Floating offshore wind turbines: challenges and opportunities

Seminar VI

Mikel De Prada Gil
Associate Researcher (IREC)
Outline

• Challenges and opportunities of floating wind
  – Motivation
  – State of the art
  – Key challenges and opportunities
  – Floating Offshore Wind Vision Statement

• EU H2020 LIFES 50+ Project
Outline

• Challenges and opportunities of floating wind
  – Motivation
  – State of the art
  – Key challenges and opportunities
  – Floating Offshore Wind Vision Statement

• EU H2020 LIFES 50+ Project
More than 91% of all offshore wind capacity is installed in European waters, with an average depth of 27 meters.

- Shallow waters are scarce and limited in space
- Higher wind speeds far offshore
- Bottom-fixed wind turbines face technical and economic feasible limits with increasing water depths
Motivation

- Floating wind turbines are the promising solution
  - Low constraints to water depths and soil conditions
  - Harness the vast wind resources far offshore
  - Leverage existing infrastructure and supply chain capabilities from the offshore O&G and BFOW industry
  - Opportunity for France, Norway, Portugal, Spain, Scotland, USA, Japan, Taiwan ...
Market potential

The offshore wind market has so far been dominated by countries with relatively shallow water depths (<50m). However, there is extensive wind resource in deep water locations (>50m depth) suitable for floating wind foundations.

<table>
<thead>
<tr>
<th>COUNTRY / REGION</th>
<th>SHARE OF OFFSHORE WIND RESOURCE IN +60m DEPTH</th>
<th>POTENTIAL FOR FLOATING WIND CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>80%</td>
<td>4,000 GW</td>
</tr>
<tr>
<td>USA</td>
<td>60%</td>
<td>2,450 GW</td>
</tr>
<tr>
<td>Japan</td>
<td>80%</td>
<td>500 GW</td>
</tr>
</tbody>
</table>

Source: Carbon Trust
State of the art

Floating wind foundation typologies

Mooring line stabilized (50-400m)
Buoyancy stabilized (45-350m)
Ballast stabilized (90-700m)

Source: EWEA (2013)
# State of the art

## Floating wind foundation typologies

<table>
<thead>
<tr>
<th>Typology</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-submersible</td>
<td>✓ Flexible application due to the ability to operate in shallow water depths</td>
<td>× High structural mass to provide sufficient buoyancy and stability</td>
</tr>
<tr>
<td></td>
<td>✓ Low vessel requirement – only basic tug boats required</td>
<td>× Complex steel structures with many welded joints can be difficult to fabricate</td>
</tr>
<tr>
<td></td>
<td>✓ Onshore turbine assembly</td>
<td>× Potentially costly active ballast systems</td>
</tr>
<tr>
<td></td>
<td>✓ Amenable to port-side major repairs</td>
<td></td>
</tr>
<tr>
<td>Spar-buoy</td>
<td>✓ Simple design is amenable to serial fabrication processes</td>
<td>× Constrained to deep water locations</td>
</tr>
<tr>
<td></td>
<td>✓ Few moving parts (no active ballast required)</td>
<td>× Offshore turbine assembly requires dynamic positioning vessels and heavy-lift cranes</td>
</tr>
<tr>
<td></td>
<td>✓ Excellent stability</td>
<td>× Large draft limits ability to tow the structure back to port for major repairs</td>
</tr>
<tr>
<td>Tension leg platform</td>
<td>✓ Low structural mass</td>
<td>× High loads on the mooring and anchoring system</td>
</tr>
<tr>
<td></td>
<td>✓ Onshore turbine assembly</td>
<td>× Challenging installation process</td>
</tr>
<tr>
<td></td>
<td>✓ Few moving parts (no active ballast required)</td>
<td>× Bespoke installation barge often required</td>
</tr>
<tr>
<td></td>
<td>✓ Excellent stability</td>
<td></td>
</tr>
</tbody>
</table>

