DTU

Floating Wind Farm Design & Optimization

EERA Deepwind’2021 Conference

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Outline

- Floating wind global potential and R&D
- Floating wind farm design
  - Fixed-bottom wind farm design
  - Floating wind concepts
  - Floating wind farm design
- Example design problem: shared vs. unshared anchors
- Summary and Next steps

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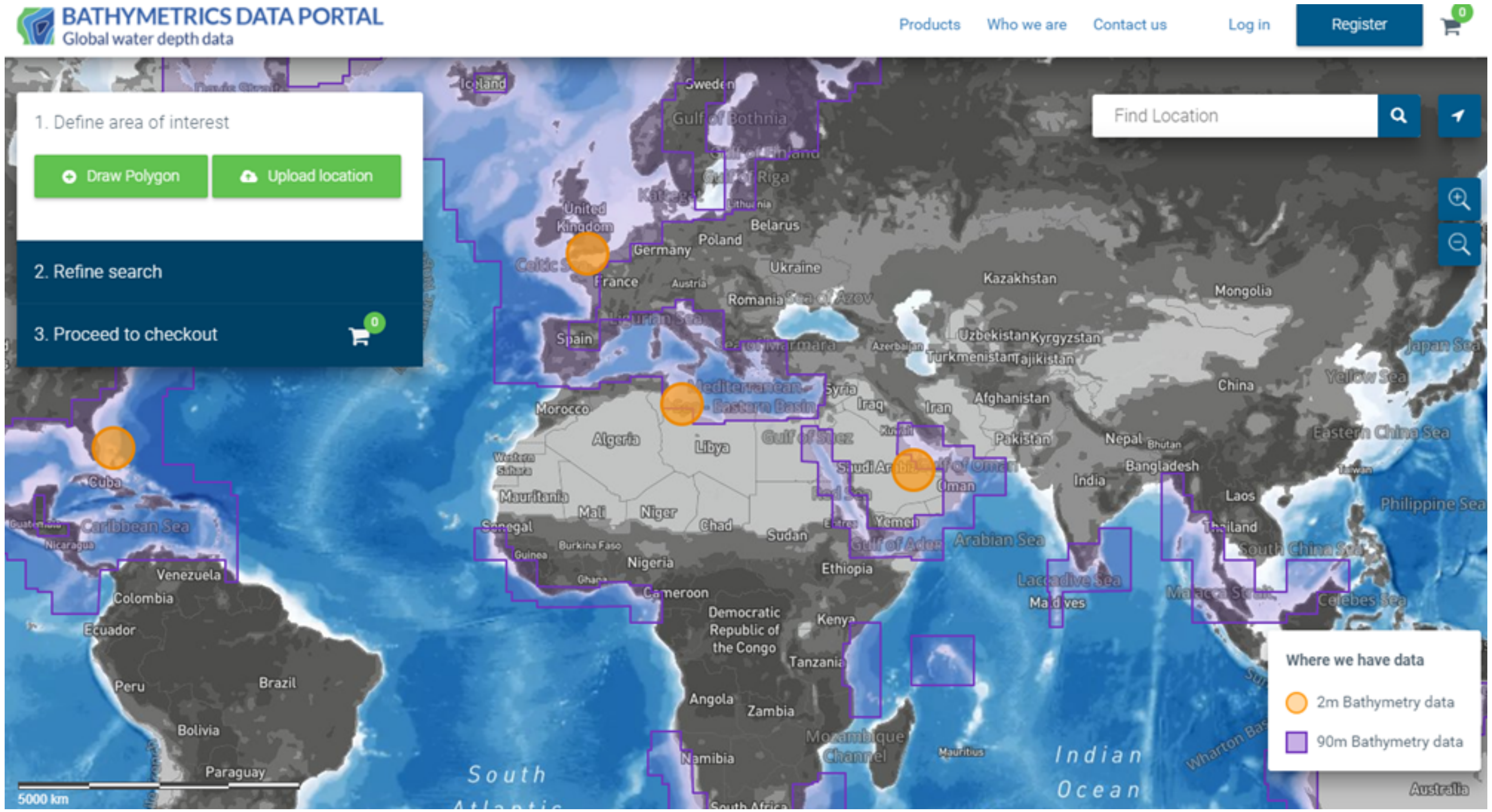
Floating Wind Potential

- Sea depth variation across the globe – majority of the resource in deep water (> 60 m)

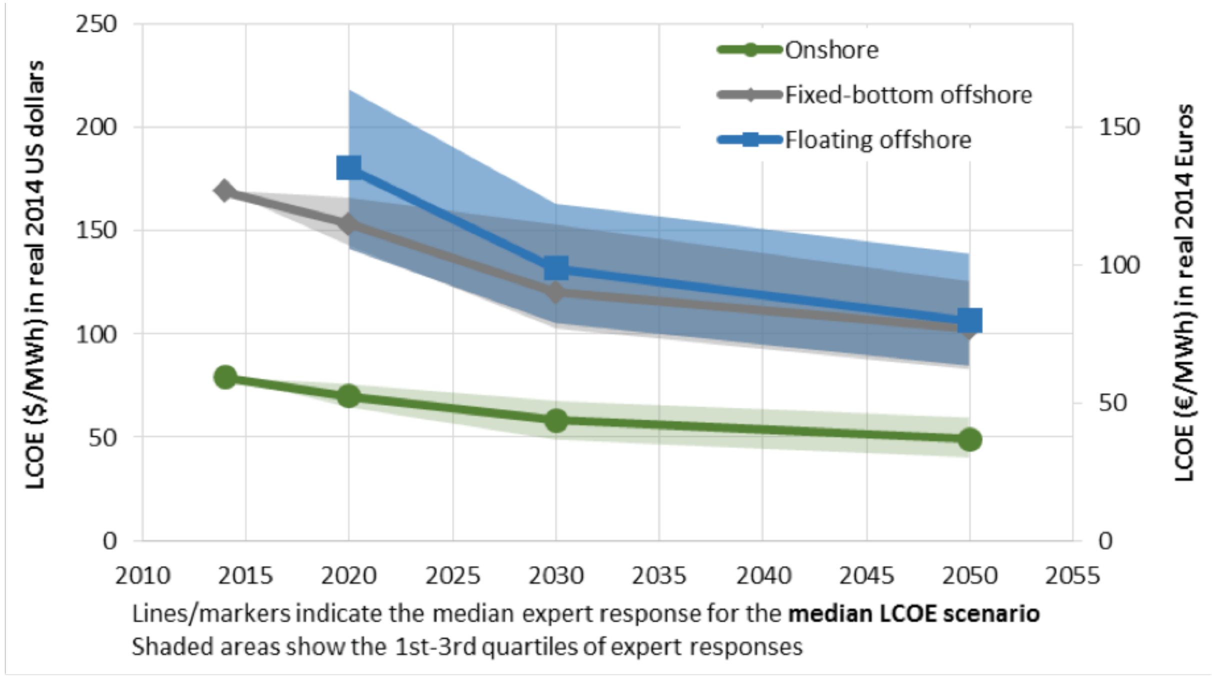


COUNTRY / REGION	SHARE OF OFFSHORE WIND RESOURCE IN +60m DEPTH	POTENTIAL FOR FLOATING WIND CAPACITY
Europe	80%	4,000 GW
USA	60%	2,450 GW

Source: WindEurope Floating Wind Vision Statement 2017

Source: DHI https://www.dhigroup.com/global/news/2017/09/new-bathymetrics-data-portal-delivers-quality-water-depth-data-online

