Floating offshore wind turbines: challenges and opportunities

Seminar VI

Mikel De Prada Gil

Associate Researcher (IREC)

Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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

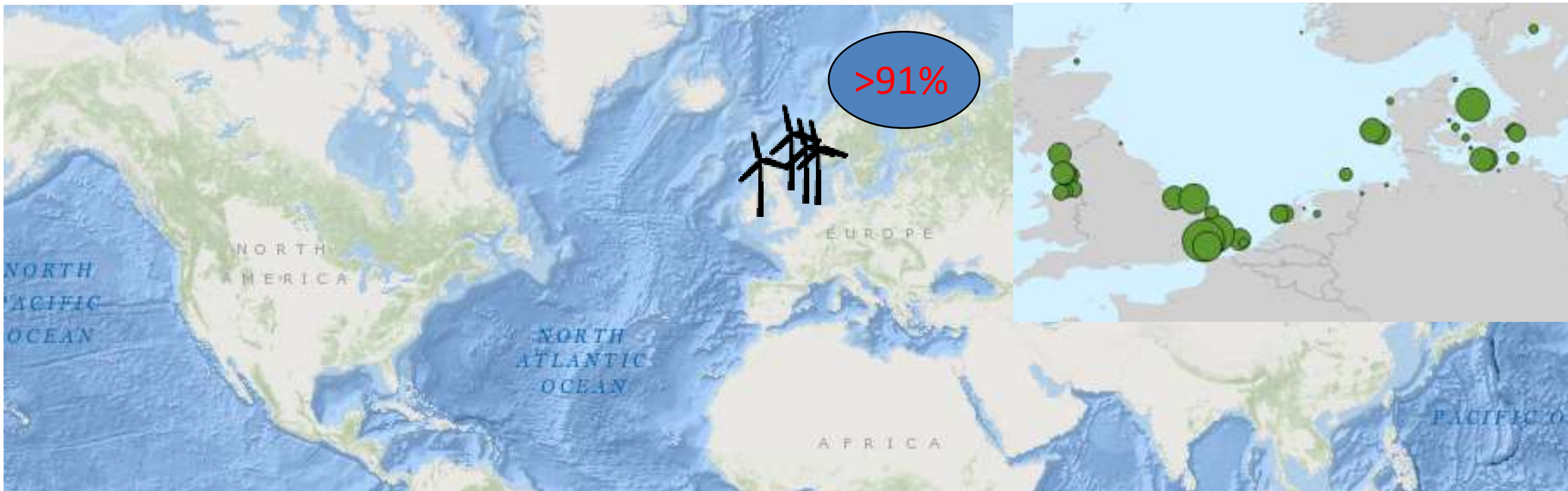
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

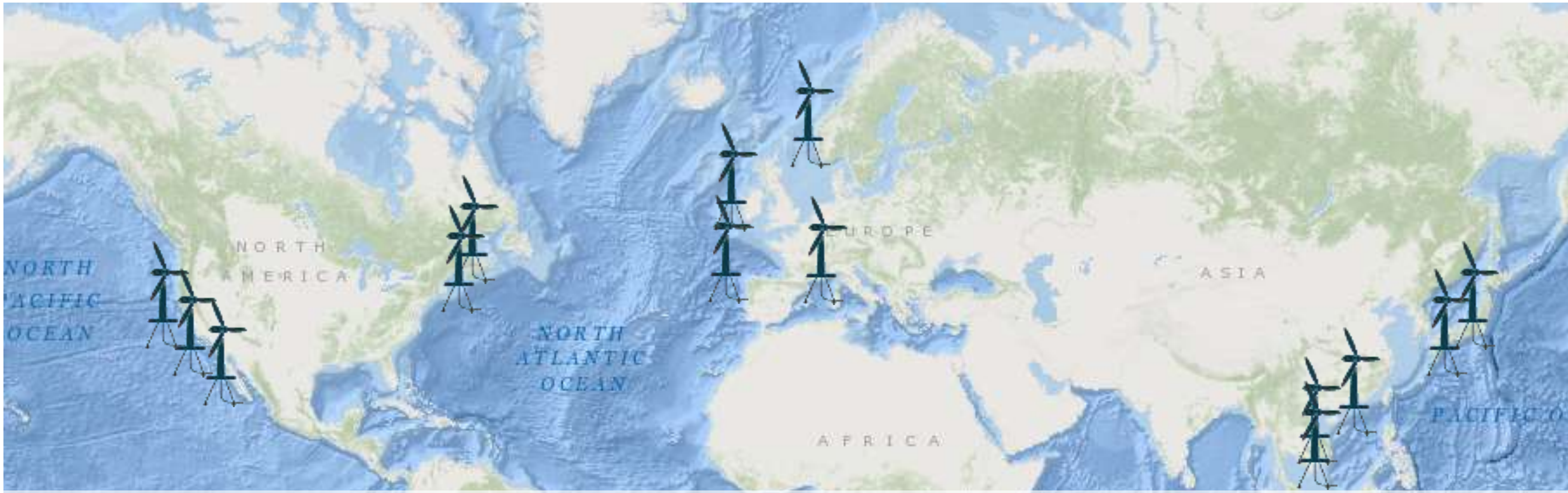
Motivation



- 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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

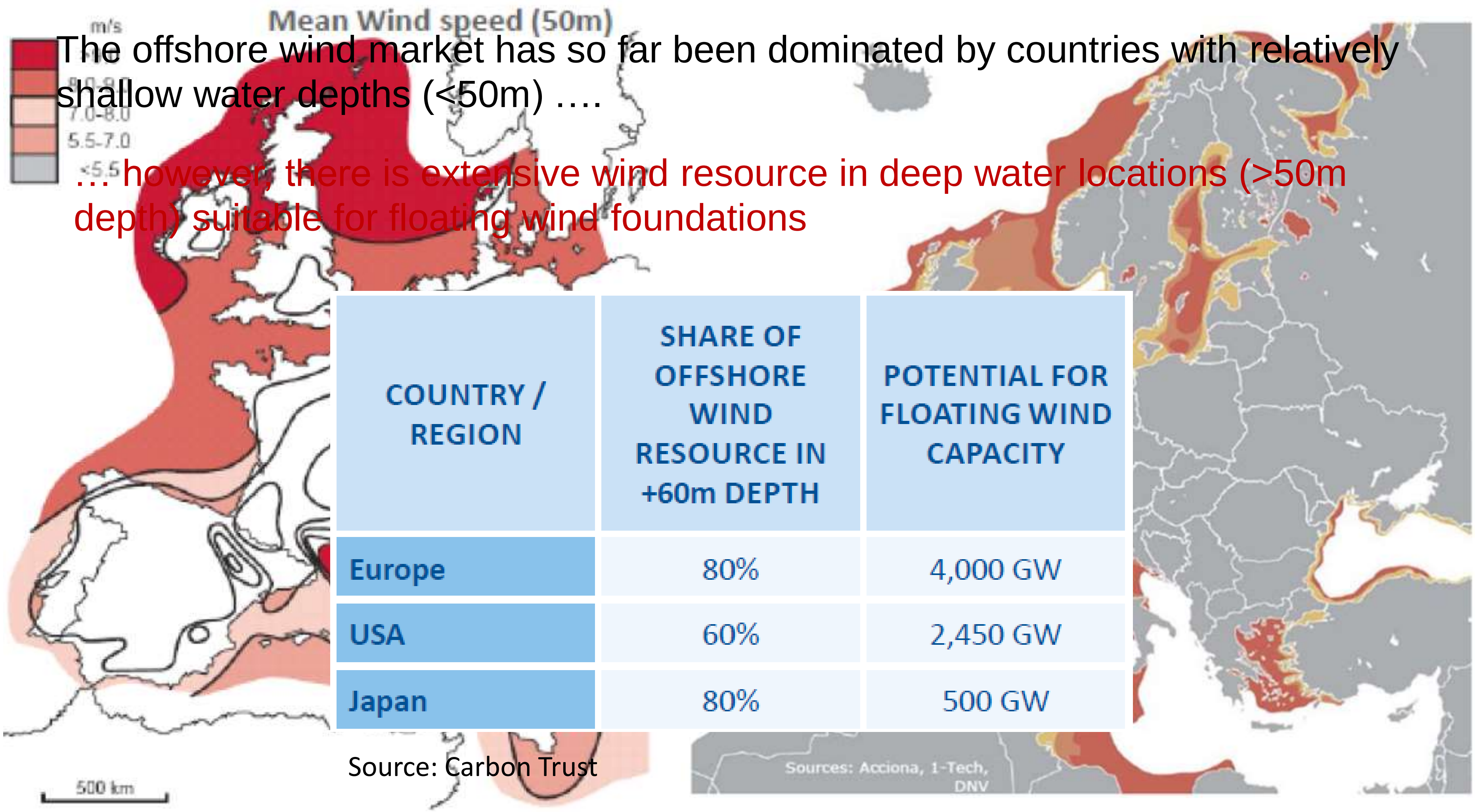
Motivation



- **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 …

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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

