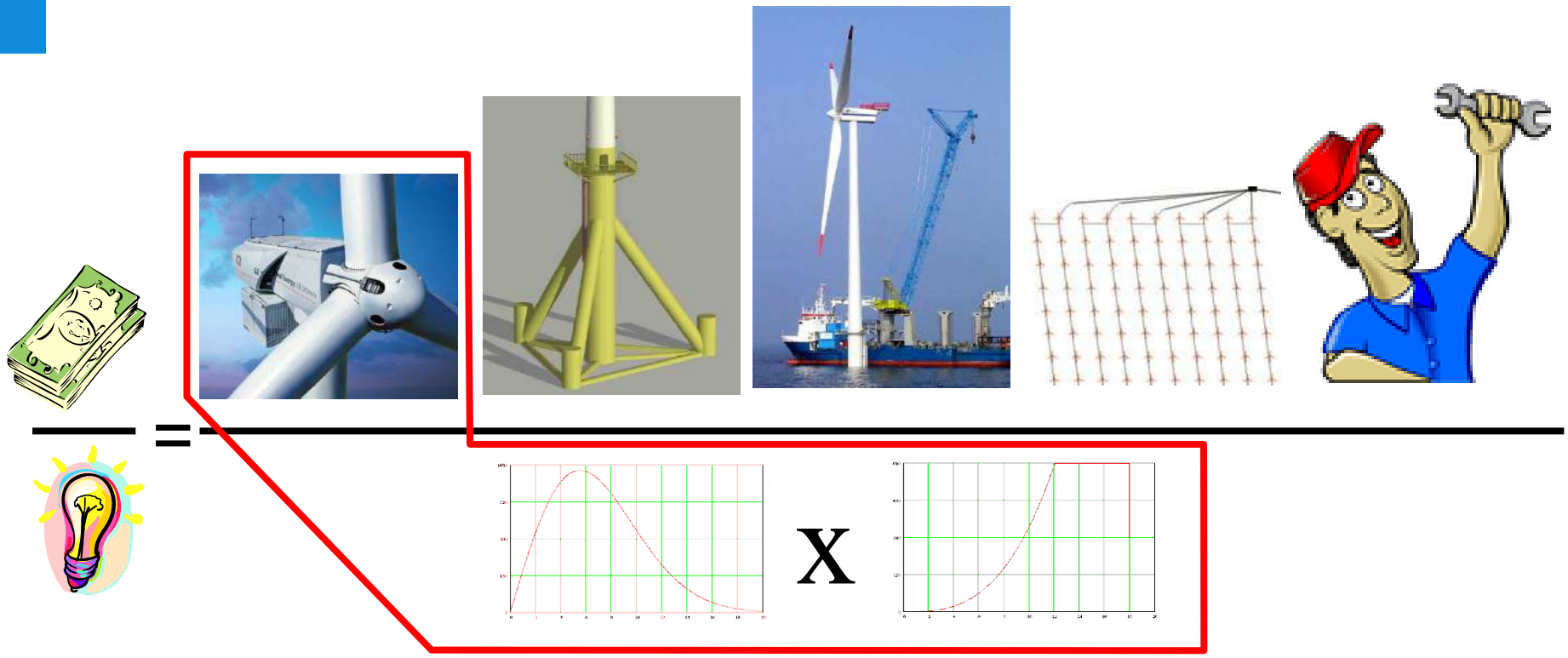
→ other trade-offs!



Offshore

- Wind turbine 34%
- Support structure & installation 24%
- Grid connection 15%
- Management 1%
- Operation & maintenance 23%
- Decommissioning 3%

Example of design solution (1)



Upscaling – trade-off between turbine performance and 'offshore' costs

Example of design solution (2)

Onshore (typical):

Aluminium

(3x)

- Cheaper to manufacture
- Cheaper material
- Easier to bend (installation)

Offshore (typical):

Copper

- Cheaper to install
- Bending no problem
  (large vessels available)
- Lower losses