Floating Wind Cost Trajectories



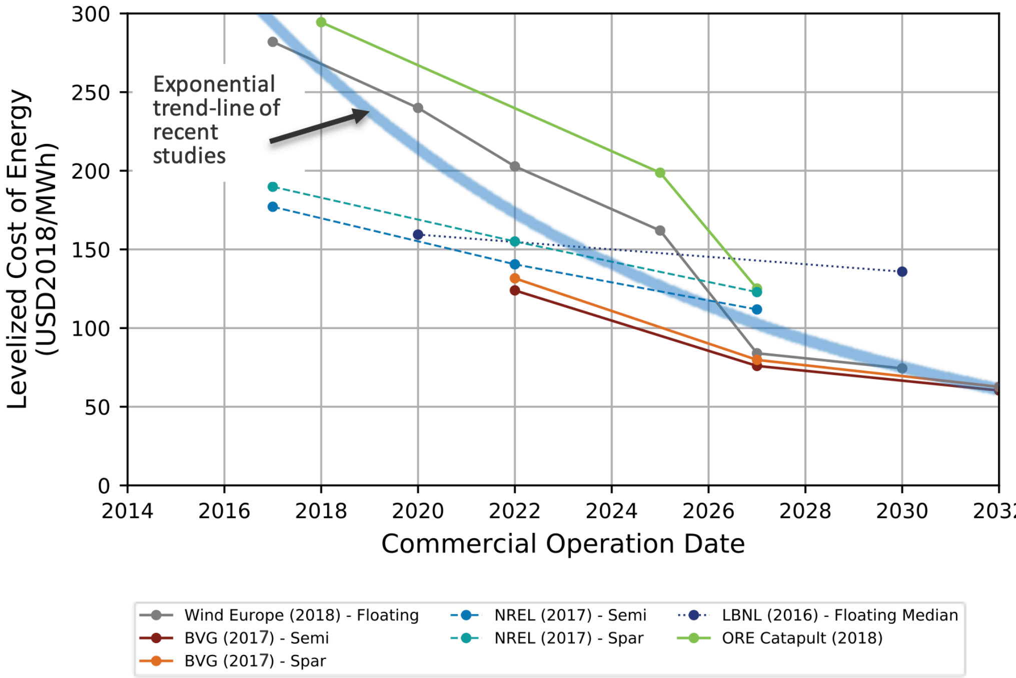


Figure 36. Global LCOE estimates for floating technology[72]

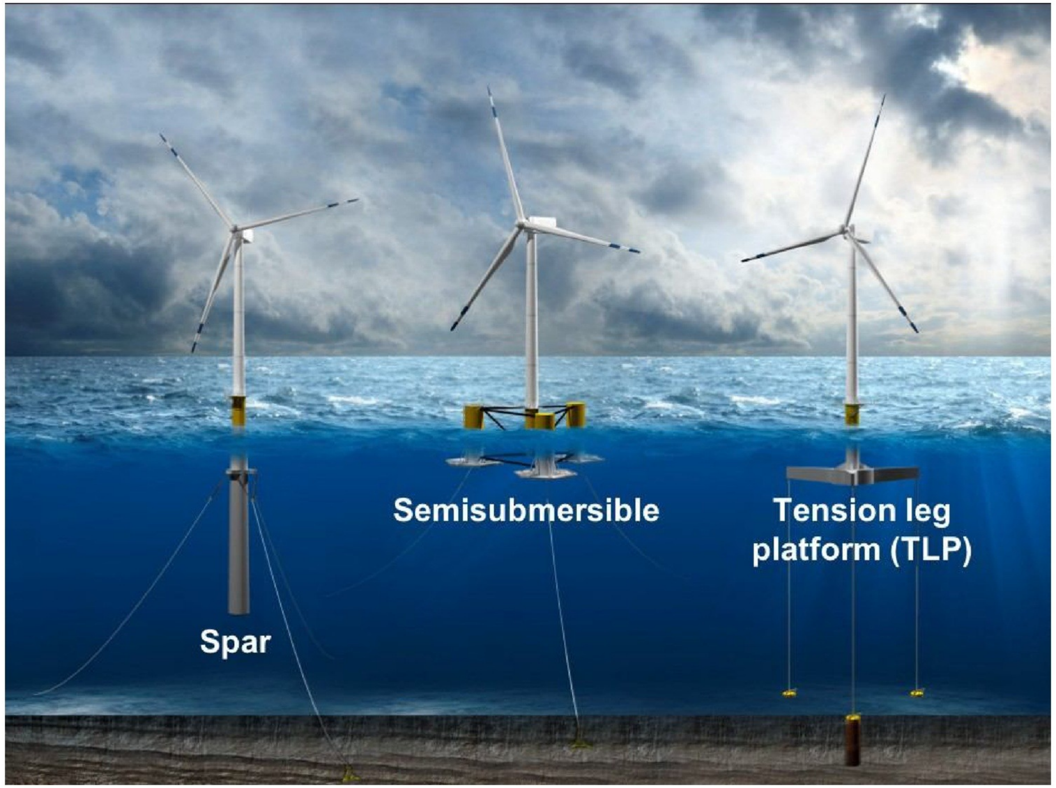
Sources: WindEurope (2018), Hundleby et al. (2017), Beiter et al. (2017), Wiser et al. (2016), ORE Catapult (2018)[73]

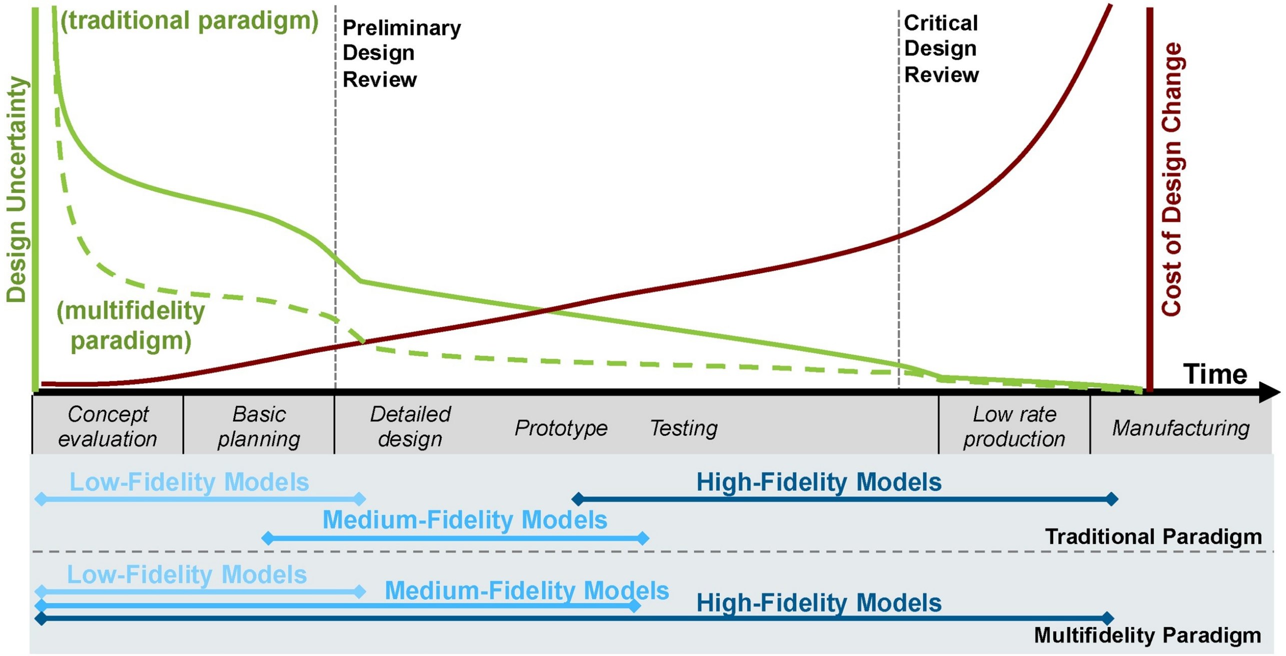
Ryan Wiser, Karen Jenni, Joachim Seel, Erin Baker, Maureen Hand, Eric Lantz, Aaron Smith. "Expert Elicitation Survey on Future Wind Energy Costs. Article No. 16135." Nature Energy, Vol. 1 (2016): 8 pp. https://dx.doi.org/10.1038/nenergy.2016.135 .

Walter Musial, Philipp Beiter, Paul Spitsen, Jake Nunemaker, Vahan Gevorgian. 2019. 2018 Offshore Wind Technologies Market Report. DOE/GO-102019-5192. https://www.nrel.gov/docs/fy19osti/74278.pdf .