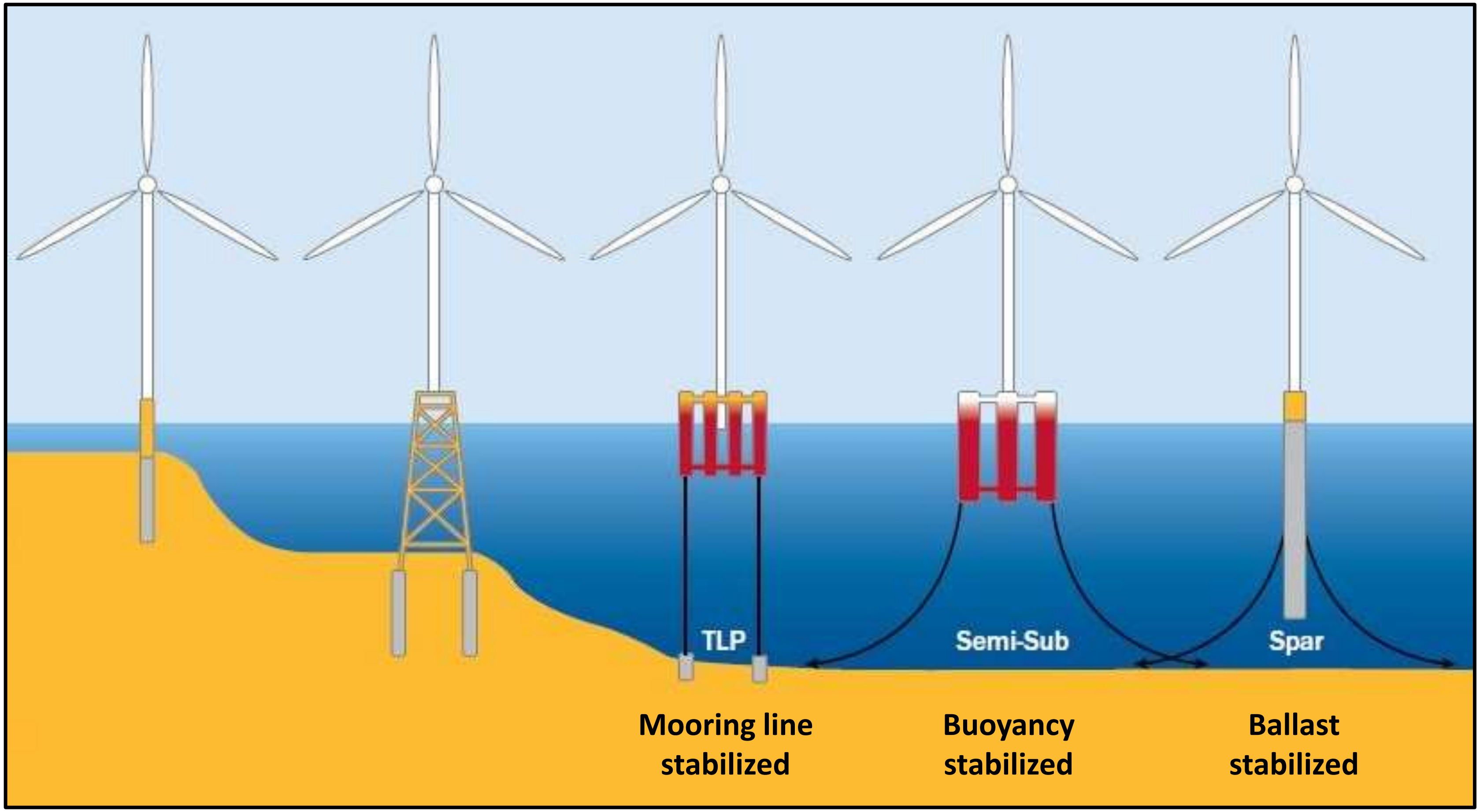
COUNTRY / REGION	SHARE OF OFFSHORE WIND RESOURCE IN +60m DEPTH	POTENTIAL FOR FLOATING WIND CAPACITY
Europe	80%	4,000 GW
USA	60%	2,450 GW
Japan	80%	500 GW

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Floating wind foundation typologies



Source: EWEA (2013)

(50-400m) (45-350m) (90-700m)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Floating wind foundation typologies

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

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Review of Existing Floating Wind Concepts

Semi-Submersible

- WindFloat (Principle Power)
- VERTIWIND (Technip/Nenuphar)
- SeaReed (DCNS)
- Tri-Floater (GustoMSC)
- Nautilus (Nautilus)
- Nezzy SCD (Aerodyn Engineering)

TLP

- PelaStar (Glosten Associates)
- Blue H TLP (Blue H Group)
- GICON-SOF (GICON)
- TLPWind (Iberdrola)

Spar-buoy

- Hywind (Statoil)
- Sway (Sway A/S)
- WindCrete (UPC)
- Hybrid spar (Toda construction)
- Deepwind spar (Deepwind consortium)

Other concepts

- Hexicon (Hexicon)
- SKWID (Modec)
- WindLens (Riam/Kyushu University)

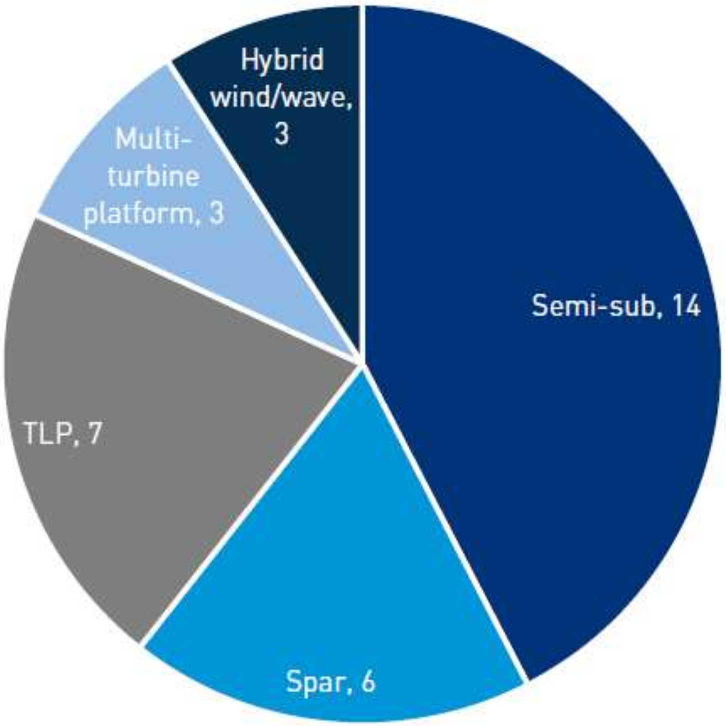
There is no clear winner with regard to which is most likely to be deployed at scale in the future, but a range of leading devices suitable for different site conditions, and influenced by local infrastructure and supply chain capabilities.