Source: Carbon Trust
State of the art
Review of Existing Floating Wind Concepts

There is no clear winner with regard to which is most likely to be deployed at scale in the future, but a range of leading devices suitable for different site conditions, and influenced by local infrastructure and supply chain capabilities.
State of the art
Review of Existing Floating Wind Concepts

Geographical origin and typology of floating wind concepts

Typologies under development

Semi-sub, 14
Spar, 6
TLP, 7
Multi-turbine platform, 3
Hybrid wind/wave, 3

No. concepts

Japan, 6
USA, 4
France, 4
Norway, 3
Spain, 2
European Consortium, 2
Germany, 1
Netherlands, 1
Sweden, 1
UK, 1
Denmark, 1

incite

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 675318
A large number of different floating wind turbine concepts exist ranging from early designs to prototypes and pre-commercial projects.

Most advanced projects are:

<table>
<thead>
<tr>
<th>PROJECT NAME</th>
<th>CAPACITY</th>
<th>COUNTRY</th>
<th>EXPECTED COMMISSIONING DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dounreay Tri</td>
<td>2 x 5 MW</td>
<td>Scotland</td>
<td>2018</td>
</tr>
<tr>
<td>Gaelectric</td>
<td>30 MW</td>
<td>Ireland</td>
<td>2021</td>
</tr>
<tr>
<td>Hywind Scotland</td>
<td>30 MW</td>
<td>Scotland</td>
<td>2017</td>
</tr>
<tr>
<td>WindFloat Atlantic</td>
<td>30 MW</td>
<td>Portugal</td>
<td>2018-2019</td>
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<tr>
<td>Kincardine</td>
<td>48 MW</td>
<td>Scotland</td>
<td>From 2018</td>
</tr>
<tr>
<td>French pre-commercial farms</td>
<td>4 x 25 MW</td>
<td>France</td>
<td>2020</td>
</tr>
<tr>
<td>Antlantis / Ideol project</td>
<td>100 MW</td>
<td>UK</td>
<td>2021</td>
</tr>
</tbody>
</table>

Source: WindEurope 2017
State of the art
Hywind Scotland - the world’s first floating wind farm
State of the art
Capital Expenditure (CAPEX)

- **Turbine**: 45%
- **Foundation**: 30%
- **Moorings & anchors**: 15%
- **Installation**: 10%
- **Balance of System**: 5%
- ** Decommissioning**: 2%

**Legend**:
- Fixed-bottom
- Floating
Cost benefit will be heavily influenced by site conditions, particularly in relation to distance from shore and met-ocean conditions.

State of the art
Operational Expenditure (OPEX)

- **Cost of minor repairs:** Expected to be similar (analogous methods of turbine access by crew transfer vessel)

- **Cost of major repairs:**
  - **BFOV:** Require expensive jack-up or dynamic positioning vessels (longer mobilisation timeframes but rapid repairs once available)
  - **Floating:** They can be disconnected from their moorings and towed back to shore to conduct repairs at port (slower repair process but rapid mobilisation of standard tug boats)

**Net impact:**
- Similar downtime, and associated lost revenue.
- Reduced charter rates and mobilisation costs for standard tug boats
- Lower weather dependency for repairs

\[\downarrow \text{OPEX}\]
State of the art
Levelised Cost of Energy (LCOE)

\[
LCOE = \frac{CAPEX + OPEX}{AEP}
\]

Capacity factor:
- Onshore \(~25-30\%\)
- Bottom-fixed offshore \(~40\%\)
- Statoil’s 2.3MW Hywind demonstrator \(~50\%\)

Source: Carbon Trust
Cost Competitiveness of Floating Wind
Cost Reduction Potential (from prototype to commercial scale)

Cost reductions can be achieved through a combination of:

- Learning effects (gaining maturity)
- Benefiting from economies of scale
- Design standardisation (less constrained by water depth than BFLOW)
- Targeted RD&D initiatives to overcome common industry challenges