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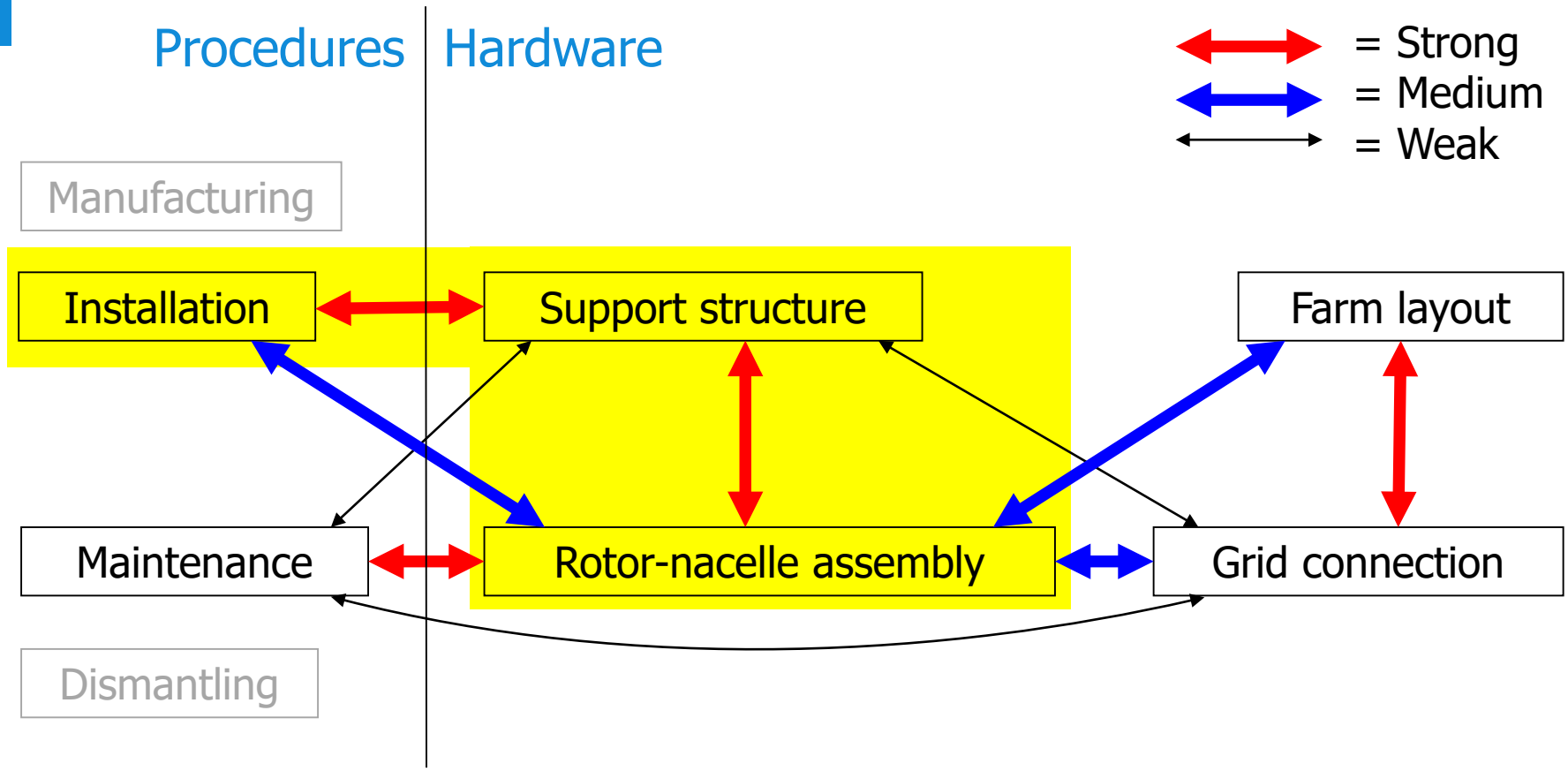
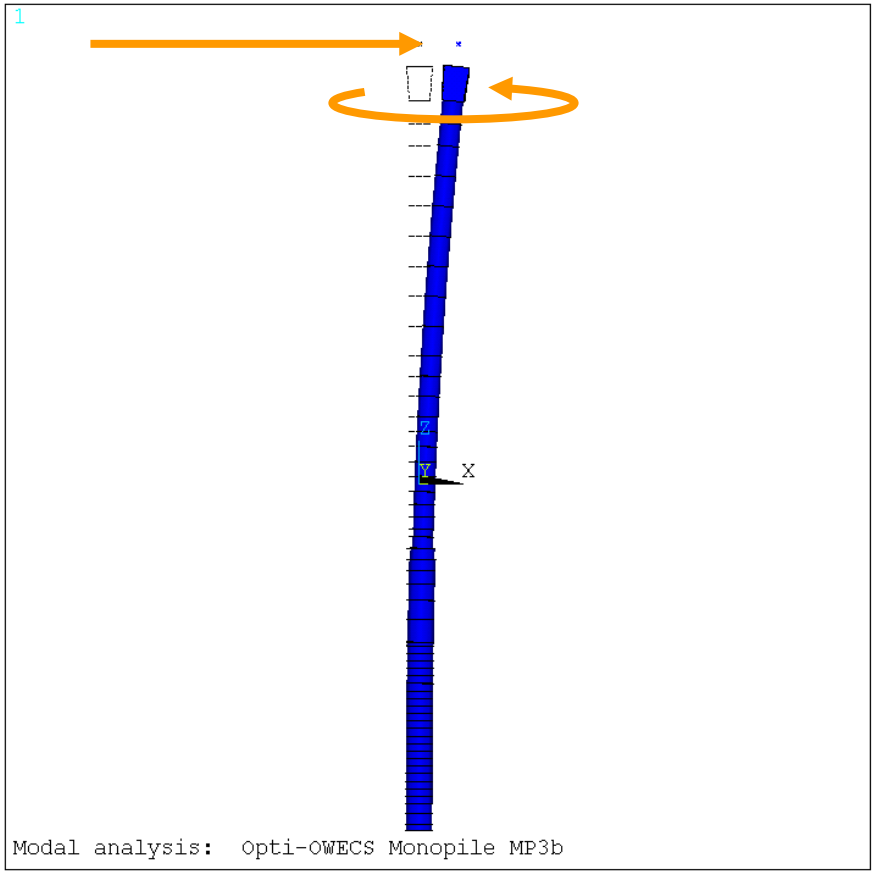
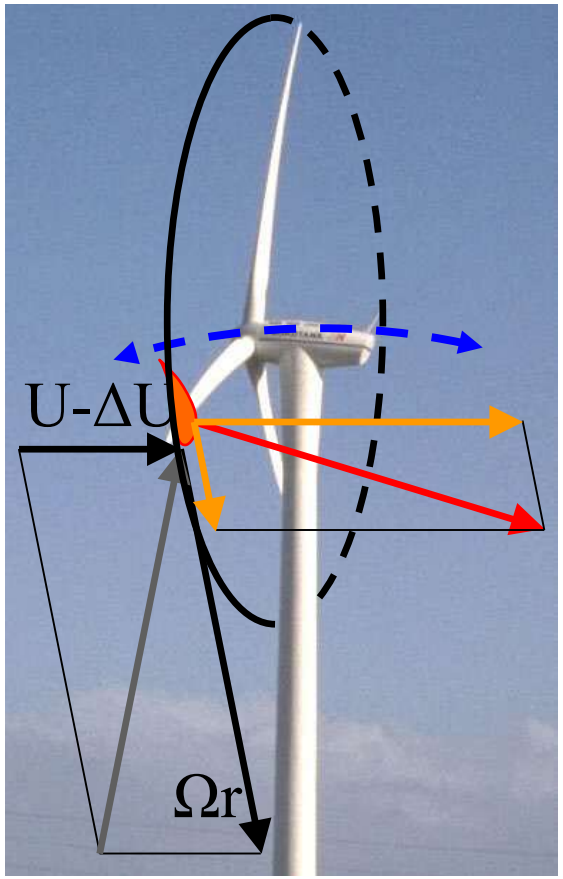
Overview of physical interactions