incite

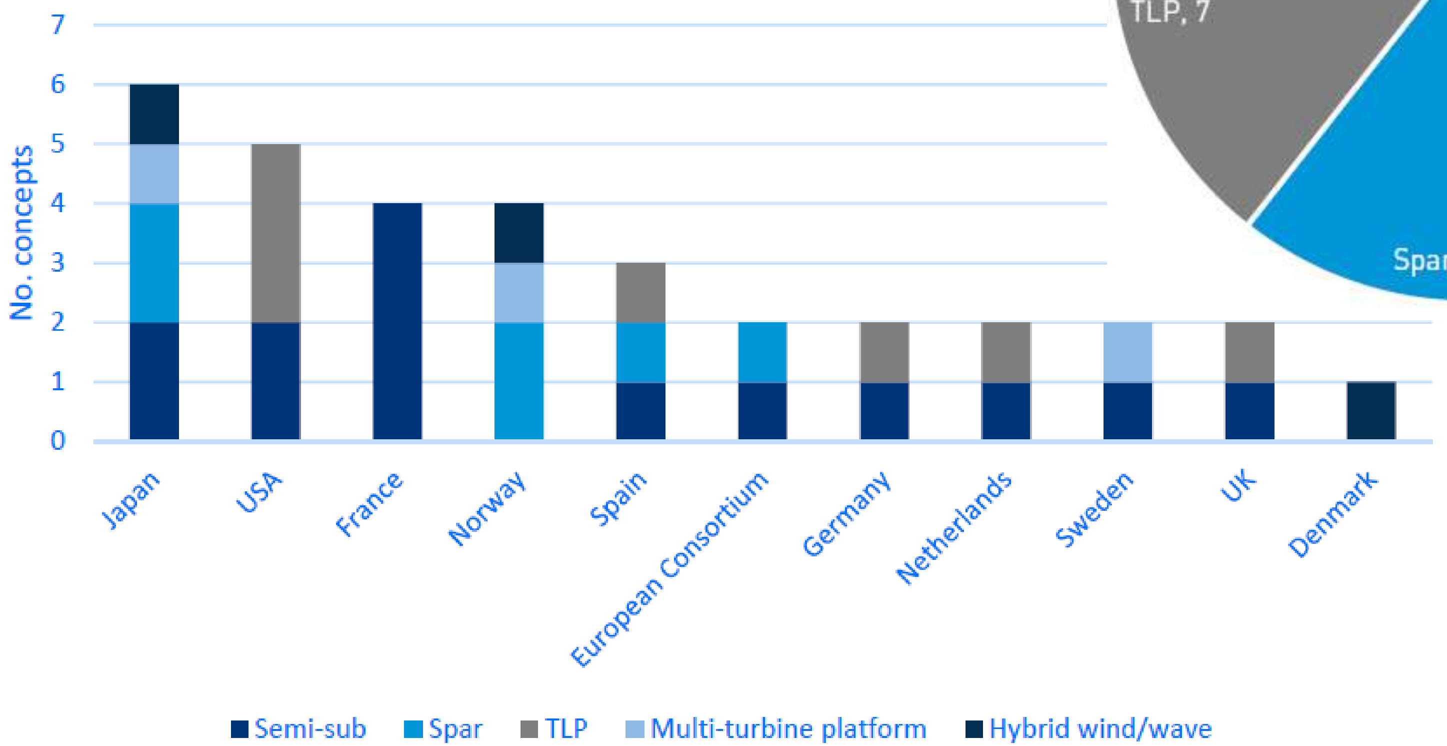
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Review of Existing Floating Wind Concepts



Geographical origin and typology of floating wind concepts



Typologies under development

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Wind Review of Existing Floating Concepts

- A large number of different floating wind turbine concepts exist ranging from early designs to prototypes and pre-commercial projects

➢ Most advanced projects are:

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

Source: WindEurope 2017

incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

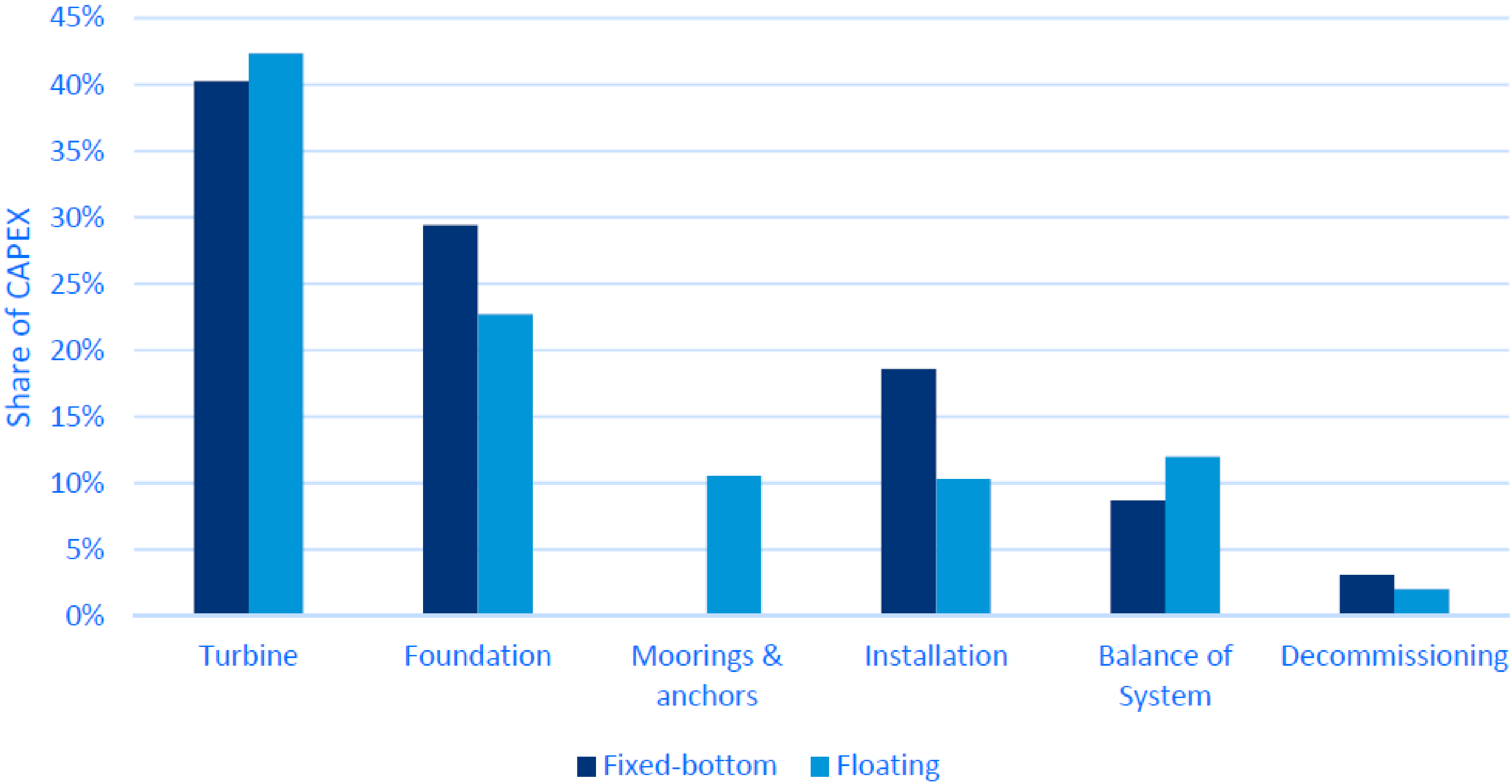
State of the art

Hywind Scotland - the world's first floating wind farm

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Capital Expenditure (CAPEX)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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:**
  - BFOW: 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

→ ↓ **OPEX**

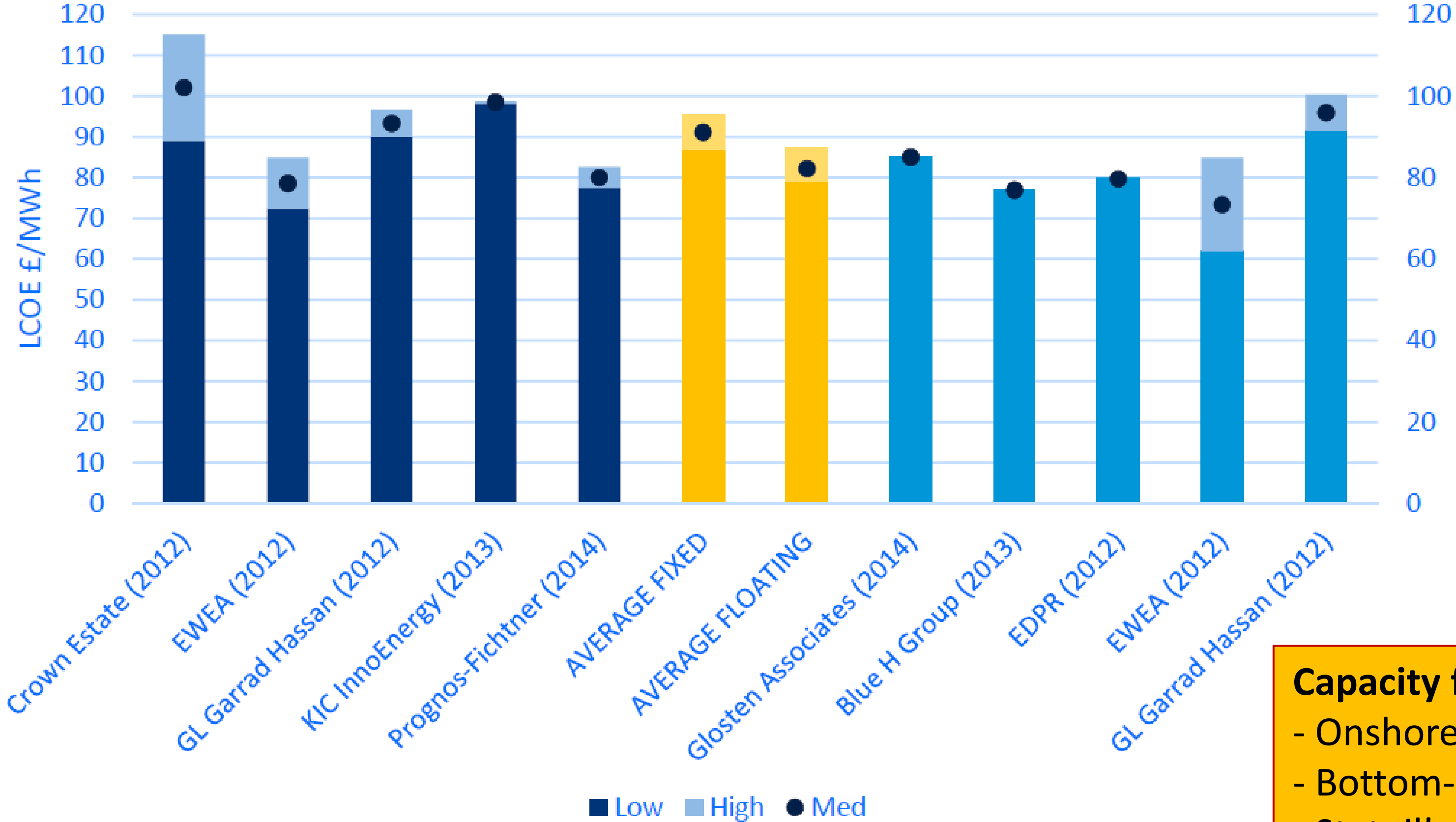
Cost benefit will be heavily influenced by site conditions, particularly in relation to distance from shore and met-ocean conditions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Levelised Cost of Energy (LCOE)