Source: Carbon Trust
### Key challenges and opportunities

**Key market barriers**

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Mitigation</th>
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</thead>
<tbody>
<tr>
<td>Perception that fixed-bottom offshore wind sites need to be exhausted before industry moves to deeper floating wind.</td>
<td>Demonstrate that LCOE for floating wind in deep water can be lower than fixed-bottom foundations.</td>
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<tr>
<td>Lack of awareness in industry of the technology options and LCOE potential of floating wind.</td>
<td>Public support for full-scale prototypes of the most promising concepts to demonstrate cost reduction potential.</td>
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<tr>
<td>Financial risk of new technology (bankability)</td>
<td>Need for investor commitment. Engagement with banks on pilot and pre-commercial projects.</td>
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<tr>
<td>Lack of access to high quality simulation facilities at an affordable cost.</td>
<td>Investment in test facilities</td>
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</tbody>
</table>
## Key challenges and opportunities

### Fabrication challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial fabrication</td>
<td>Advanced design focused to simplify the manufacturing process</td>
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<tr>
<td>Reduce man-hours during fabrication</td>
<td>Efficient, well-coordinated design with the yard and the supplier</td>
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<tr>
<td>Logistics</td>
<td>Parallel serial fabrication of floater and wind turbine</td>
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<tr>
<td>Shipyards with sufficient dock size (dry dock with sufficient beam and water depth)</td>
<td>Extend dry dock capacity</td>
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<td></td>
<td>Use of submersible barge can replace dry-dock</td>
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<tr>
<td>Launching of the floater – load out can be highly variable depending on facility used</td>
<td>Adapt floater design to make load-out easier</td>
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<tr>
<td>RNA assembly (high hub height and large weight)</td>
<td>Large port-side cranes</td>
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</tbody>
</table>

Source: Carbon Trust
# Key challenges and opportunities

## O&M challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing wind turbines in difficult sea-states</td>
<td>Crew transfer vessels which can operate in more challenging met-ocean conditions</td>
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<tr>
<td></td>
<td>Design the unit to allow easy inspection and maintenance at sea. All critical components should be above water level and reachable.</td>
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<tr>
<td></td>
<td>Weather monitoring</td>
</tr>
<tr>
<td>System reliability</td>
<td>Low maintenance designed into whole system</td>
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<td></td>
<td>Remote control systems and conditioning monitoring to reduce offshore visits</td>
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<tr>
<td>Replacing heavy turbine components</td>
<td>Special-purpose cranes, or transport structure to shore</td>
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<tr>
<td></td>
<td>Mooring system, electrical cable connection and other systems should all be designed to accommodate a quick disconnect and reversible installation process. This includes ensuring that all units, upstream and downstream of a disconnected unit, can continue operating.</td>
</tr>
<tr>
<td>Availability of local infrastructure for port-side repairs</td>
<td>Visibility on the availability of local shipyards</td>
</tr>
</tbody>
</table>
## Key challenges and opportunities

Prioritisation of key technical barriers

<table>
<thead>
<tr>
<th>Technical challenge</th>
<th>Cost reduction potential</th>
<th>Urgency</th>
<th>IP sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform size &amp; weight</td>
<td>2.7</td>
<td>2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Installation procedures</td>
<td>2.5</td>
<td>2.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Port-side O&amp;M (major repair procedures)</td>
<td>2.3</td>
<td>2.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Floating substations/transformer modules</td>
<td>2.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Advanced control systems for floating WTGs</td>
<td>2.2</td>
<td>2.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Mooring design &amp; installation</td>
<td>2.2</td>
<td>2.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Anchor design &amp; installation</td>
<td>2.1</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Advanced tank testing facilities</td>
<td>2.0</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Wind farm operation (wake effects, yield, AEP)</td>
<td>1.9</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Advanced modelling tools</td>
<td>1.9</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>High voltage dynamic cables</td>
<td>1.8</td>
<td>2.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Bespoke standards for floating wind</td>
<td>1.8</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>1.4</td>
<td>2.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*NB. Scoring from 1-3; High = 3, Med = 2, Low = 1.*