Global Floating Wind R&D to Date

- Heavy emphasis on concept exploration (large number of different topologies) to drive down LCOE
- Focus on turbine / support structure design and installation and O&M (IO&M)

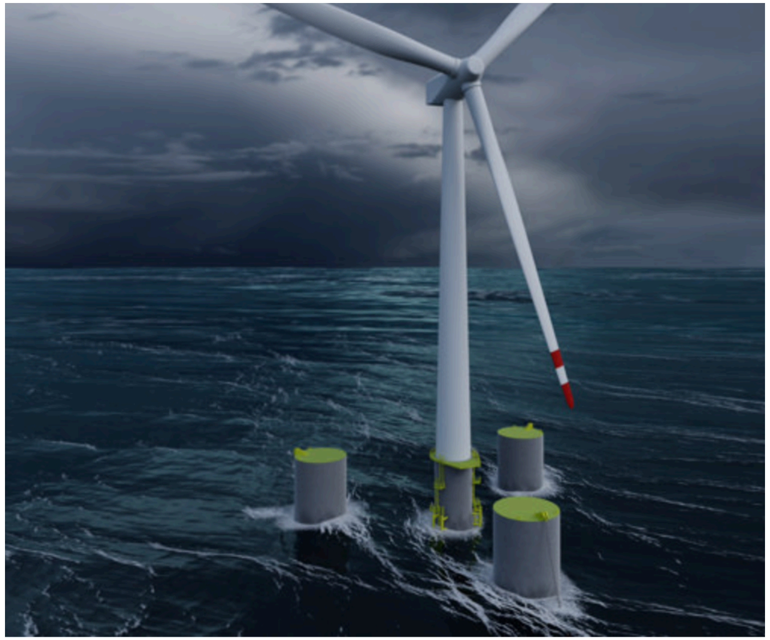




Source: Barter et al 2020

Global Floating Wind R&D to Date

- Still a significant potential for reducing LCOE for floating systems focusing on individual turbine/support structure units:
  - New concepts still coming
  - Systems engineering approaches picking up steam (including co-design with controls)
- Large scale demonstrations for 10+ MW machines on their way
- Small-scale commercial projects in development and larger projects coming down the pipeline



Source: EU FLAGSHIP project led by Iberdrola with DTU Wind involvement

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Global Floating Wind R&D Needs

- Moving from floating wind demonstrators to floating wind farms will require research in several key areas:
  - Mooring system analysis and $\boxed{\text{design}}$ at farm level including consideration of anchor types, anchor sharing, failure modes and reliability, risk assessment and more
  - Electrical collection system $\boxed{\text{design}}$ and effects of dynamics on electrical cables (as well as integrated analysis with mooring system for full plant, and also substation and export)
  - IO&M $\boxed{\text{strategies}}$ for full floating wind farm and their $\boxed{\text{optimization}}$
  - $\boxed{\text{Design optimization}}$ for full floating wind farm accounting for support structures, mooring, electrical collection system, controls (i.e. co-design), and more

iea wind

INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

Topical Expert Meeting #99 on

Floating Offshore Wind Array Challenges and Opportunities

IEA Wind Task 11

July 15, 17 & 20, 2020

Online meeting

Source: Principle Power

NREL MaREI Principle Power ifp Energies nouvelles PLANAIR

Technical Lead and Host:
Cian Desmond – MaREI (UCC)
Matt Hall, Matt Shields – NREL
Daniel Averbuch, Fabrice Guillemin, Pauline Bozonnet – IFPEN
Aaron Smith, Nailia Dindarova – Principle Power

Operating Agent:
Nicolas El Hayek – Planair SA

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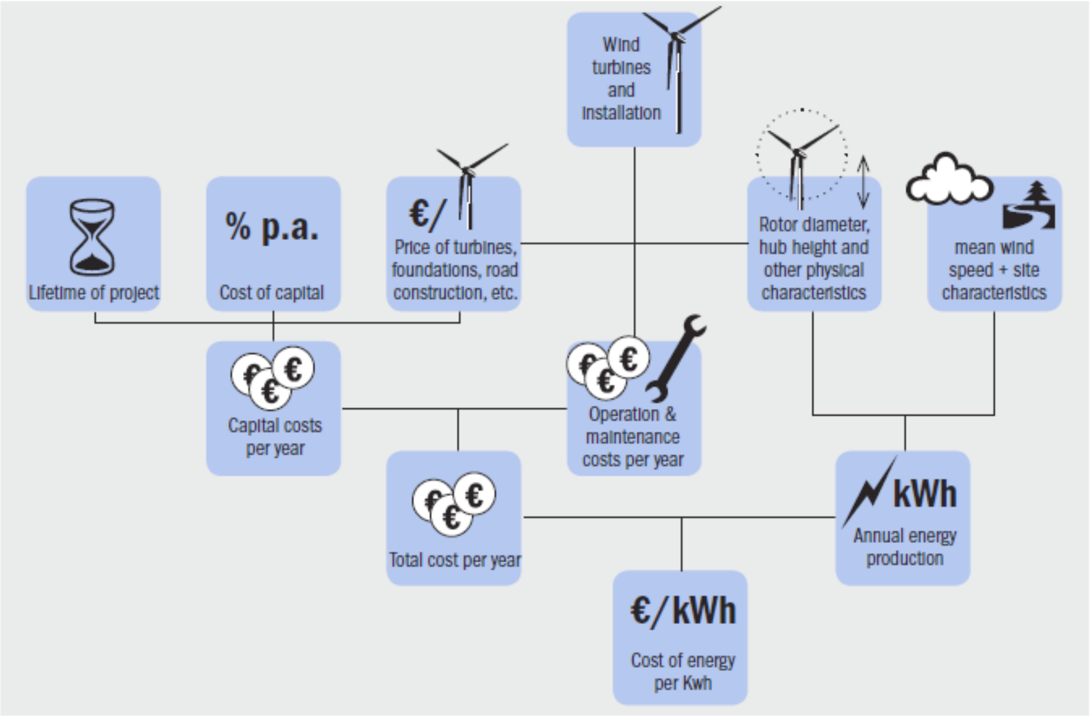
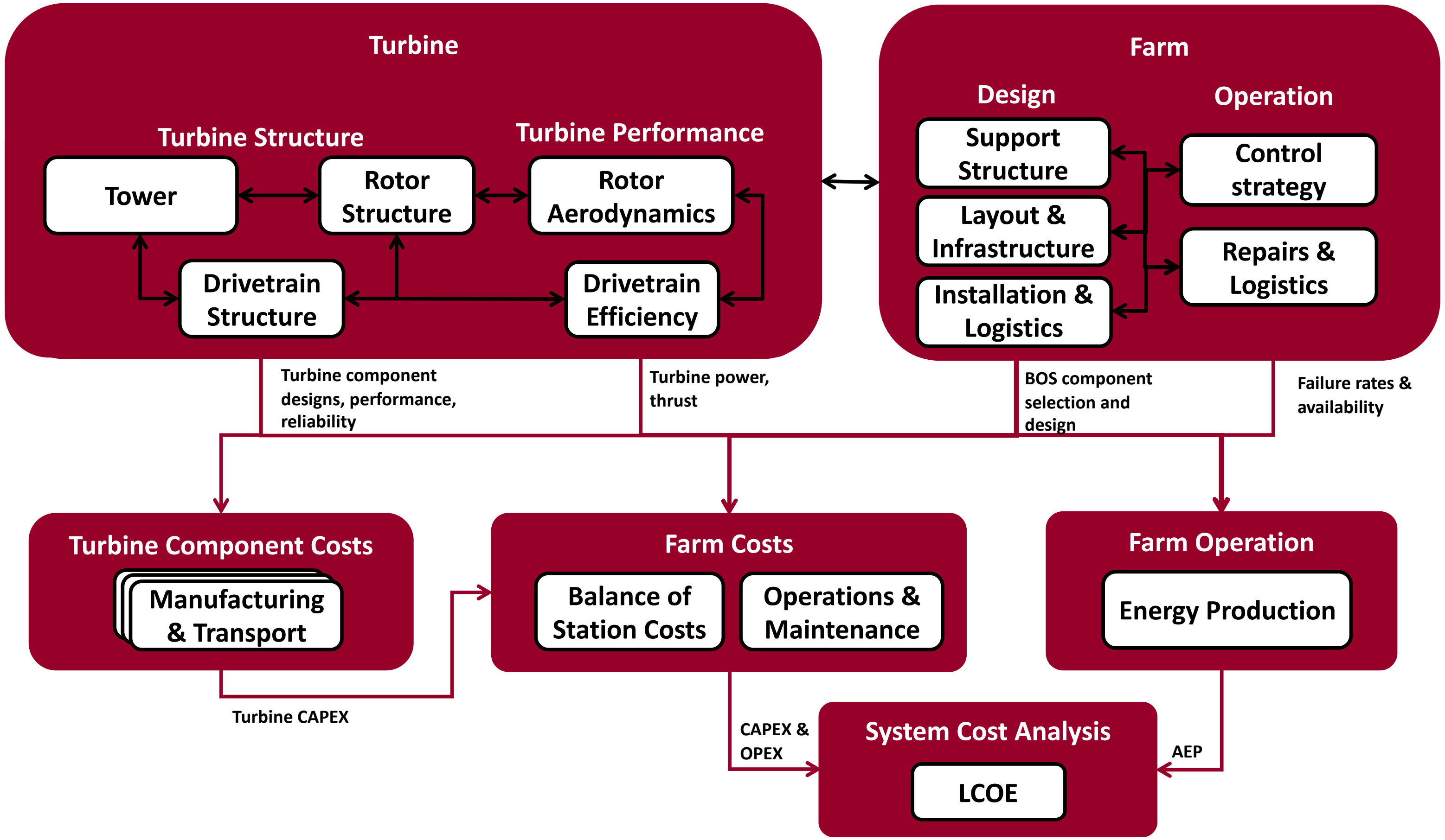
Fixed-bottom wind farm design