$$LCOE = \frac{\uparrow CAPEX + OPEX \downarrow}{\uparrow AEP}$$



Source: Carbon Trust

Estimates:
2020-2030

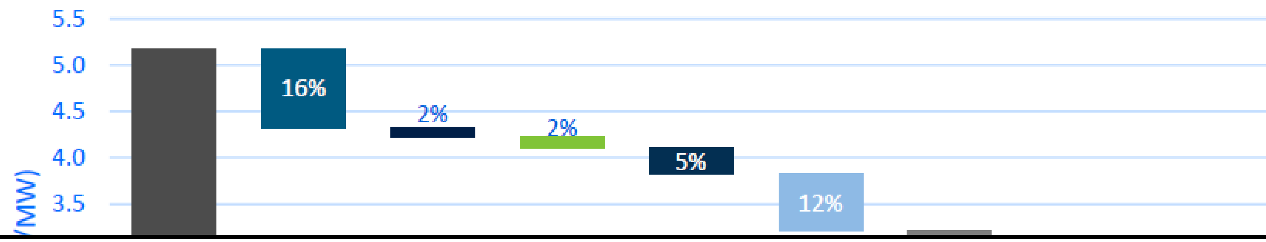
Capacity factor:
- Onshore **~25-30%**
- Bottom-fixed offshore **~40%**
- Statoil's 2.3MW Hywind demonstrator **~50%**

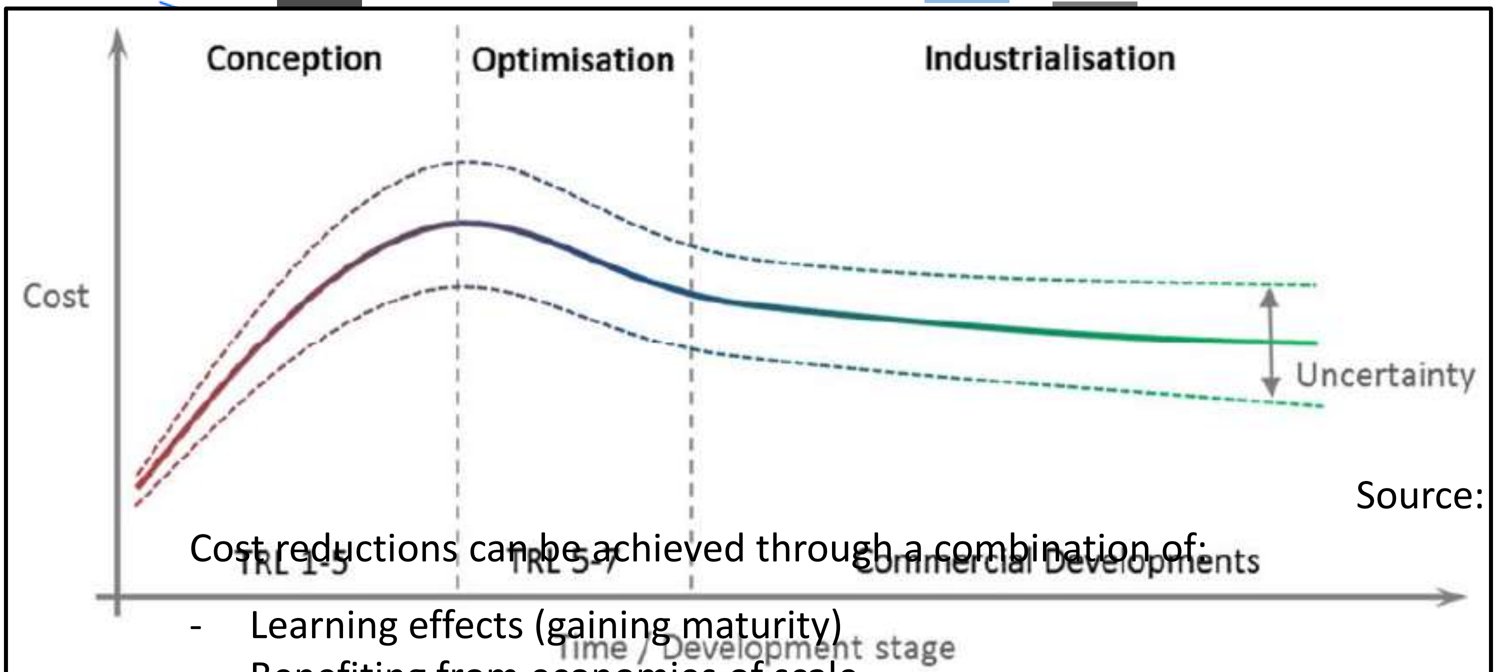
incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Cost Competitiveness of Floating Wind

Cost Reduction Potential (from prototype to commercial scale)





Source: Carbon Trust

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 BFOW)
- Targeted RD&D initiatives to overcome common industry challenges

incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Key market barriers

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Fabrication challenges

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

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

O&M challenges

Challenge	Mitigation
Accessing wind turbines in difficult sea-states	Crew transfer vessels which can operate in more challenging met-ocean conditions
	Design the unit to allow easy inspection and maintenance at sea. All critical components should be above water level and reachable.
	Weather monitoring
System reliability	Low maintenance designed into whole system
	Remote control systems and conditioning monitoring to reduce offshore visits
Replacing heavy turbine components	Special-purpose cranes, or transport structure to shore
	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.
Availability of local infrastructure for port-side repairs	Visibility on the availability of local shipyards

incite

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Prioritisation of key technical barriers

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

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

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Opportunities for component-level RD&D initiatives

Technology focus area	Detail	Cost reduction	Urgency	IP Sensitivity
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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Opportunities for component-level RD&D initiatives

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

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Opportunities for component-level RD&D initiatives