Source: Carbon Trust
## Key challenges and opportunities

Opportunities for component-level RD&D initiatives

<table>
<thead>
<tr>
<th>Technology focus area</th>
<th>Detail</th>
<th>Cost reduction</th>
<th>Urgency</th>
<th>IP Sensitivity</th>
</tr>
</thead>
</table>
| Installation optimisation     | > Faster installation  
                                  > Reduce sensitivity to met-ocean conditions  
                                  > Maximise onshore/port-side operations  
                                  > Reduce vessel requirements            | 2.5            | 2.2     | 1.8           |
| O&M – major repairs          | > Technical viability and cost benefit of port-side versus offshore repairs of major components | 2.3            | 2.2     | 1.0           |
| Substations / transformer modules | > Develop optimal solutions for transformer platforms (single substation; distributed transformer modules) | 2.3            | 2.0     | 2.0           |
| Mooring & anchoring systems   | > Understanding loads and limitations  
                                  > Advanced materials for moorings (lightweight, low cost)  
                                  > Ensure lifetime asset integrity for minimum 25 years  
                                  > Optimise installation process  
                                  > Solutions for 50-100m water depths | 2.1            | 2.1     | 2.0           |

Source: Carbon Trust
### Key challenges and opportunities

Opportunities for component-level RD&D initiatives

<table>
<thead>
<tr>
<th>Component</th>
<th>Opportunity</th>
<th>Source Score 1</th>
<th>Source Score 2</th>
<th>Source Score 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind farm operation (wake effects, yield, power output)</td>
<td>Understand floater motion and impact on wake effects in floating wind arrays, in regard to both wind farm yield and fatigue</td>
<td>1.9</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Combine with efforts to develop advanced design modelling tools and advanced control systems</td>
<td>1.9</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Integrated modelling tools</td>
<td>Developing advanced modelling software to accurately simulate coupled behaviour of floating wind systems</td>
<td>1.9</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Offshore demonstrations and tank testing can be used to validate the accuracy of the modelling tools</td>
<td>1.9</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Electrical cables</td>
<td>Develop and qualify high voltage dynamic cables</td>
<td>1.8</td>
<td>2.1</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Source: Carbon Trust
### Key challenges and opportunities

Opportunities for component-level RD&D initiatives

<table>
<thead>
<tr>
<th>Standards and best practice guidance</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop a bespoke set of industry standards and guidelines for floating wind devices</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Identify opportunities for component standardisation</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental impact</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact of floating wind structures on the seabed, marine mammals, and local fishing activities</td>
<td>1.4</td>
<td>2.1</td>
</tr>
</tbody>
</table>

*N.B. Scoring from 1-3; High = 3, Med = 2, Low = 1.*

Source: Carbon Trust
Floating Offshore Wind Vision Statement

Median LCOE Cost Reduction Scenario

Source: www.ieawind.org/task_26_public/PDF/062316/lbnl-1005717.pdf
Outline

• Challenges and opportunities of floating wind
  – Motivation
  – State of the art
  – Key challenges and opportunities
  – Floating Offshore Wind Vision Statement

• EU H2020 LIFES 50+ Project
EU H2020 LIFES 50+ Project

“Qualification of innovative floating substructures for 10 MW wind turbines and water depths greater than 50 m”

- Duration: 06/2015 – 10/2018
- Total budget: 7.3 M€
- Led by Sintef Ocean (previously MARINTEK)

LIFES50+ has 12 partners:
- 7 Research partners
- 4 Design/industry partners
- 1 Classification society
External Advisory Group (EAG)

**Members**
- Statoil (Utility)
- Siemens (Wind turbine manufacturer)
- NREL (Research Institute)
- EDF (Utility)
- ABS (Classification Body)

**Interaction**
- Invited and participated to Annual meetings
- Invited and participated at the Evaluation Workshop
- Skype meetings
- Face-to-face meetings
EU H2020 LIFES 50 + Project