Support structure ←→ Rotor nacelle



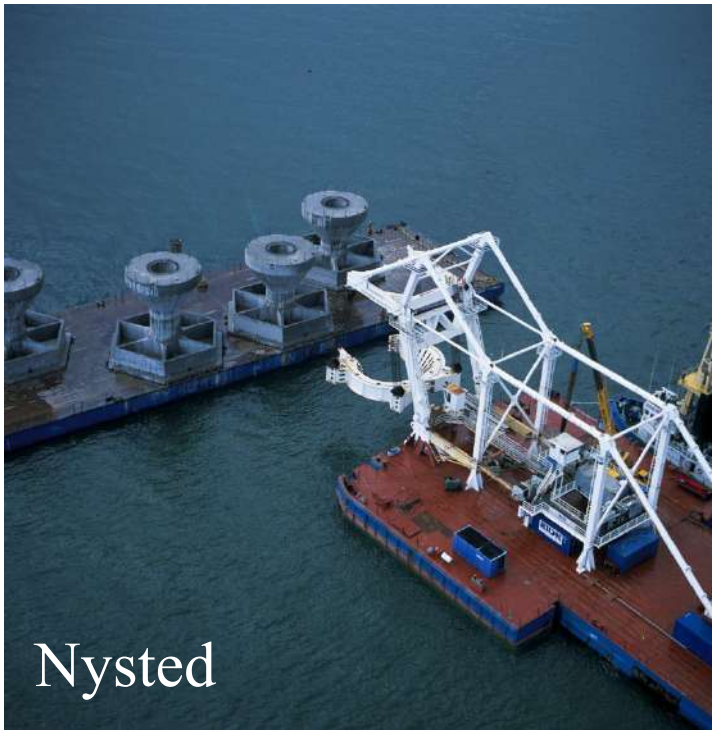
Loads



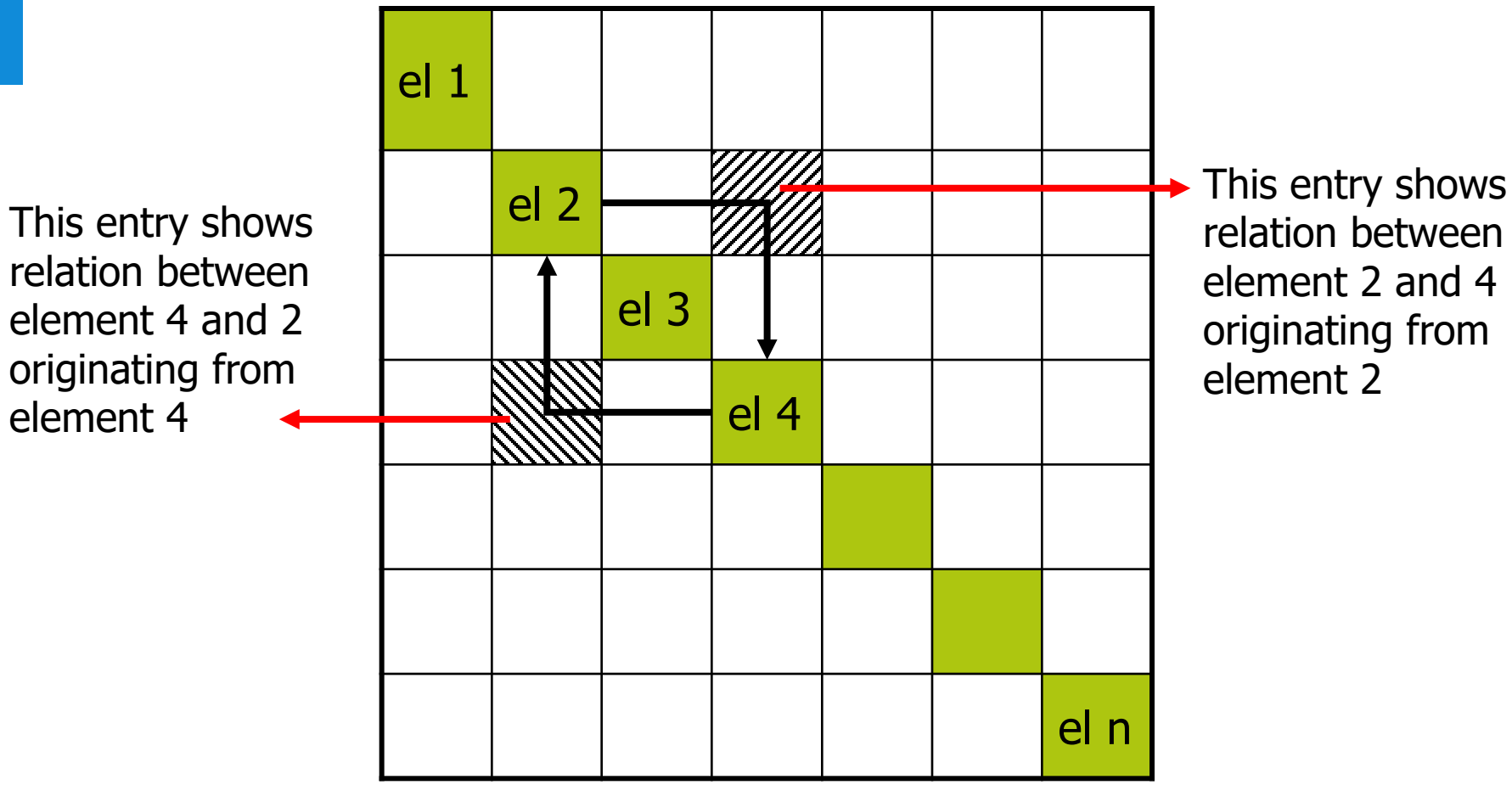
Response (aerodynamic damping)

Support structure ←→ Installation

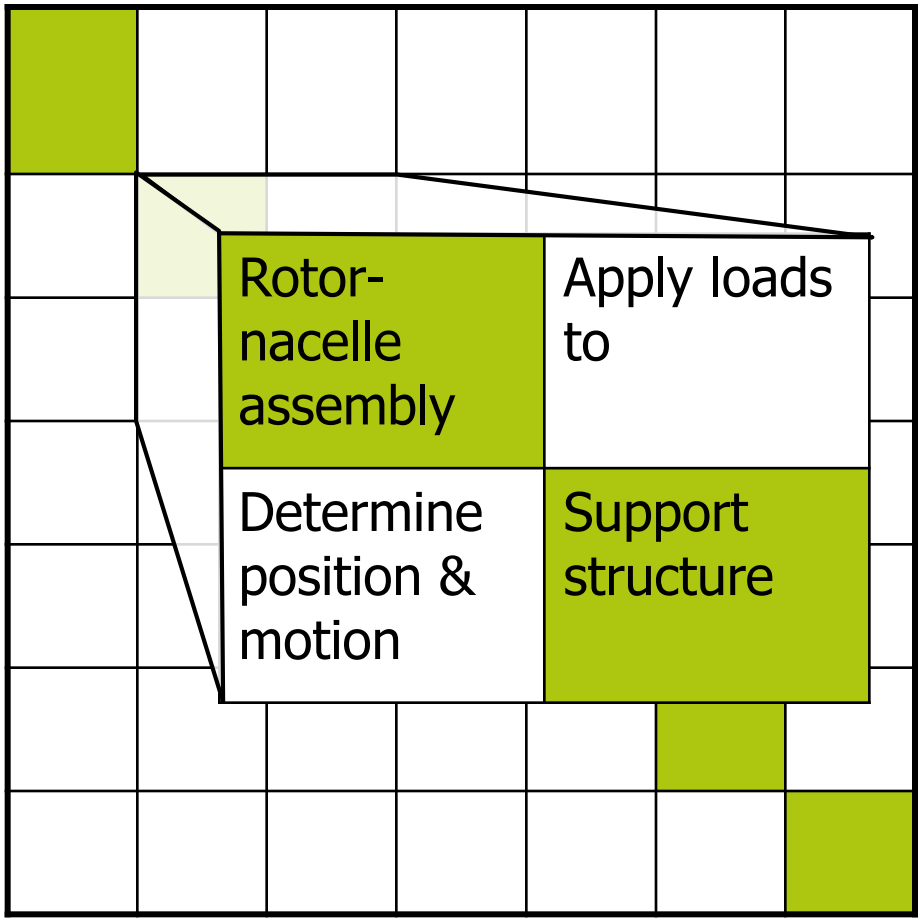
Geometry – mass – working principles – installation loads