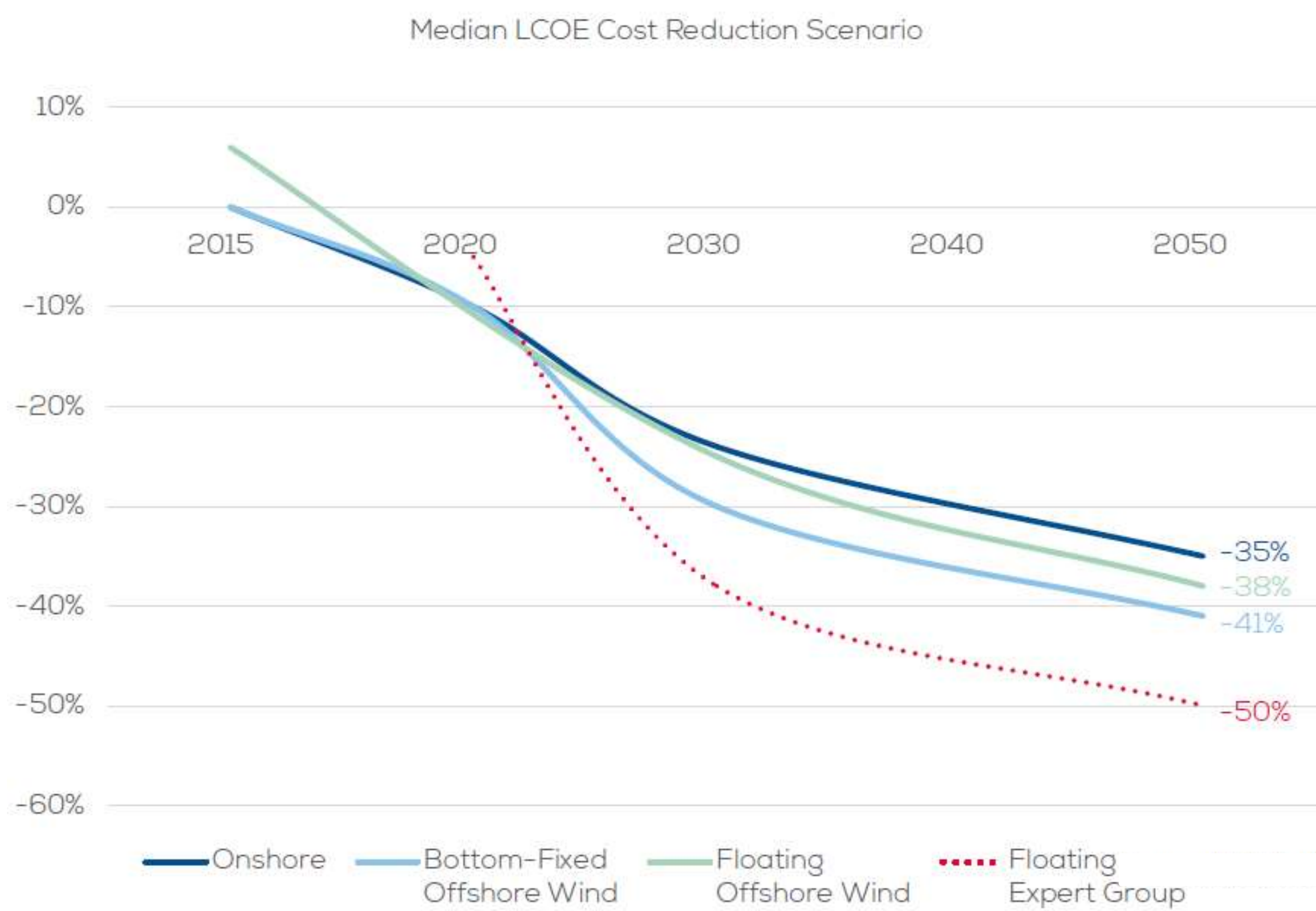
Standards and best practice guidance	> Develop a bespoke set of industry standards and guidelines for floating wind devices > Identify opportunities for component standardisation	1.8	2.0	1.0
Environmental impact	> Impact of floating wind structures on the seabed, marine mammals, and local fishing activities	1.4	2.1	1.0

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

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Floating Offshore Wind Vision Statement



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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

LIFES50+

"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)

PARTNERS

DNV·GL | DTU Technical University of Denmark | SINTEF | RAMBOLL

ideol | IREC | tecnalia | CATAPULT

POLITECNICO MILANO 1863 | DR. TECHN. OLAV OLSEN | University of Stuttgart Germany | IBERDROLA

incite

LIFES50+ has 12 partners:

- 7 Research partners
- 4 Design/industry partners
- 1 Classification society

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

External Advisory Group (EAG)

LIFES50+

- **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

incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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 termSkype meetings

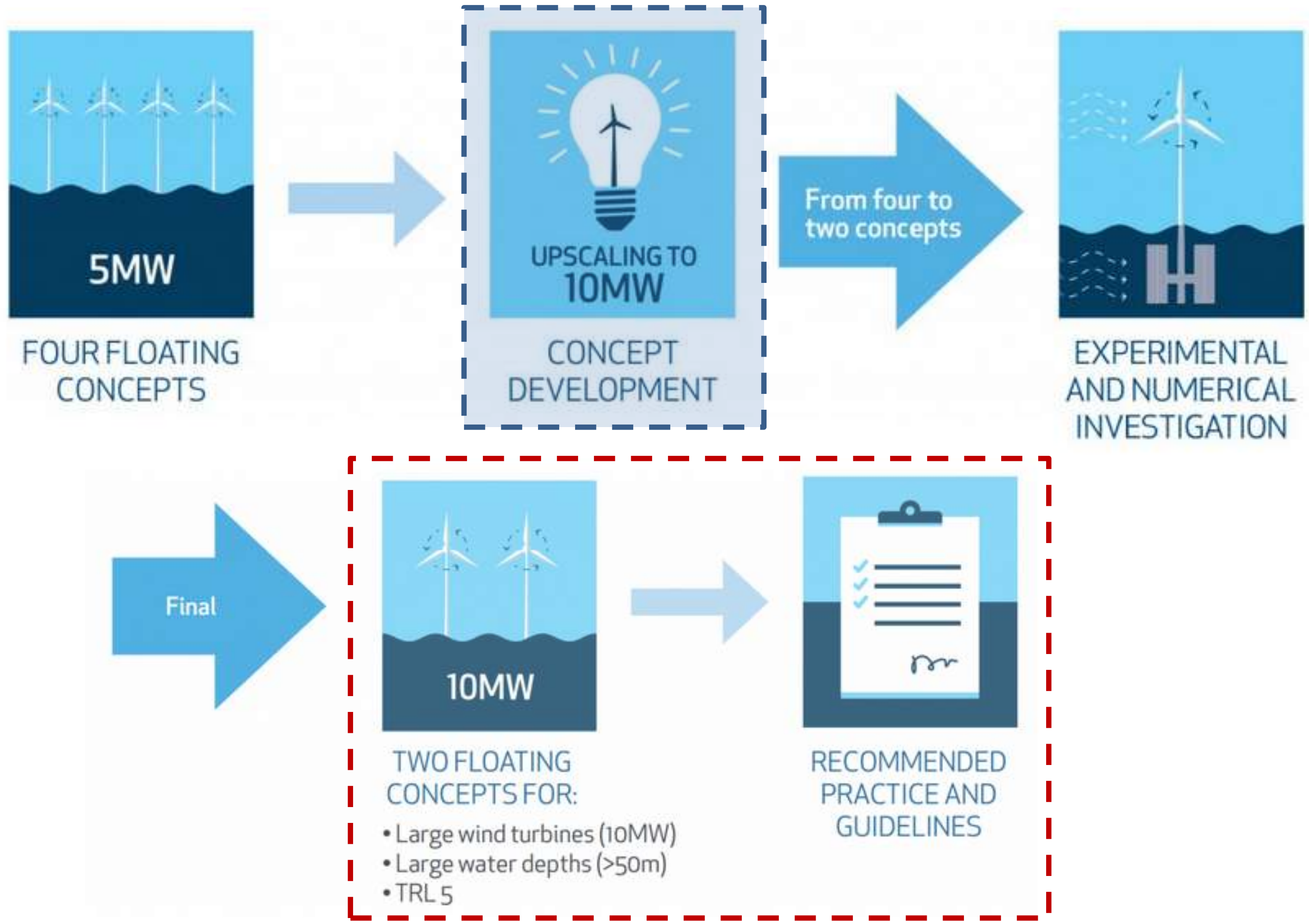
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