Objectives

- Optimize and qualify to a Technology Readiness Level (TRL) of 5, two innovative substructure designs for 10MW turbines
- Develop a streamlined and KPI (key performance indicator) based methodology for the evaluation and qualification process of floating substructures

Scope

- Floating wind turbines installed in water depths from 50m to 200m
- Offshore wind farms of large wind turbines (10MW) – identified to be the most effective way of reducing cost of energy in short term

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 675318
EU H2020 LIFES 50 + Project

**Approach**

**Phase I Evaluation**

- **5MW**
  - Four Floating Concepts

- **Upscaling to 10MW**
  - Concept Development
  - From four to two concepts
  - Experimental and Numerical Investigation

- **Final**

- **10MW**
  - Two Floating Concepts for:
    - Large wind turbines (10MW)
    - Large water depths (>50m)
    - TRL 5

**Phase II Evaluation**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 675318
EU H2020 LIFES 50 + Project

Floating Substructure Concepts

- **NAUTILUS**
  - Semi-submersible
  - Steel

- **Olav Olsen OO-STAR**
  - Semi-submersible
  - Concrete

- **IDEOL**
  - Barge
  - Concrete

- **IBERDROLA**
  - Tension Leg Platform
  - Steel

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EU H2020 LIFES 50 + Project

Implementation

Objectives:

- Multi-criteria evaluation of 4 floating substructure designs

Outcome:

- Demonstration of the feasibility and competitiveness of the substructure designs
- Selection of the 2 best performed designs for further development up to TRL5
WP2: Concept Evaluation

Evaluation baseline:

- 3 wind farm sizes (50, 5 and 1 WT) → (500MW, 50MW and 10MW)
- 3 selected sites (input from WP1)

Golfe de Fos, France

- Moderate Met-ocean conditions
- Water depth: 70m
- Distance: 38km

Gulf of Maine, USA

- Medium Met-ocean conditions
- Water depth: 130m
- Distance: 58km

West of Barra, Scotland

- Severe Met-ocean conditions
- Water depth: 95m
- Distance: 180km
EU H2020 LIFES 50 + Project

Multi-criteria assessment

Objective
- Selection of the two best performed concepts

Criteria
- Economic
- Environmental
- Risk

Indicator
- LCOE
  Unit: €/MWh
- Global Warming Potential
  Unit: Kg CO2 equiv.
- Primary Energy
  Unit: MJ equiv.
- Abiotic Depletion Potential
  Unit: Sb equiv.
- Technological Risk
  Unit: dimensionless

Ranking
- Economic
  70%
- Environmental
  10%
- Risk
  20%

Technical KPIs will be considered to verify and check the consistency of the data provided and results obtained
WP2 overview

<table>
<thead>
<tr>
<th>WP2 planning</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M 1-4</td>
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<td>Task 2.1</td>
<td>M 13-16</td>
<td>M 17-20</td>
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<td>Task 2.5</td>
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<td>project</td>
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Evaluation Workshop March’17

MS3 – Evaluation methodology ready (M16)

MS4 – Phase 1 qualification performed (M19) → M22

MS5 – Phase 2 qualification performed (M40)
EU H2020 LIFES 50 + Project
EU H2020 LIFES 50 + Project

Import of Data:
1. Automatically - EXCEL file
2. Manually – Tool
EU H2020 LIFES 50 + Project

LCOE Module

\[
\text{LCOE} = \frac{\text{Sum of costs over lifetime}}{\text{Sum of electrical energy injected}} = \frac{\sum_{t=1}^{n} \frac{I_t + O&M_t + D_n}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t - I_n}{(1+r)^t}} \quad [\text{€/MWh}]
\]
EU H2020 LIFES 50 + Project

Energy Production

Available wind energy

Wake losses

Turbine losses

Availability losses

Energy Production

Levelized Cost of Energy

Net Energy

Collection & Transmission losses

Life Cycle Cost

Development

Manufacturing

Installation

Transport

Operation & Maintenance

Decommissioning

CAPEX

OPEX

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 675318
Detailed breakdown of costs and energy losses
Experimental HIL testing

Model testing
(Ocean Basin)

Aero simulation
(NREL's FAST code)

Actuated rotor loads

Measured platform motions

Waves & current

Wind

Opposite for wind tunnel, with calibrated hydro model.
HexaFloat Robot

6-DoF Robotic Platform for Wind Tunnel Tests of Floating Wind Turbines
Thank you for your attention!