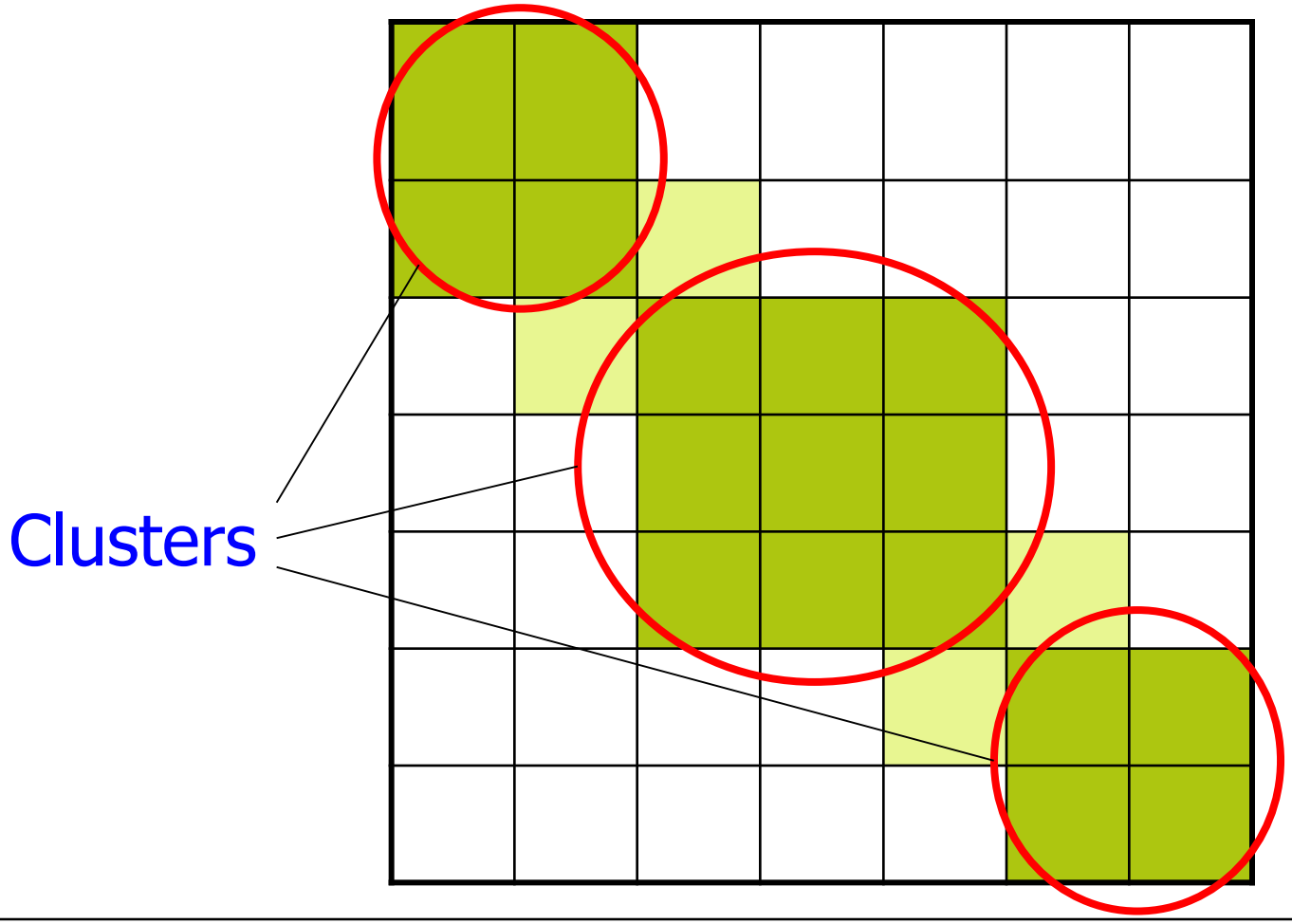
Interactions: The N2 diagram



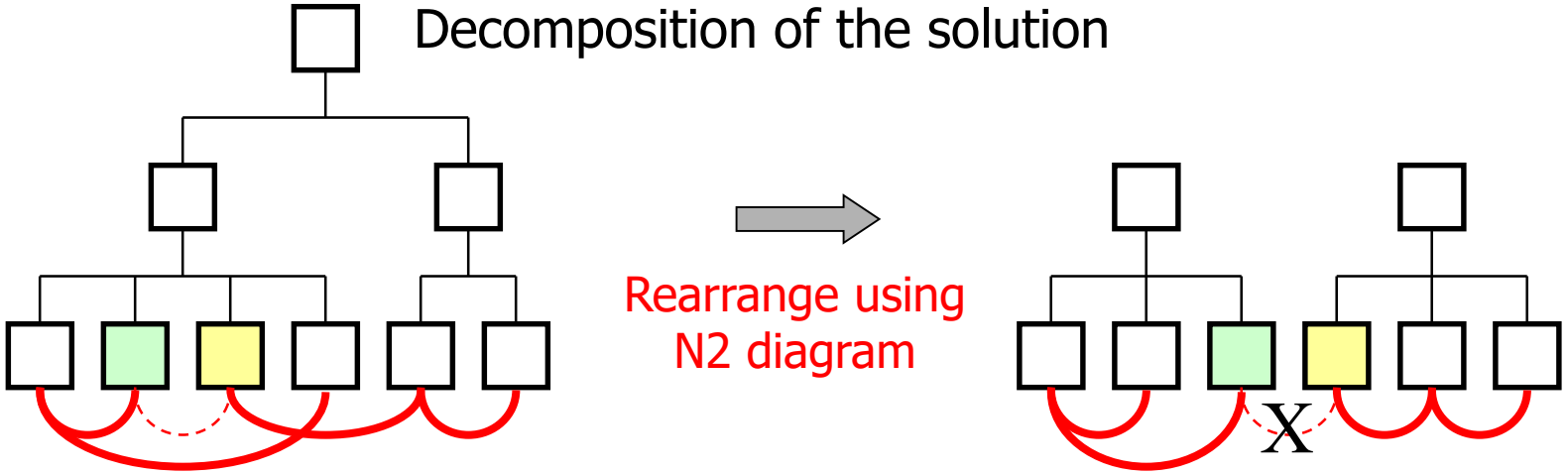
N2 diagram - Example



Dealing with interactions (1)



Dealing with interactions (2)



- Clusters driven by internal coherence (interactions)
- Internal interactions maximised, external interactions minimised
- External interactions replaced by interface requirements
- Close cooperation in semi-autonomous cluster

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Examples of trade-offs

Design solution / target	(Claimed) Positive effect	(Claimed) Negative effect
Low hub height	Low support / installation costs	Low energy yield
Large spacing	Low losses (wake)	Long cables / more space
Closer to shore	Low support / cable / maintenance costs	Low wind speed / yield
Floating support (vs fixed)	Easy to install	High costs for structure
DC (vs AC)	Low losses	High costs
Irregular layout (vs regular)	High yield / persistence	High (worst-case) fatigue loading

Support structure (concept trade-off)