- Integrated design of a wind farm involves a full levelized cost of energy (LCOE) perspective



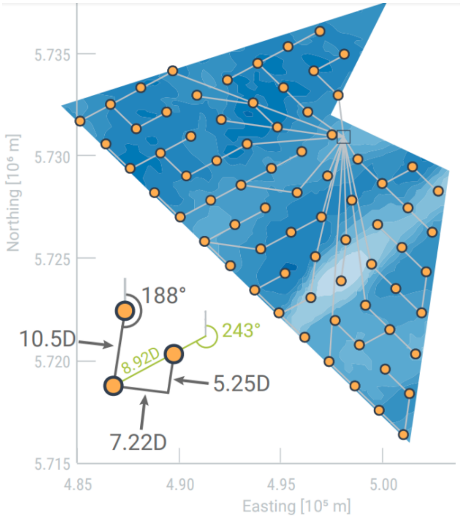
Fixed-bottom wind farm design

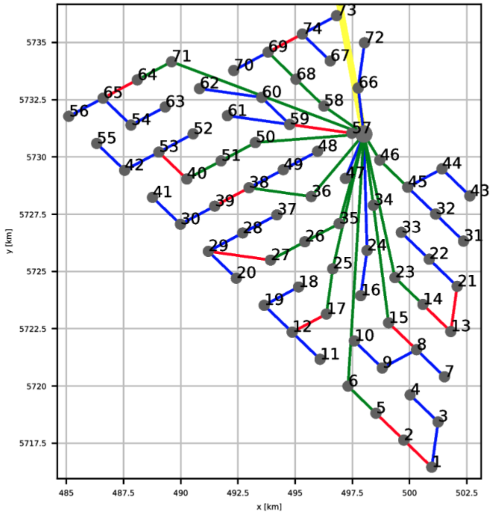
- Modelling of LCOE is complex and involves a large scope and timeframe with many sub-systems and disciplines including both physical and cost modelling of the system
  - Significant couplings
    - E.g. farm layout → support structures, collection system, energy production, IO&M
    - E.g. control strategy → energy production, reliablity
  - LCOE modeling a constant balance of fidelity (computational cost) and accuracy (believability)

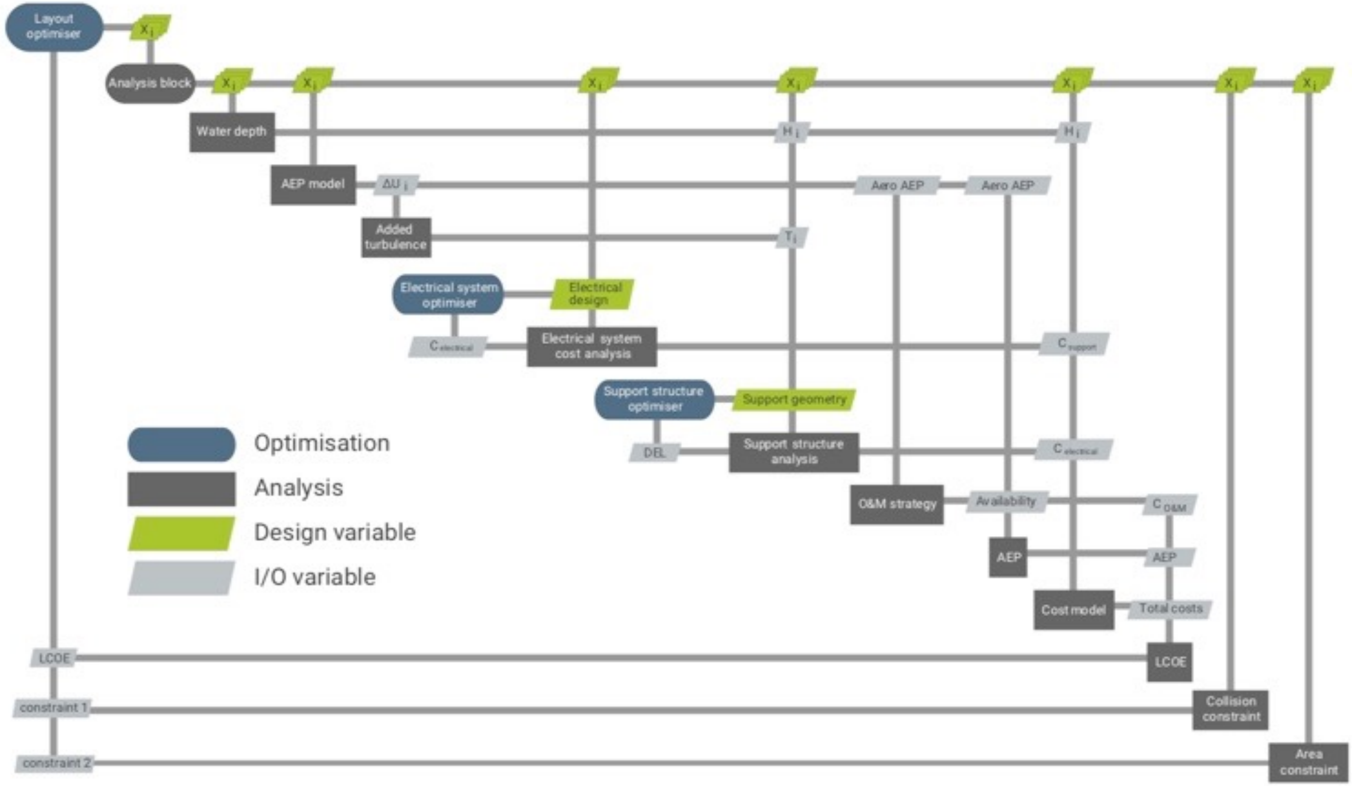


Fixed-bottom wind farm optimization

- IEA Wind Task 37 reference wind farm integrated optimization of offshore fixed-bottom wind farm accounting for:
  - Energy production
  - Support structure costs
  - Electrical collection system costs



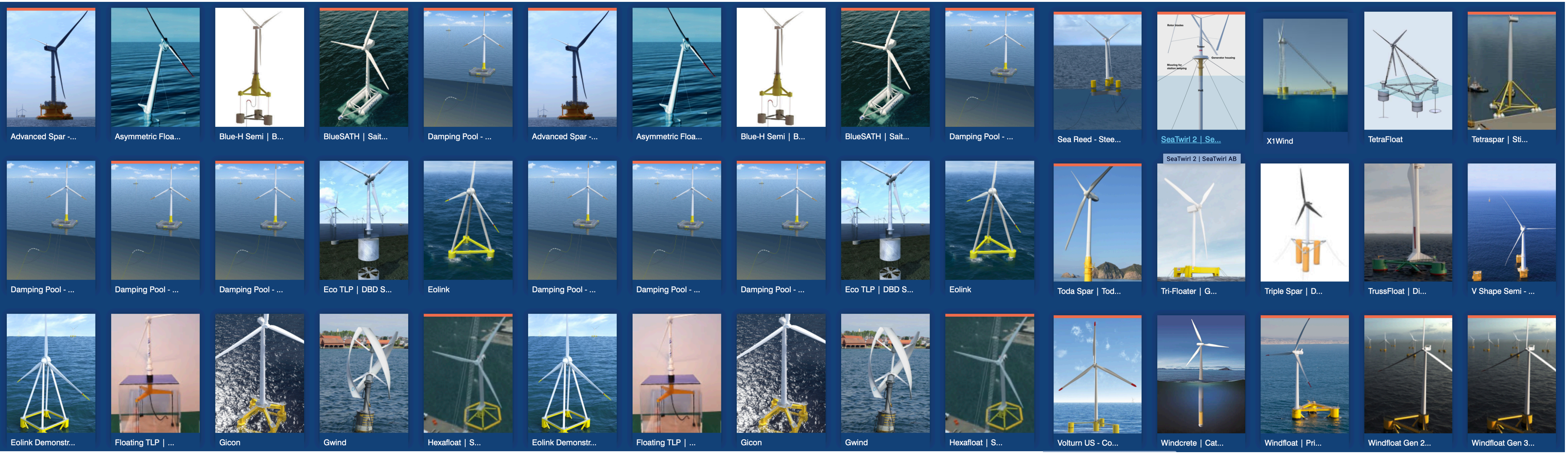




Wind plant layout optimization workflow for an offshore reference wind plant (Source: Sanchez Perez-Moreno et al 2017)