LIFES50+

Approach

Phase I Evaluation



Phase II Evaluation

incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

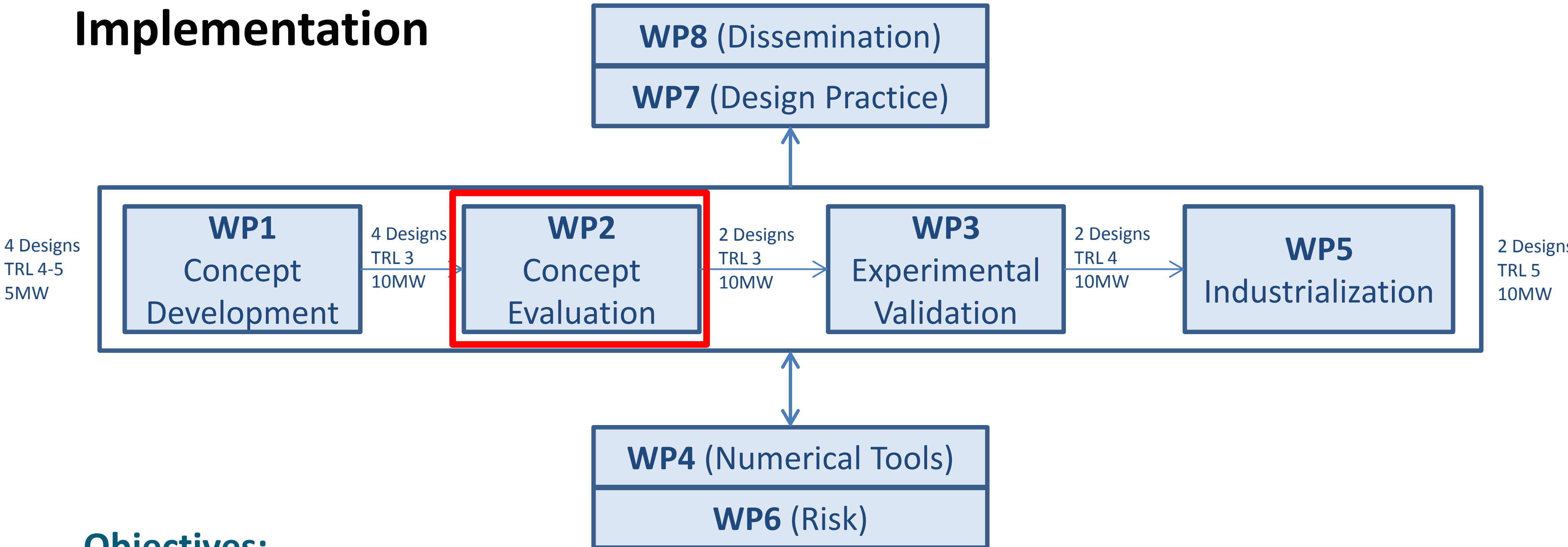
Floating Substructure Concepts

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

LIFES50+

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

incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

WP2: Concept Evaluation

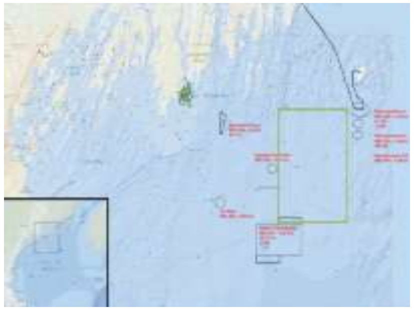
Evaluation baseline:

- 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

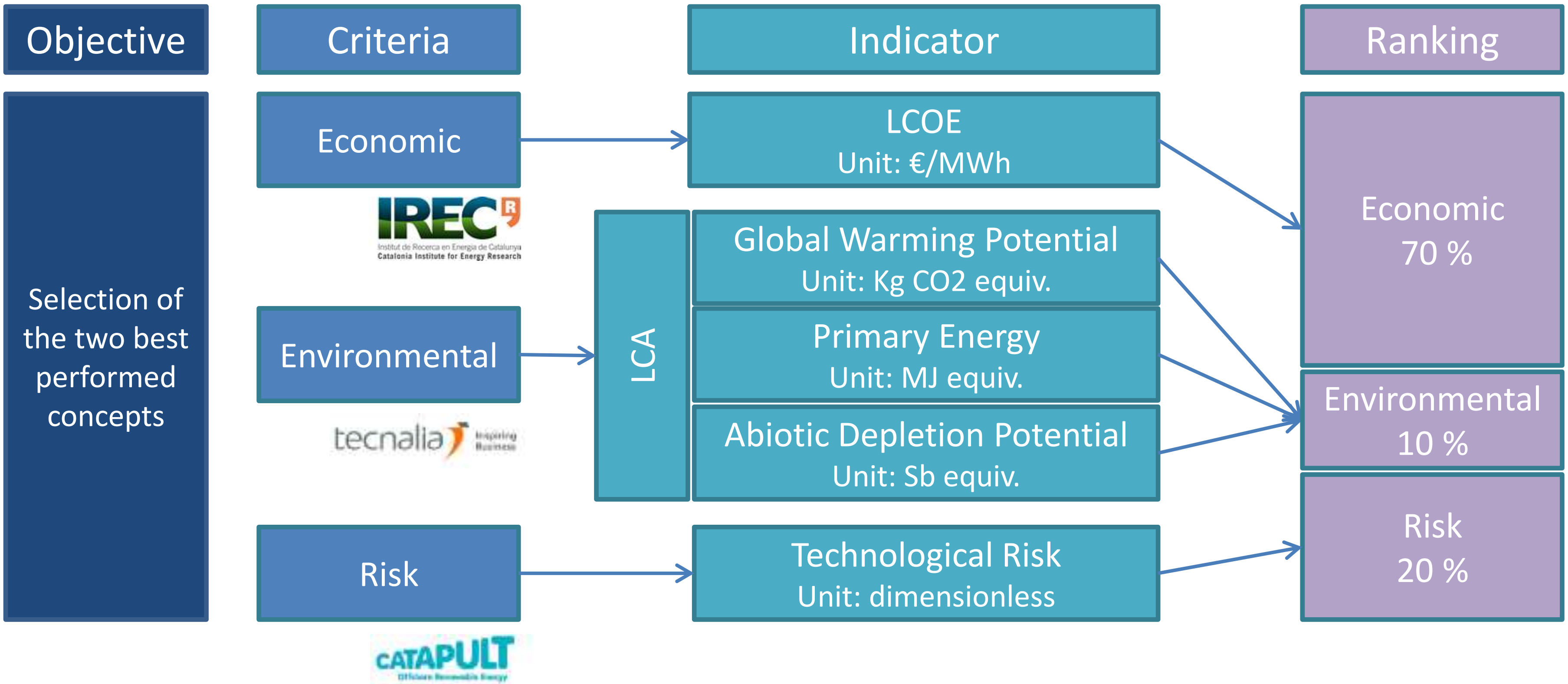
Severe
Met-ocean conditions

Water depth: 95m
Distance: 180km

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

Multi-criteria assessment



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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

WP2 overview

		2016			2017			2018		
WP2 planning	M 1-4	M 5-8	M 9-12	M 13-16	M 17-20	M 21-24	M 25-28	M 29-32	M 33-36	M 37-40
Task 2.1 Evaluation methology and an evaluation tool set		FOWAT		MS3						
Task 2.2 Phase I - First evaluation of the concepts upscaled to 10MW						MS4				
Task 2.3 Phase 2 - Final evaluation of the optimized substructure designs										MS5
Task 2.4 Anticipated LCOE estimations at the time of introduction to market										
Task 2.5 Dissemination of the methodology, results and improvements during the project										
	RP1				RP2				Today	

Evaluation Workshop March'17

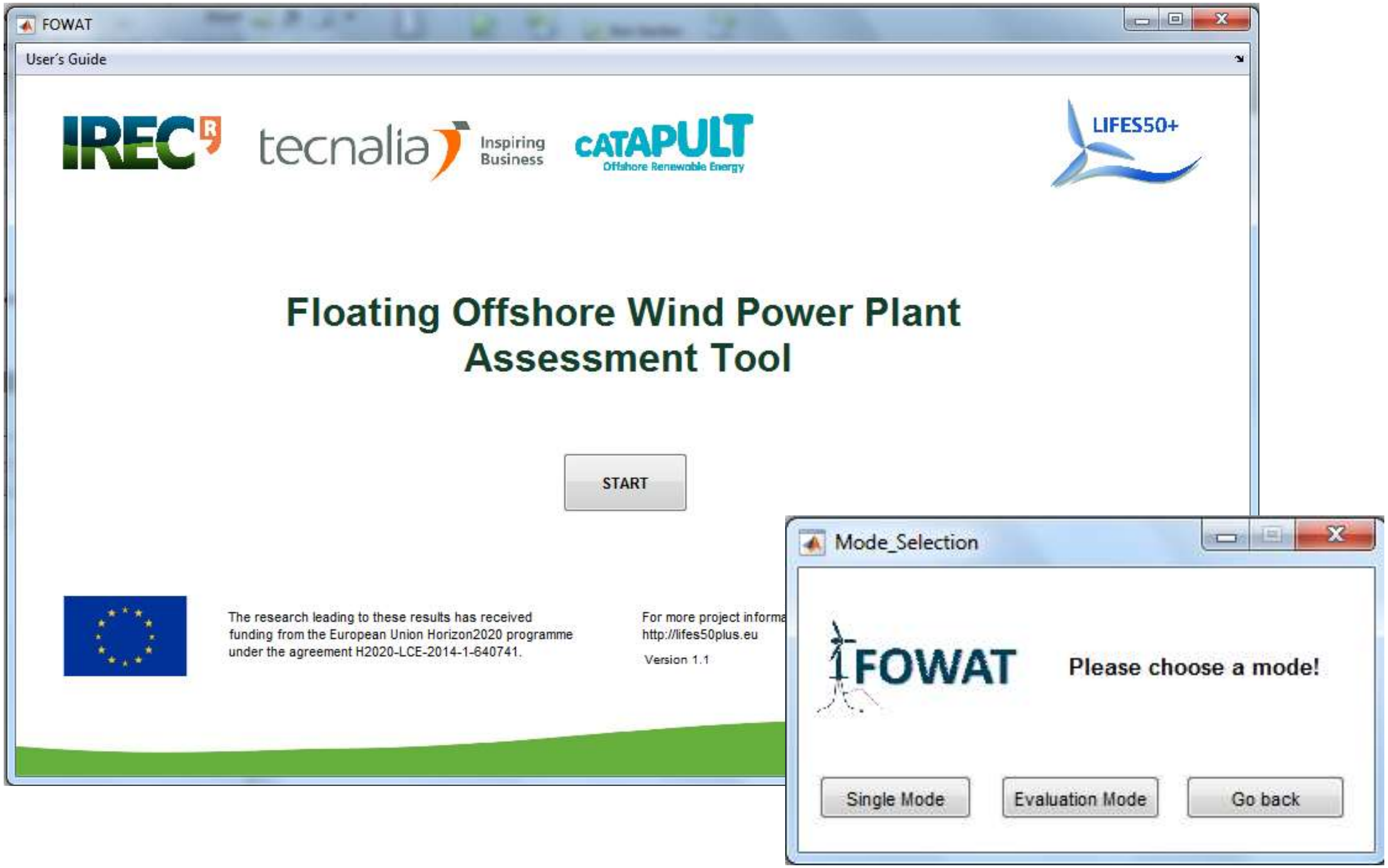
MS3 – Evaluation methodology ready (M16) ✓