Questions?

Contact:

mdeprada@irec.cat
Back-up
## State of the art

### Mooring systems

<table>
<thead>
<tr>
<th>Taut-leg</th>
<th>Catenary</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.jpg" alt="Example: Glosten PelaStar" /></td>
<td><img src="image2.jpg" alt="Example: DCNS SeaReed" /></td>
</tr>
</tbody>
</table>

- Synthetic fibres or wire which use the buoyancy of the floater and firm anchor to the seabed to maintain high tension for floater stability.
- Long steel chains and/or wires whose weight and curved shape holds the floating platform in place.
- Small footprint
- Large footprint
- Vertical loading at anchoring point
- Horizontal loading at anchoring point
- Large loads placed on the anchors – requires anchors which can withstand large vertical forces
- Long mooring lines, partly resting on the seabed, reduce loads on the anchors
- Very limited horizontal movement
- Some degree of horizontal movement
- High tension limits floater motion (pitch/roll/heave) to maintain excellent stability
- Weight of mooring lines limits floater motion, but greater freedom of movement than taut-leg
- Challenging installation procedure
- Relatively simple installation procedure
State of the art
Anchoring systems

<table>
<thead>
<tr>
<th>Drag-embedded</th>
<th>Driven pile</th>
<th>Suction pile</th>
<th>Gravity anchor</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Drag-embedded" /></td>
<td><img src="image" alt="Driven pile" /></td>
<td><img src="image" alt="Suction pile" /></td>
<td><img src="image" alt="Gravity anchor" /></td>
</tr>
<tr>
<td>• Best suited to cohesive sediments, though not too stiff to impede penetration</td>
<td>• Applicable in a wide range of seabed conditions</td>
<td>• Application constrained by appropriate seabed conditions - not suitable in loose sandy soils or stiff soils where penetration is difficult</td>
<td>• Requires medium to hard soil conditions</td>
</tr>
<tr>
<td>• Horizontal loading</td>
<td>• Vertical or horizontal loading</td>
<td>• Vertical or horizontal loading</td>
<td>• Usually vertical loading, but horizontal also applicable</td>
</tr>
<tr>
<td>• Simple installation process</td>
<td>• Noise impact during installation (requires hammer piling)</td>
<td>• Relatively simple installation, less invasive than other methods</td>
<td>• Large size and weight can increase installation costs</td>
</tr>
<tr>
<td>• Recoverable during decommissioning</td>
<td>• Difficult to remove upon decommissioning</td>
<td>• Easy removal during decommissioning</td>
<td>• Difficult to remove upon decommissioning</td>
</tr>
</tbody>
</table>

Project and site specific, often dictated by the seabed conditions.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 675318.
Key Findings

Conclusions

• Most influencing parameters are CAPEX related
   Substructure, turbine, anchor and mooring cost have largest influence
   Cost optimized design needed and to be considered at early design stage
   Optimized manufacturing processes and upgrade of port facilities
• Offshore substation cost has also a large influence
   Further research on floating substation is required to study mutual behaviour
• Power cables length and cost possess increased influence with distance
   Further study and cost optimization of high capacity dynamic power cables
• Severe metocean conditions posses a significant influence
   Requires a more robust structure and specialized vessel spread
• Installation and transportation cost
   Could be decreased with higher experience in the sector
• Maintenance cost and in particular failure rate are also important
   Only a few prototypes have been operated
   Lack of experience with maintainance activities on FOWT
   Better understanding of loads and motions acting on FOWT and increased operation will decrease uncertainty
State of the Art