From fixed-bottom to Floating wind

- Concepts are numerous and will perform better or worse in certain operational environments
- Concept selection has significant influence on farm design including mooring, electrical collection system & IO&M



Source: Quest Floating Wind Energy *https://questfwe.com/definitive-guide-to-floating-wind-concepts/*

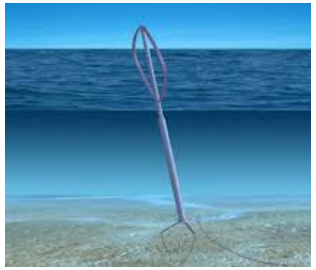
Floating wind farm design

- Concept choice impacts many elements of LCOE:
  - AEP: individual turbine energy productions, wakes, available control strategies
  - CAPEX: support structure design and cost, mooring and anchor system design and cost, collection system design and cost, transportation, assembly, installation and overall logistics
  - OPEX: service strategies and logistics, reliability and unplanned maintenance / component replacements, available control strategies
  - Finance: risk profile, plant lifetime
  - Revenue: energy, capacity, services – integration with storage, PtX, etc

Floating wind farm design

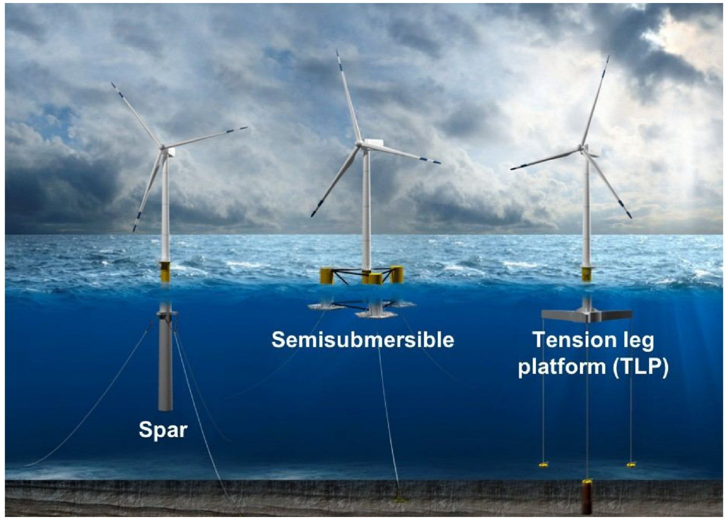
- Many architecture and design decisions

Turbine



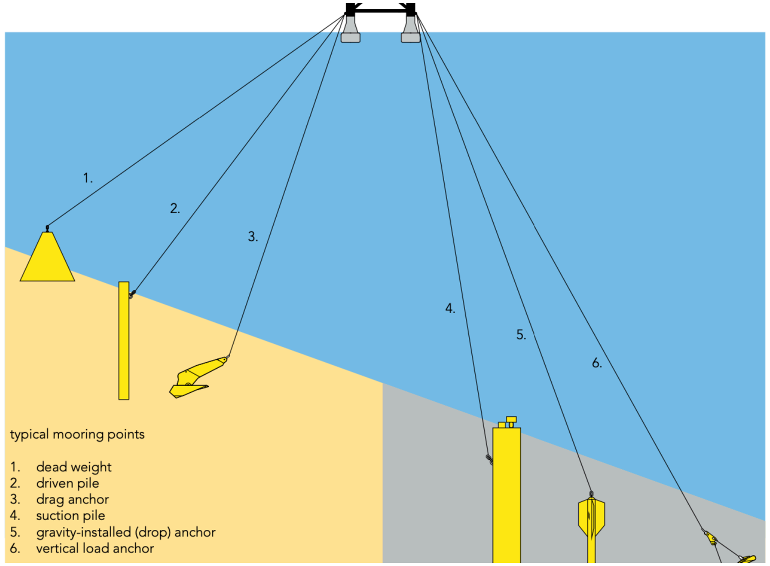
- Vertical-axis turbines
- Horizontal-axis turbines
- Multi-rotor turbines
- Upwind/downwind configuration
- …

Platform



- Barge
- Spar
- Semi-submersible
- Tension-leg platform
- …

Mooring System

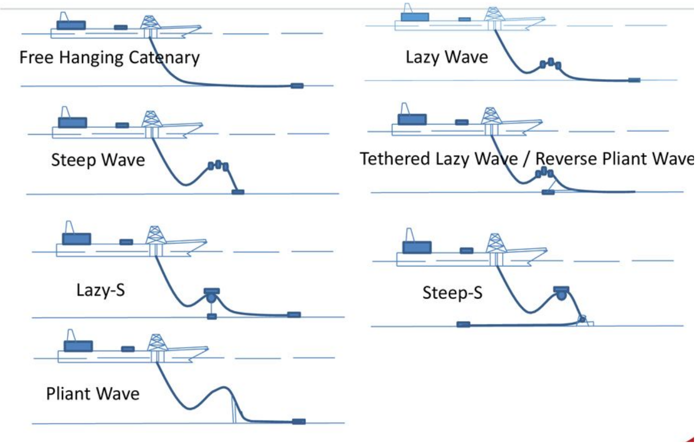


- Anchor type
- Line number per turbine
- Shared / unshared anchors
- Inter-turbine lines’
- …