Lattice tower & installation steps

Floating platform & installation

Dealing with trade-offs (1): Multi-criteria analysis

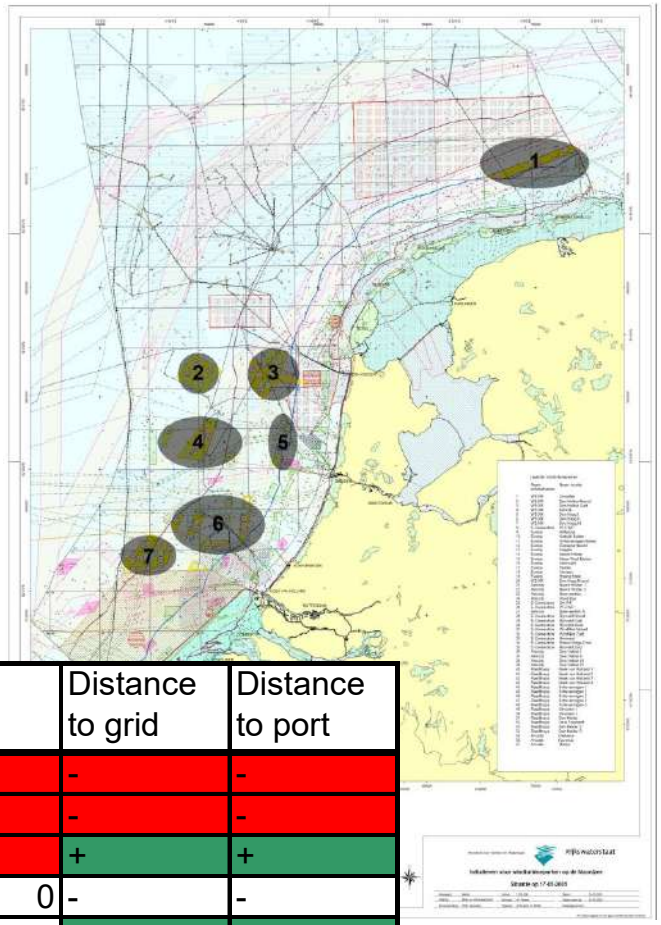
- Define criteria (performance indicators)
- Identify 'killer requirements'
- Define weighing factors
- Define performance classifications (Computed numbers when possible (e.g. costs) Otherwise e.g. 'Good' =8, 'Poor' =2)
- Use colour scheme for first impression
- Avoid ranking per criterion (not arithmetic)

Criteria

Options

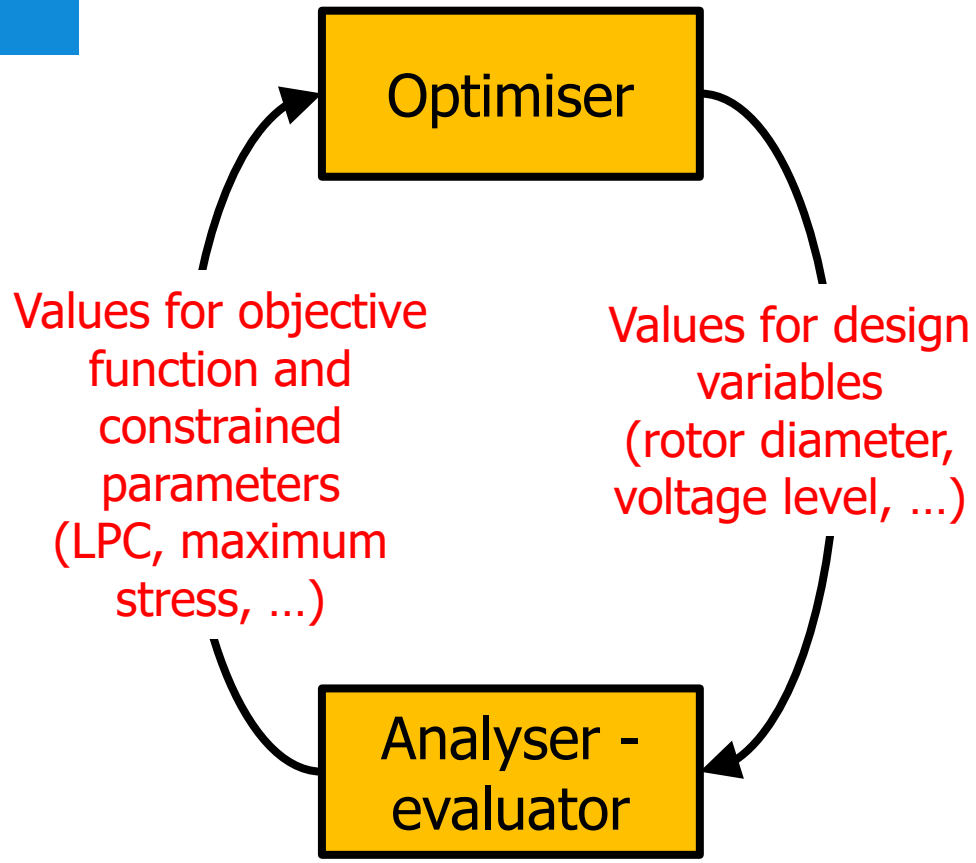
	α	β	Score
Weight	0.7	0.3	
A	9	5	7.8
B	7	3	5.8

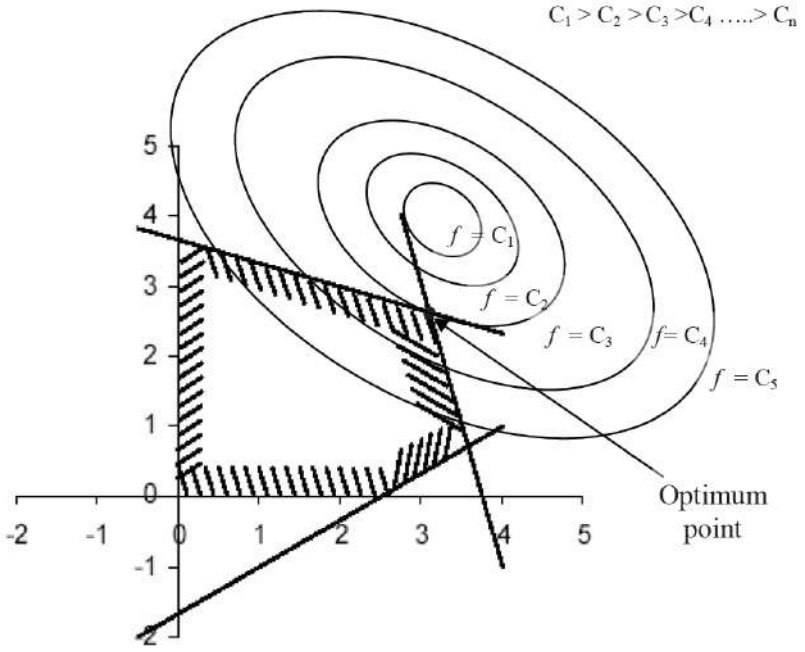
Example: Site selection



Criteria / Location	Wind climate	Wave climate	Currents	Soil conditions	Water depth	Other users	Distance to grid	Distance to port
1	+	+	0	0	0	-	-	-
2	0	0	0	0	0	-	-	-
3	0	+	0	0	0	-	+	+
4	0	0	0	0	0	0	-	-
5	-	+	0	0	+	0	+	+
6	0	+	-	0	+	+	+	+
7	0	0	-	0	0	+	0	0