- Major research projects:
  - Lifes50plus
  - Fukushima FORWARD
  - Floating Wind Joint Industry Project led by Carbon Trust, DNV-GL
  - OC3 (Offshore Code Comparison Collaboration), OC4, OC5
    Validation and comparison of different FOWT modelling codes

- Most known modelling tools:
  - FAST - NREL
  - SIMPACK - SIMPACK AG/USTUTT
  - Bladed - DNVGL
  - SIMA Workbench - SINTEF OCEAN
  - HAWC2 with SIMO/RIFLEX - DTU
  - DeepLines Wind - Pincipia IFP Energies Nouvelles

- LCOE tools:
  - Different assumptions used
Cost Competitiveness of Floating Wind
Cost Reduction Potential (from prototype to commercial scale)

- **Technology improvements & design optimization** (reduce structural mass, develop modular designs suitable for serial fabrication, ...)
- **Learning effects**
- **Supply chain improvements** (optimise fabrication lines, improving port facilities, ...)
- **Design standardisation** (less constrained by water depth than BFOW)
- **Increasing energy yield** (flexibility to site location enables access to areas with better wind resource)

**Rate for cost reduction?**

... it will depend on public and private support to provide:

- Secure and stable regulatory framework
- Sufficient RD&D financing to support innovation
- Targeted RD&D programmes to overcome common industry challenges
State of the Art

Leverage existing shipbuilding facilities, but modified to align with the serial production needs of the offshore wind industry

most of the decommissioning activities will be carried out onshore, reducing costs, risks and environmental impacts.

- Floating offshore wind has a very positive cost-reduction outlook.
- An increase in offshore wind installations is needed in order to meet renewable electricity generation targets set by the European Commission.
- Floating offshore wind will take advantage of cost reduction techniques developed in bottom-fixed offshore wind thanks to the significant area of overlap between these two marine renewable energy solutions.
- FOW projects can also have a smaller impact on environmental surroundings when used in far-from-shore projects, as noise and visual pollution will be less of a concern in deep, remote offshore marine areas.
Technical & market barriers

Despite its immense potential, there has not been a single utility-scale FOW project commissioned yet. Technology is no longer a barrier, but there are other challenges to overcome if FOW is to move quickly into the mainstream of power supply. Two major and interlinked challenges are access to investments and political commitment.

- Need for investor commitment: Projects require significant investments and their bankability could be eased through financial instruments that address long-term uncertainty, such as guarantees and other hedging instruments.
- FOW also needs sustained investments in R&I to accelerate cost reduction
- Political commitment is needed to incentivize industry and investors.
## Key challenges and opportunities

### Installation challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Mitigation</th>
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<tbody>
<tr>
<td>Installation time and vessel cost</td>
<td>Consider installation constraints during the platform design phase to optimise the installation process.</td>
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<tr>
<td>Weather restrictions imposed by tug boat and barge limitations</td>
<td>Good weather monitoring and installation planning</td>
</tr>
<tr>
<td>Deepwater mooring and electrical cable installation</td>
<td>Bespoke installation vessels (large-scale deployment)</td>
</tr>
<tr>
<td>Challenging seabed conditions</td>
<td>Optimise installation process</td>
</tr>
<tr>
<td>Testing and embedment of anchor requires either a high bollard pull tug (~250 t) or an external tensioning device</td>
<td>Increased availability of deep water robotic vehicles (ROVs)</td>
</tr>
<tr>
<td>Mating turbine onto structure</td>
<td>Develop appropriate anchors for challenging seabed conditions</td>
</tr>
<tr>
<td>Attachment between the tug/barge and the structure when towing to site</td>
<td>Large tug with bollard pull or use a stevtensioner during the mooring installation phase</td>
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<td></td>
<td>Improved mating systems</td>
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<td>New solutions</td>
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</tbody>
</table>

Source: Carbon Trust