Floating wind farm design

- Many architecture and design decisions

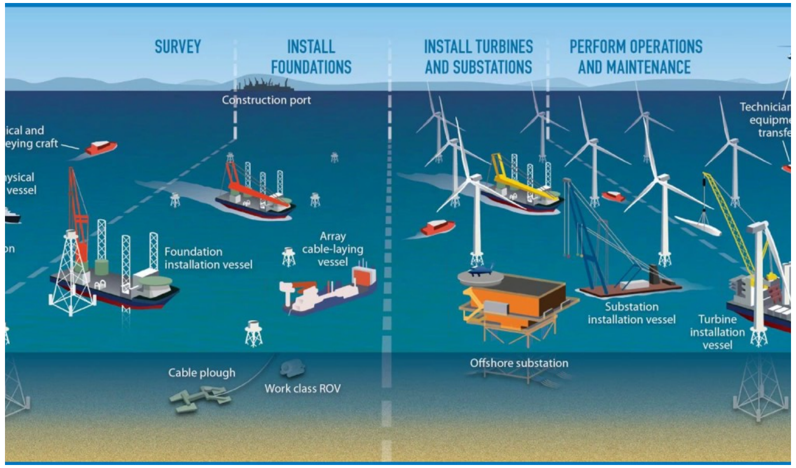
Electrical System



- Dynamic cabling configuration
- Substation and export cable configuaration
- …

Source: Victor et al 2017

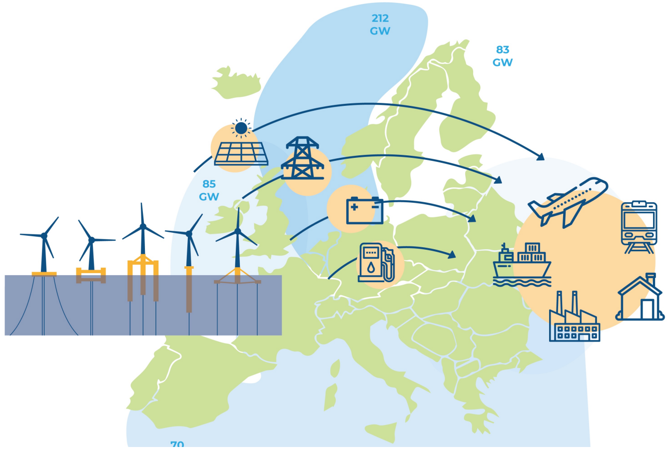
Installation & O&M



- Vessel types
- Installation procedures
- Overall IO&M strategies
- …

Source: Clean Energy Group 2017

Other Technologies

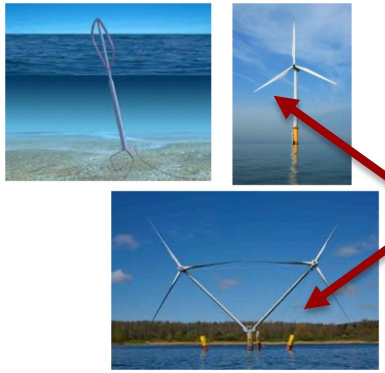


- Electricity storage
- Power-to-x
- Other generation
- …

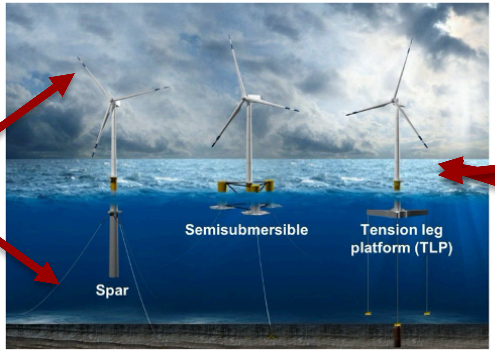
Floating wind farm design

- Many architecture and design decisions
- And not one-to-one
- Very challenging mutli-system multi-disciplinary design & optimizationo problem!

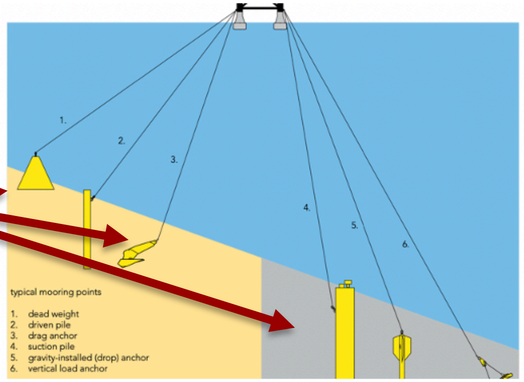
Turbine



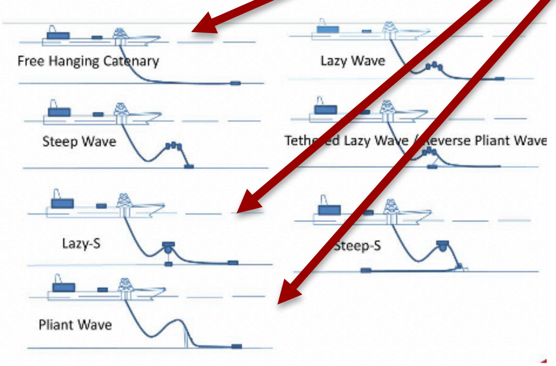
Platform



Mooring System



Electrical System



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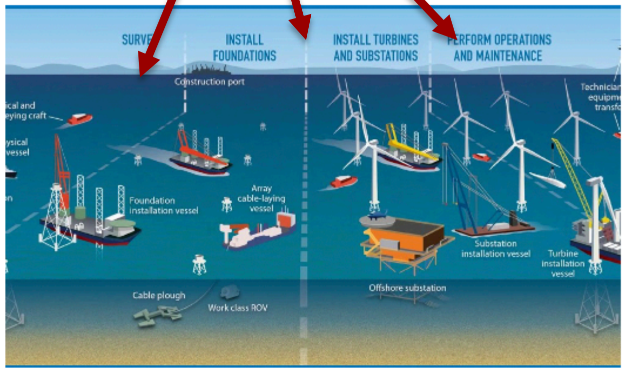

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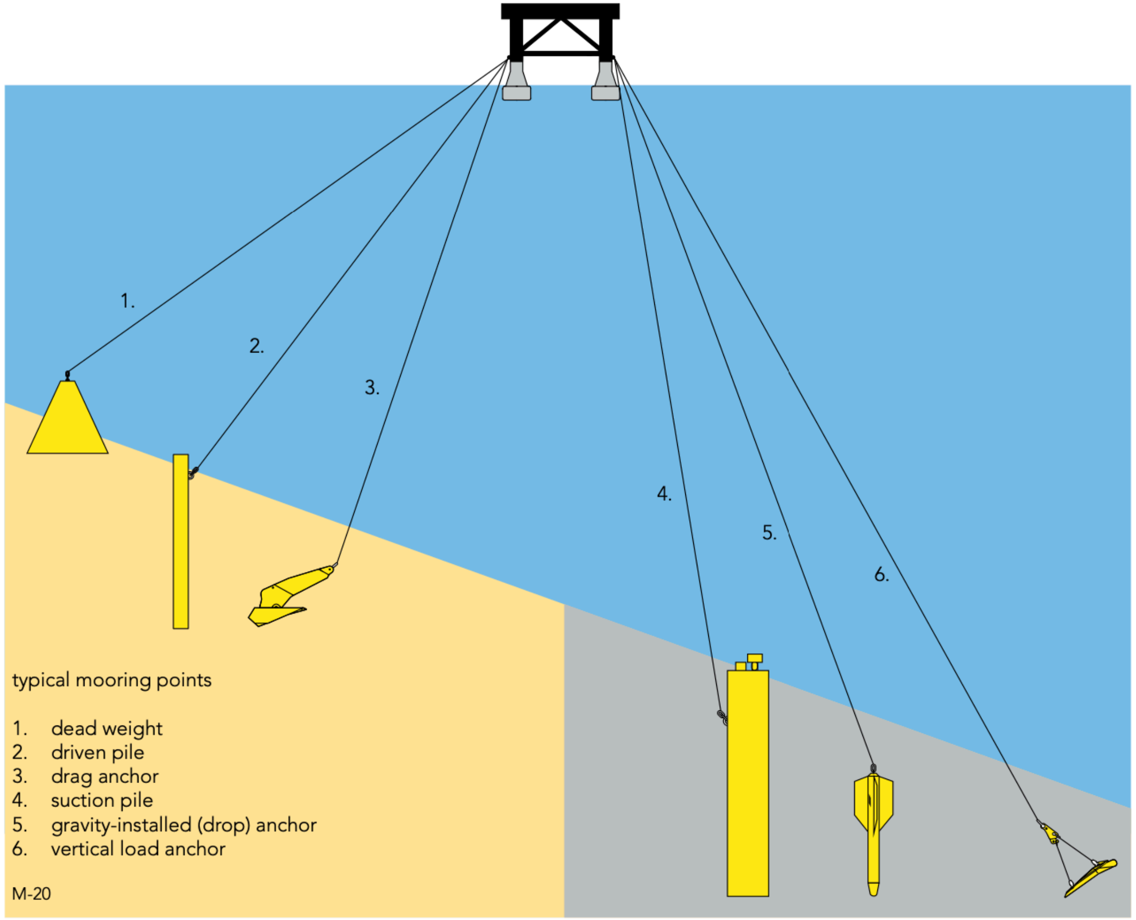
Example: shared versus unshared anchors

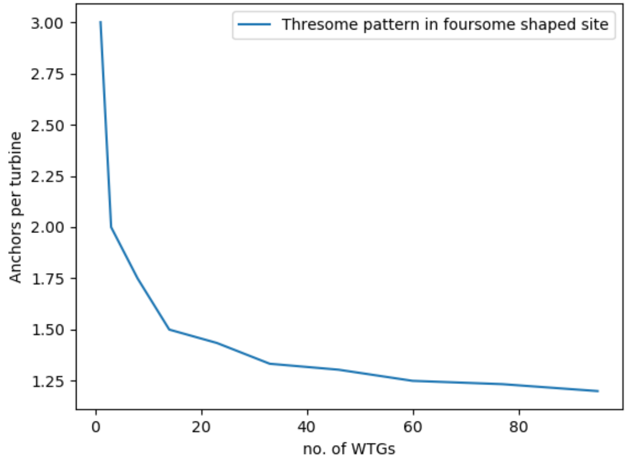
- Mooring and anchoring theory and design well-defined for O&G industry
- Mooring optimization has been applied to floating offshore wind for single systems
- Sharing of anchors is a potential pathway for LCOE reduction of a floating wind farm
- Study considers using less expensive unshared drag anchors with shared anchors using suction piles (Madsen 2020)