MS4 – Phase 1 qualification performed (M19)→M22 ✓

MS5 – Phase 2 qualification performed (M40)

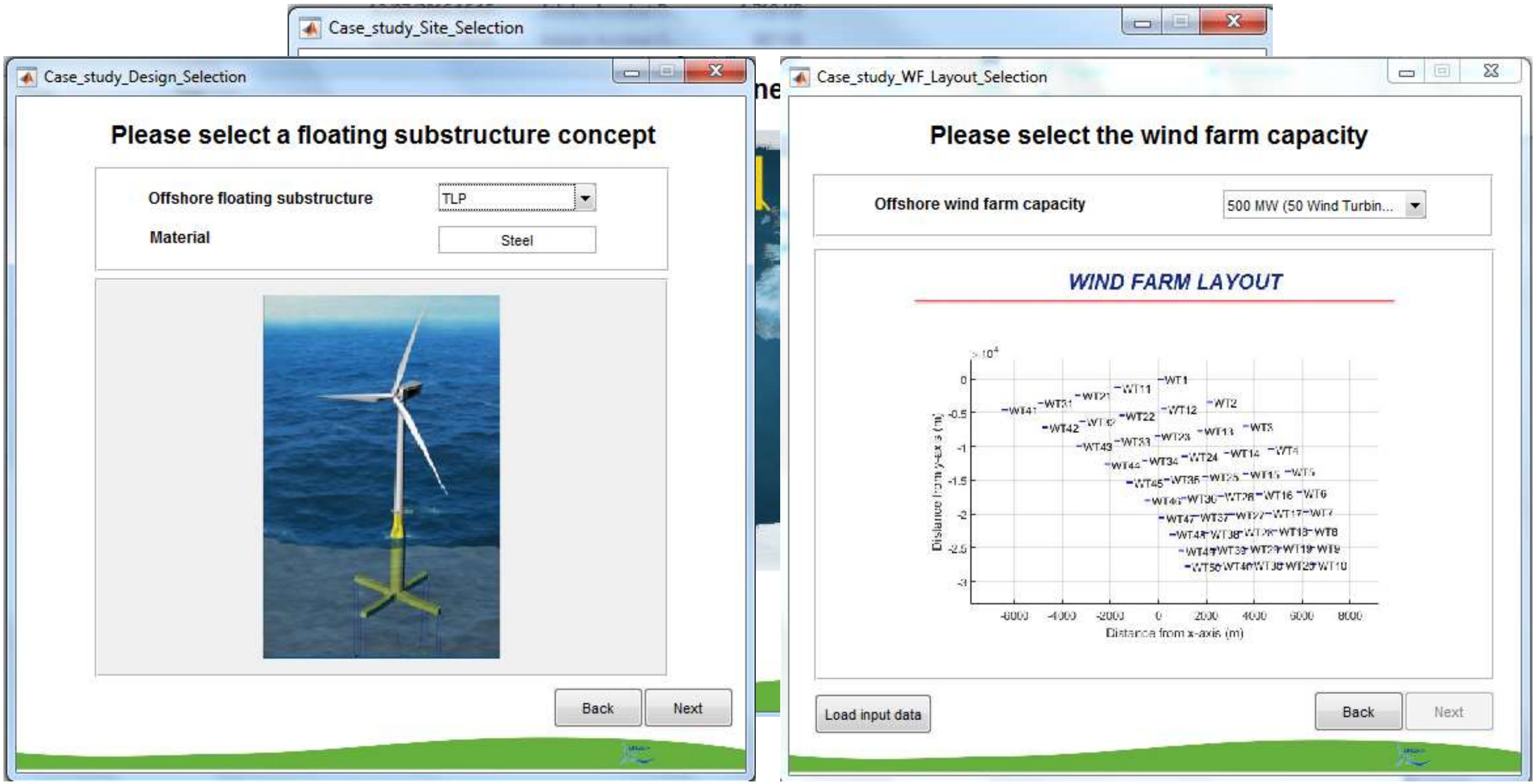
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

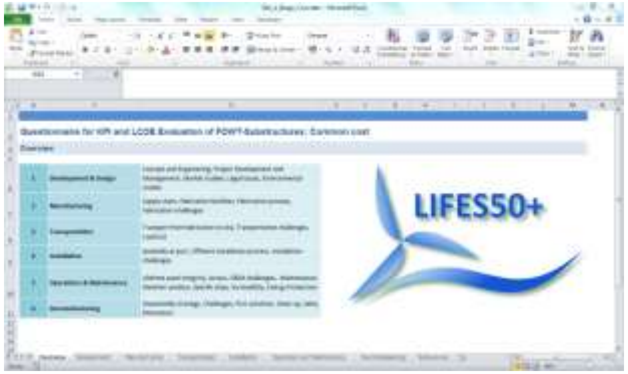


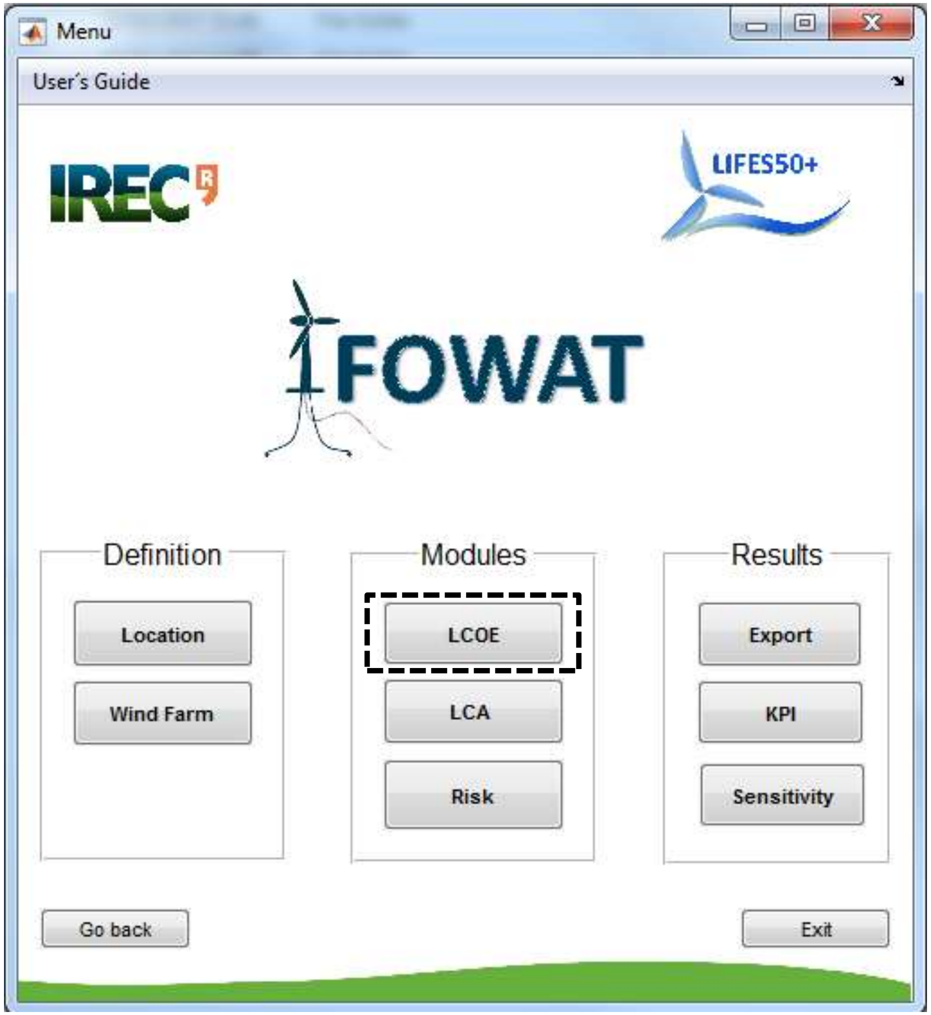
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