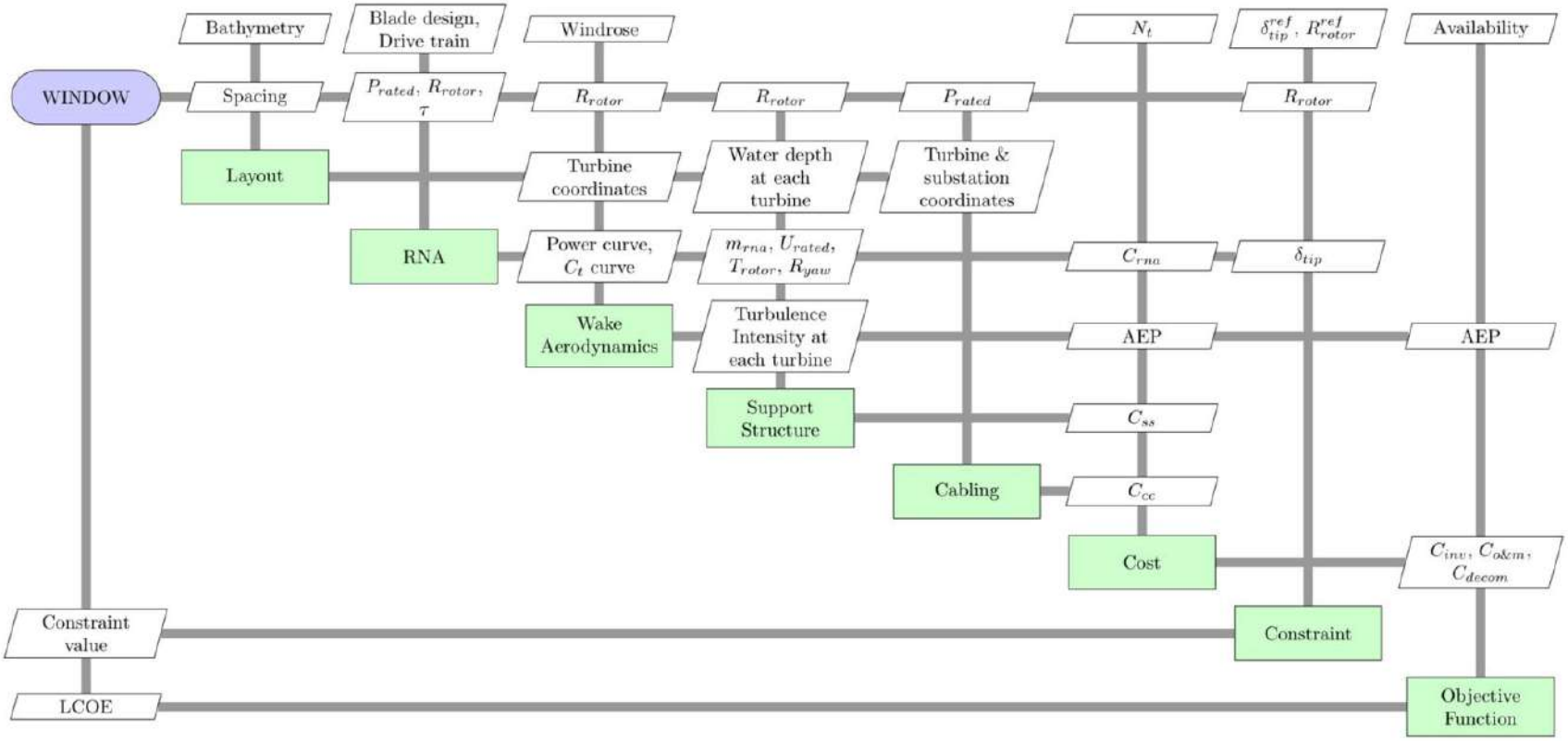
Dealing with trade-offs (2): Numerical optimisation



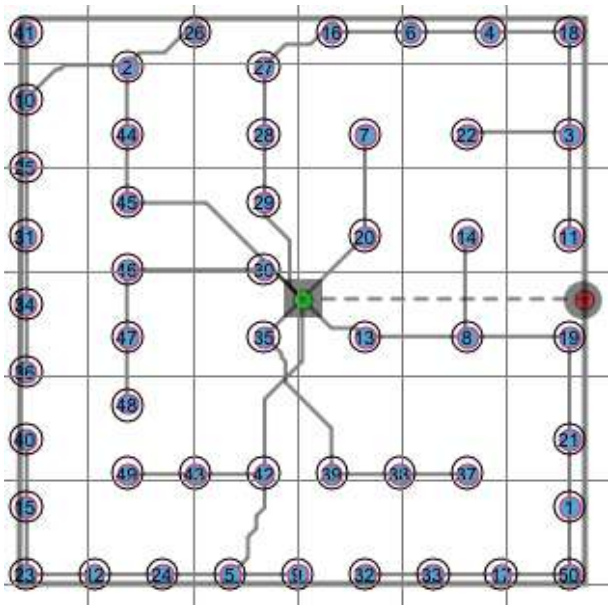


The wider the scope of the design variables and (consequentially) of the analysis, the more 'integration' (and the more complex – time consuming)

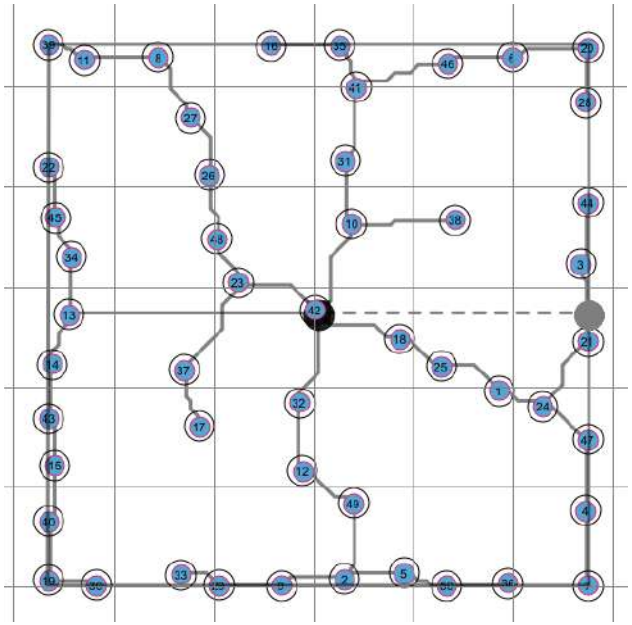
MDAO: Multidisciplinary design analysis and optimisation



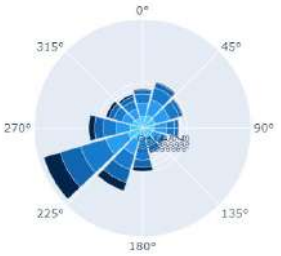
Example: Layout and cable topology



Manual



MDAO



Overview

- The design task
- The design process
- From task to solution: some reflections
- Design interactions
- Trends in farm design