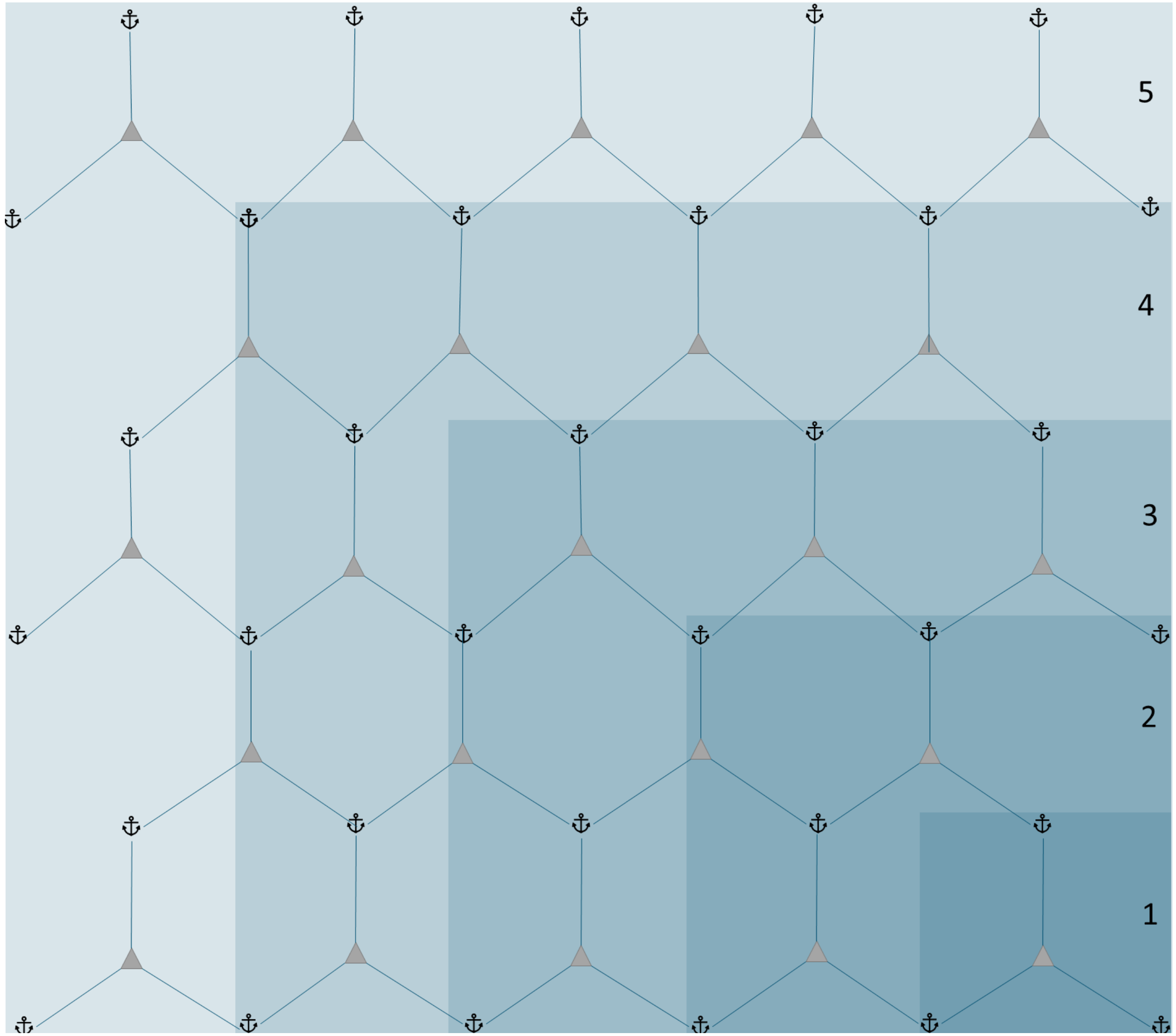


Source: Vryhoff Guide to Anchoring 2018

Patterns exploration

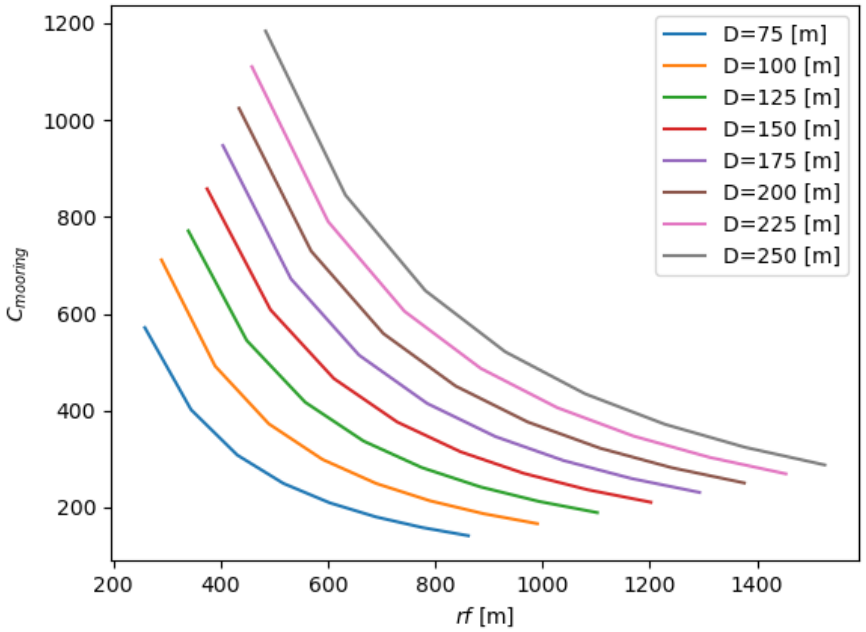
- Using shared anchors requires use of certain patterns.
- The investigation carried out on pattern with 3 mooring lines per anchor and 3 mooring lines per turbine
- As the farm size increases, the ratio of anchors/turbine decreases

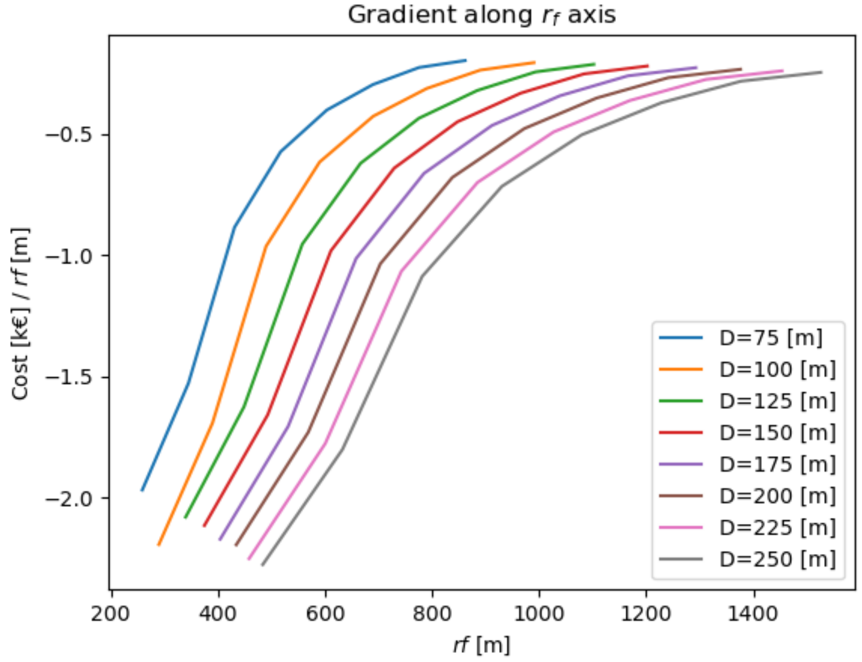




Single mooring line optimization

- Single line mooring optimizes the overall cost of mooring by varying the chain diameter and length
- Optimized mooring line cost increases with increasing depth and footprint (with decreasing sensitivity for larger footprints)

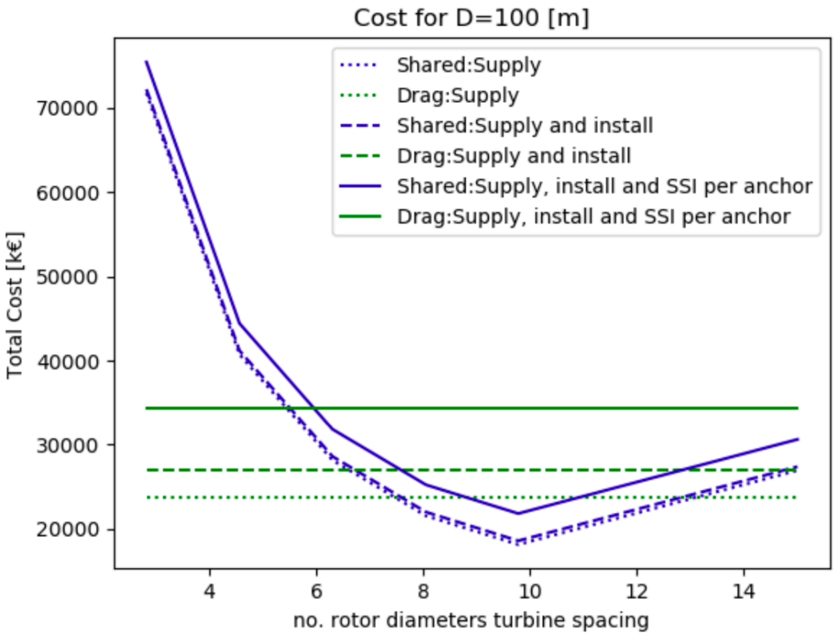


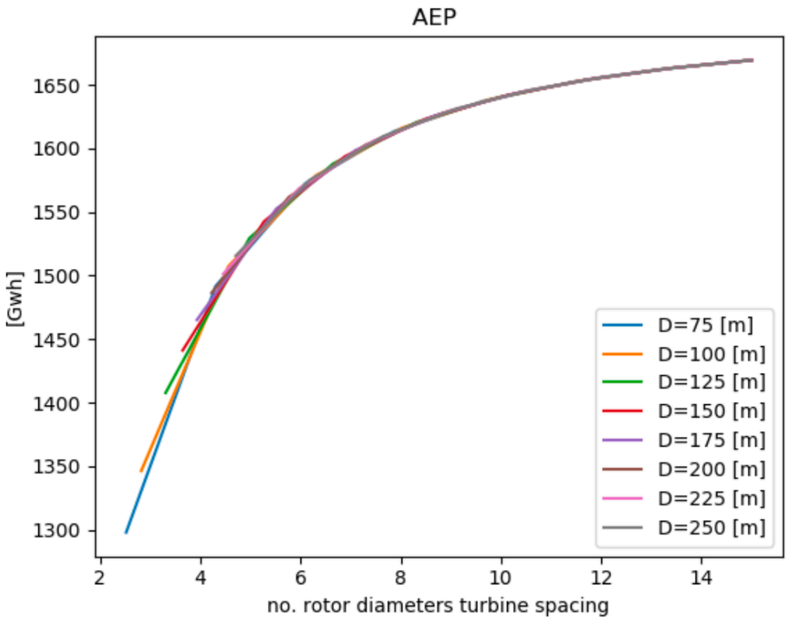


Farm optimization – spacing versus mooring/anchoring cost

- Optimization conducted for inter-turbine spacing coupled with use of shared or unshared anchor systems
  – Total cost of mooring system = cable costs + anchor costs + supply and installation costs

- Shared anchors preferred for higher diameter spacings and optimum at 10 diameters (sensiitive to cost model)

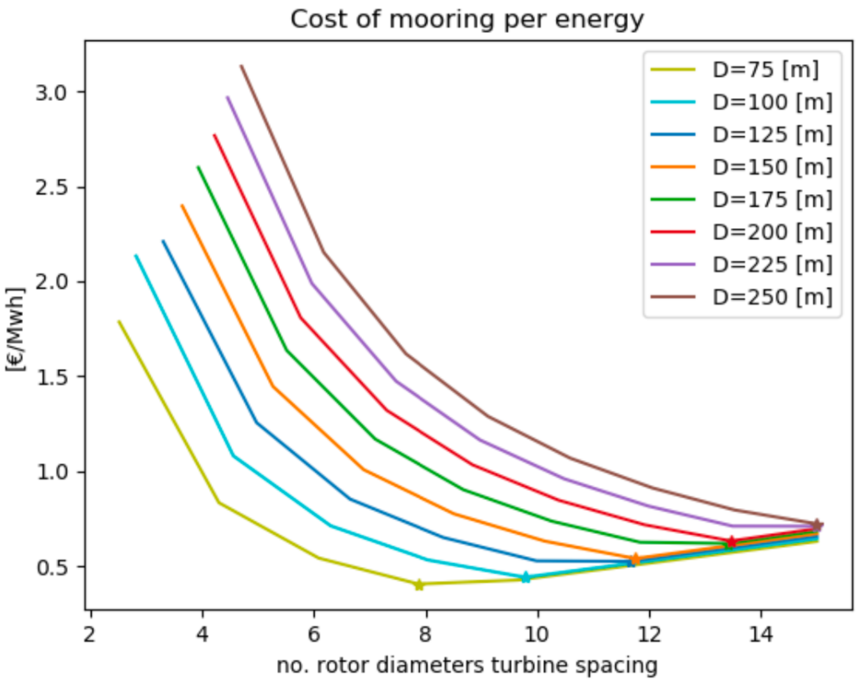


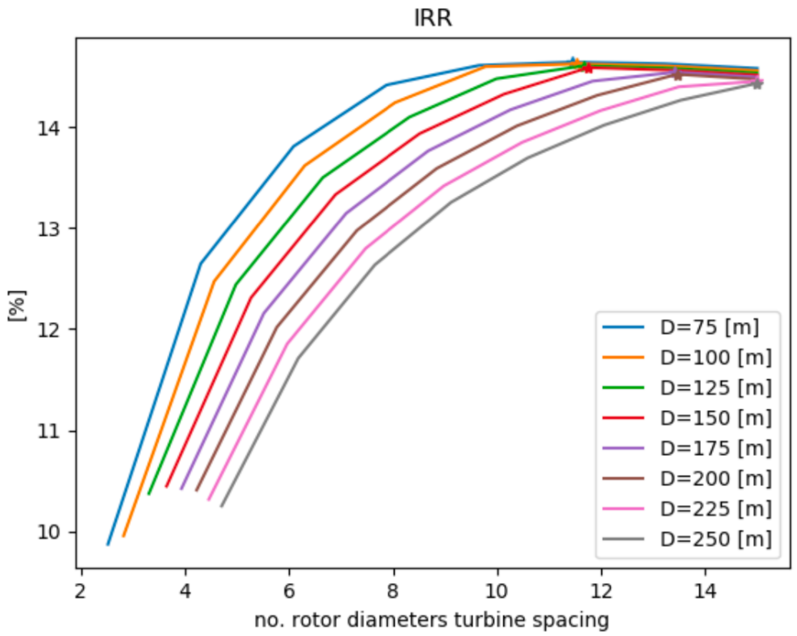


Farm optimization – spacing versus mooring/anchoring cost

- Optimization of mooring cost per unit energy depends on depth (range of 8 to 14 diameters wiith increasing depth)

- Optimization for overall internal rate of return favors even higher spacing (though other significant costs – i.e. electrical system - are neglected)





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Summary

- Floating wind resource potential and cost trajectories provide basis for a very bright future for floating wind development
- R&D in floating wind up to now has largely focused on concept innovation and exploration and demonstration of individual units
- Floating wind farm development requires significant R&D
  - Design of wind farms involves a large number of trade-offs affecting overall system performance and cost
- Many innovation pathways towards reducing overall floating wind farm LCOE
  - Example of shared anchors just one potential pathway to LCOE reduction

Next Steps

- Extension of optimization work on shared and unshared anchors
  - Improved modeling of mooring and anchor system and costs
  - Different patterns – number of lines per turbine, lines per anchor, etc
  - Incorporating more sub-systems – i.e. electrical collection system

- Expert workshop on floating wind farm design and optimization
  - LCOE impacts and science and engineering challenges
  - Hosted by DTU and TU Delft online (end of Jan. / early Feb.)

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Thank you for your attention