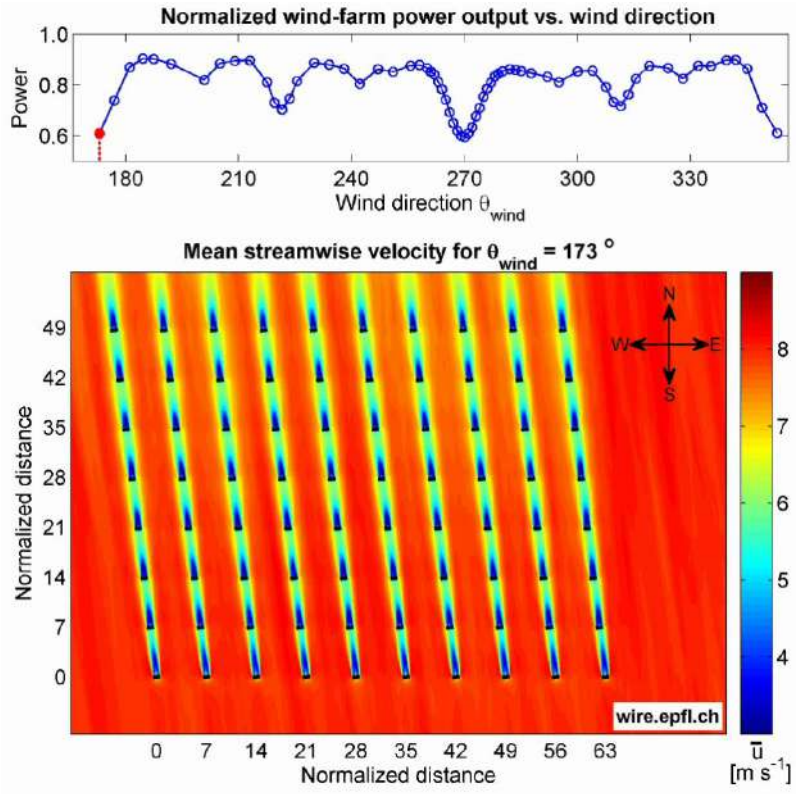
New roles and goals

- Selling power
  - Energy quantity
  - Predictability / Persistence
  - Dispatchability
- Providing services
  - Frequency response
  - Reactive power control
  - Black start capability
- Customers: Power to X
  - Hydrogen / Gas
  - Heat
- Sustainability

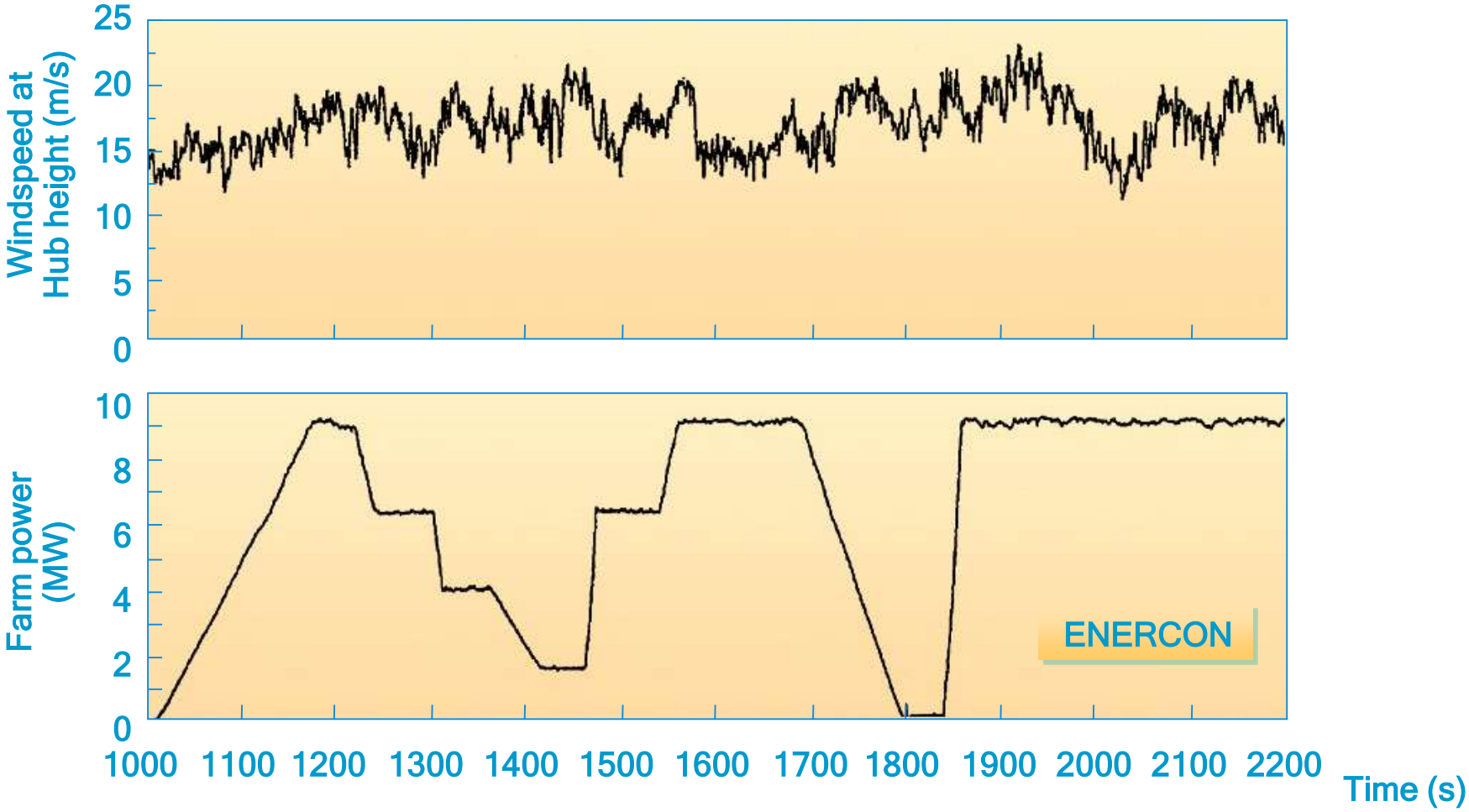
Effects of wakes/layout on value

- Energy loss
- More variability / lower persistence
- Lower predictability

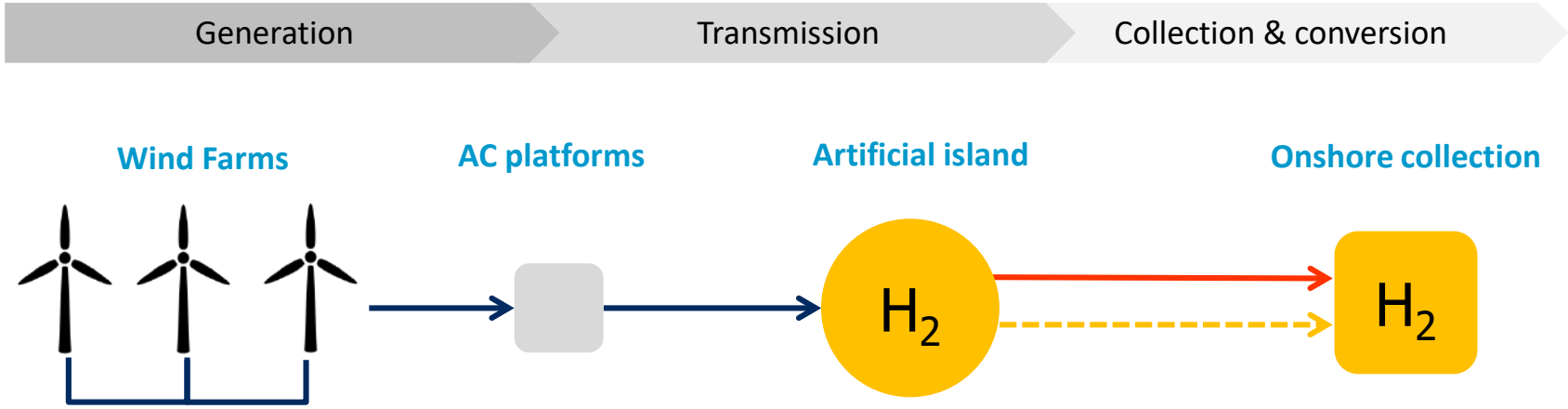
Can we design and control the farm to have less effects of wakes?



Dispatchability: wind power plant control



Hybrids to improve value and multifunctional use of space

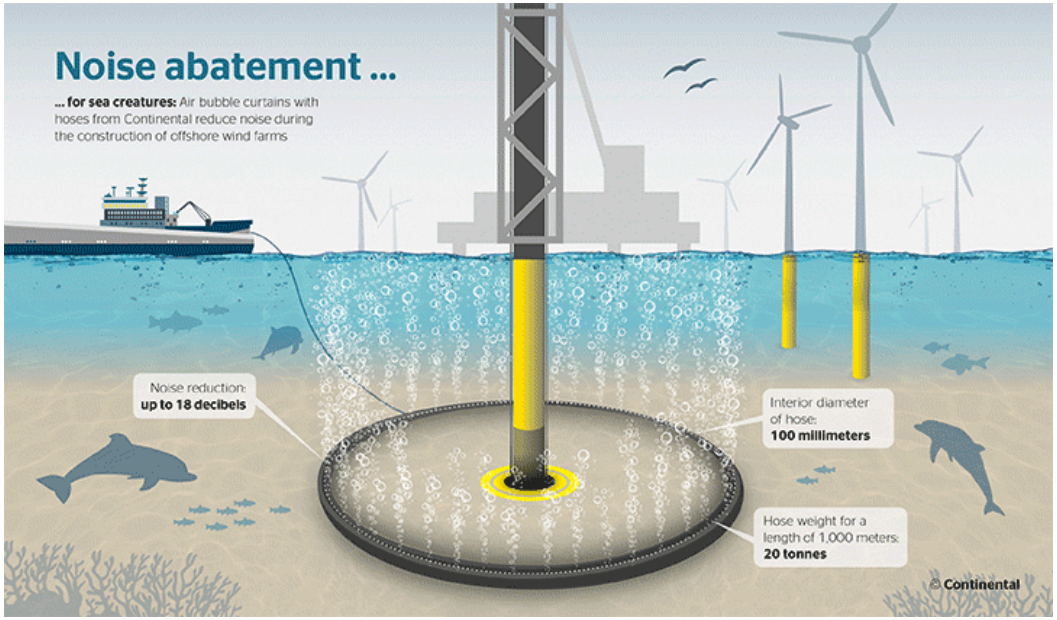


Possible future developments (?):

- Integration with power to gas (hydrogen)
- Offshore farms combined with: storage, floating solar, aquaculture, …

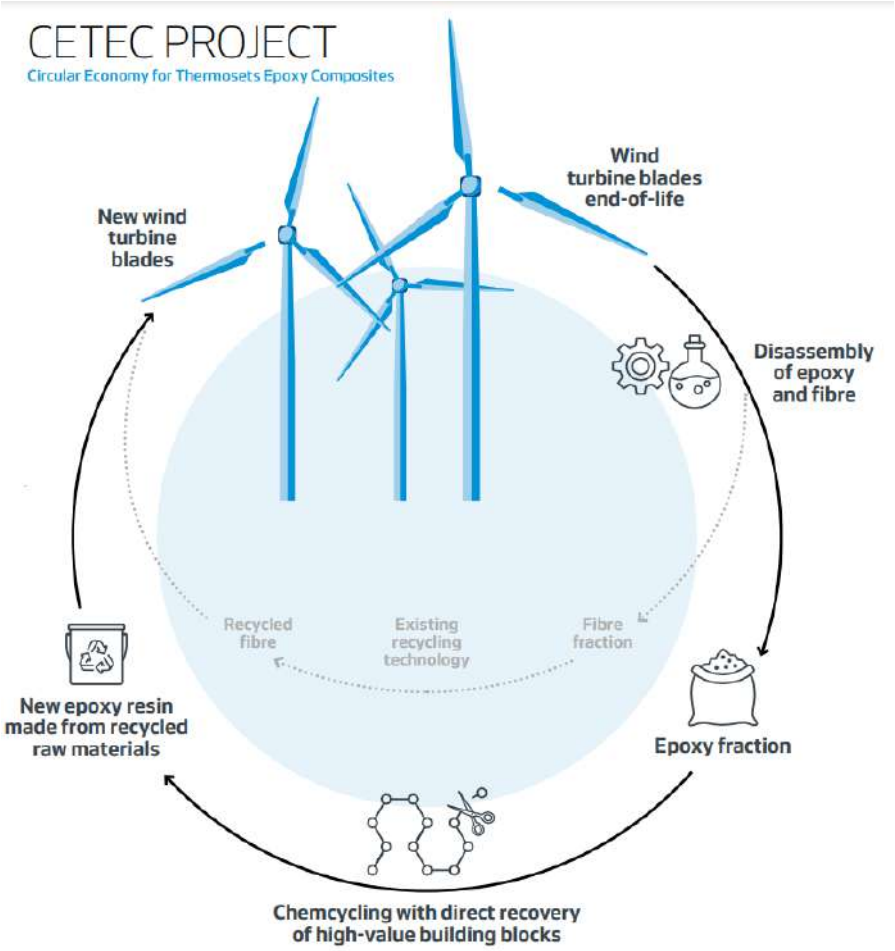
Environmental impact and circularity

- Piling noise alleviation/mitigation



Environmental impact and circularity

- Piling noise alleviation/mitigation
- Recycling (blades)



Environmental impact and circularity

- Piling noise alleviation/mitigation
- Recycling (blades)
- Removal of foundations
- Removal of cables
- Reuse of rare materials
- …

Conclusions

- The major challenge of designing an offshore wind farm is:
  - … not to get something that works (= meets the constraints)
  - … but something that works 'best' (= trade-offs in objective function)
- Many trade-offs lead to intuitive directions for the solutions:
  - Larger turbines
  - More reliable turbines
  - Turbines that are easier to install
- Insight in design process and tools help exceed the intuitive level
- Targets for wind farms are being raised (value & impact)