Menu

Import of Data:
1. Automatically - EXCEL file
2. Manually – Tool

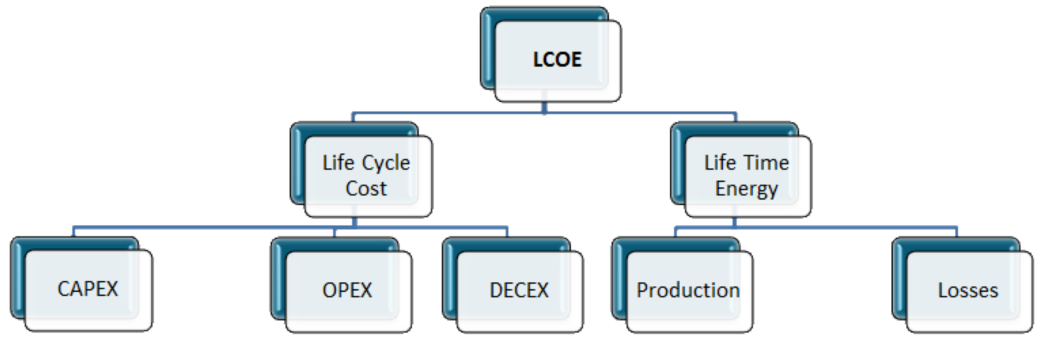




This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

LCOE Module



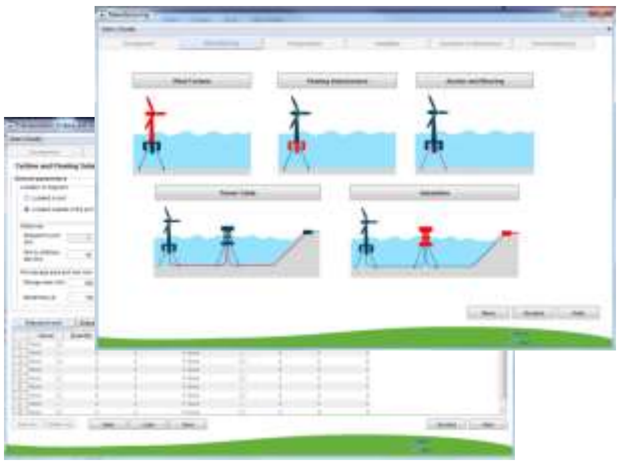
$$\text{LCOE} = \frac{\text{Sum of costs over lifetime}}{\text{Sum of electrical energy injected}} = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + D_n}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t - L_t}{(1+r)^t}} \quad [€/\text{MWh}]$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

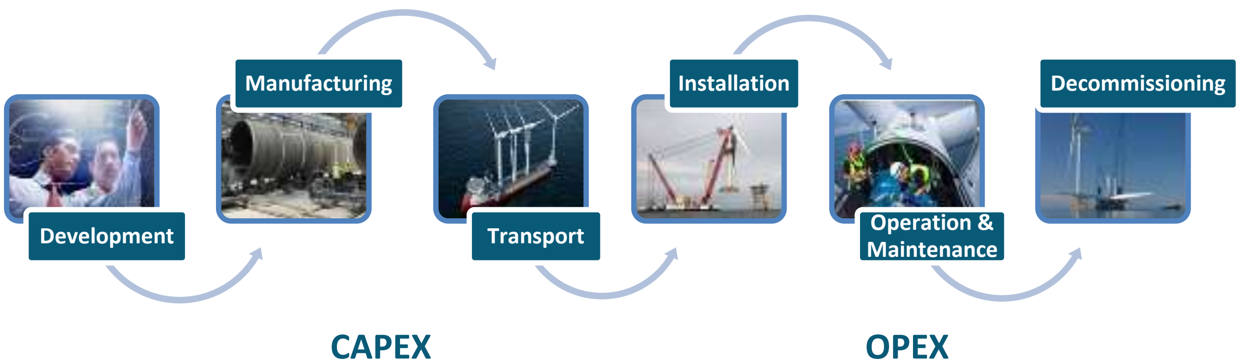
EU H2020 LIFES 50 + Project

Levelized Cost of Energy

Energy Production



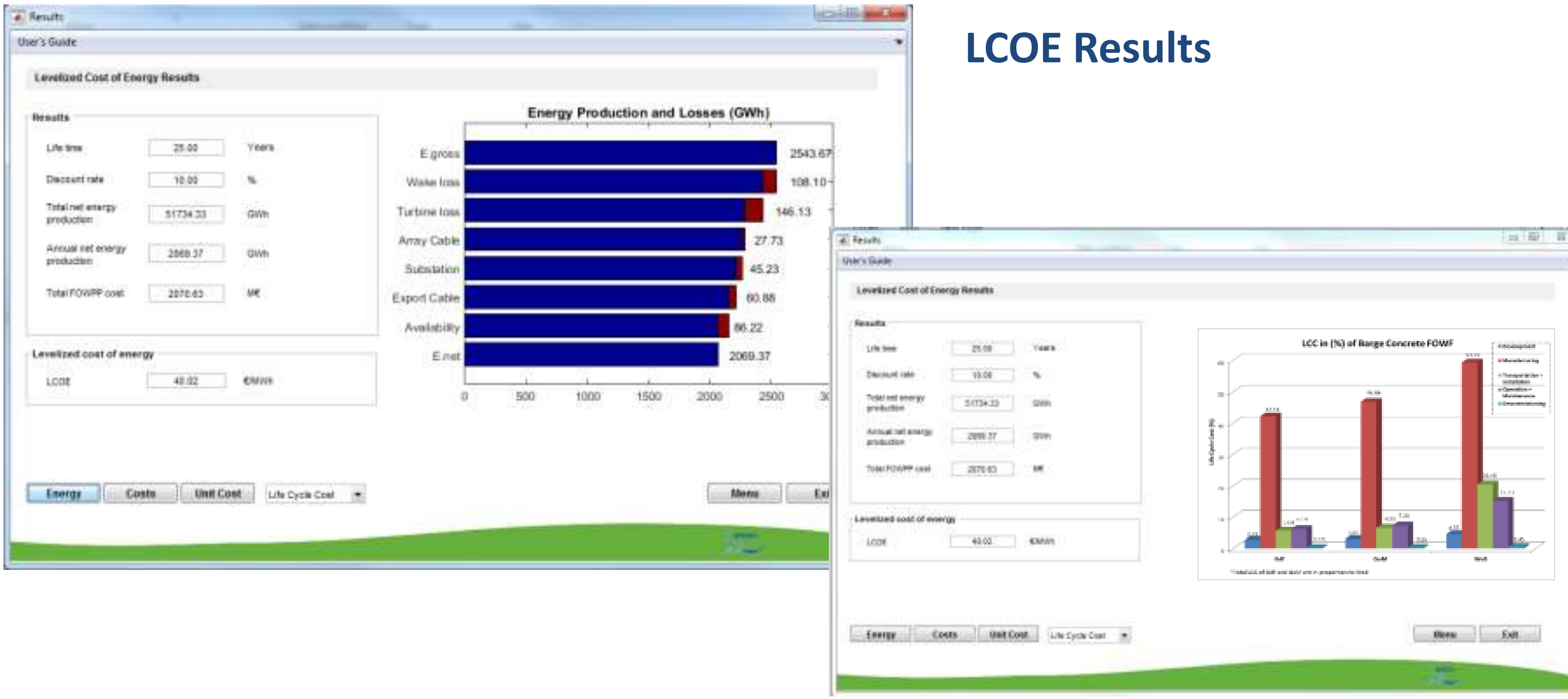
Life Cycle Cost



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

EU H2020 LIFES 50 + Project

LCOE Results



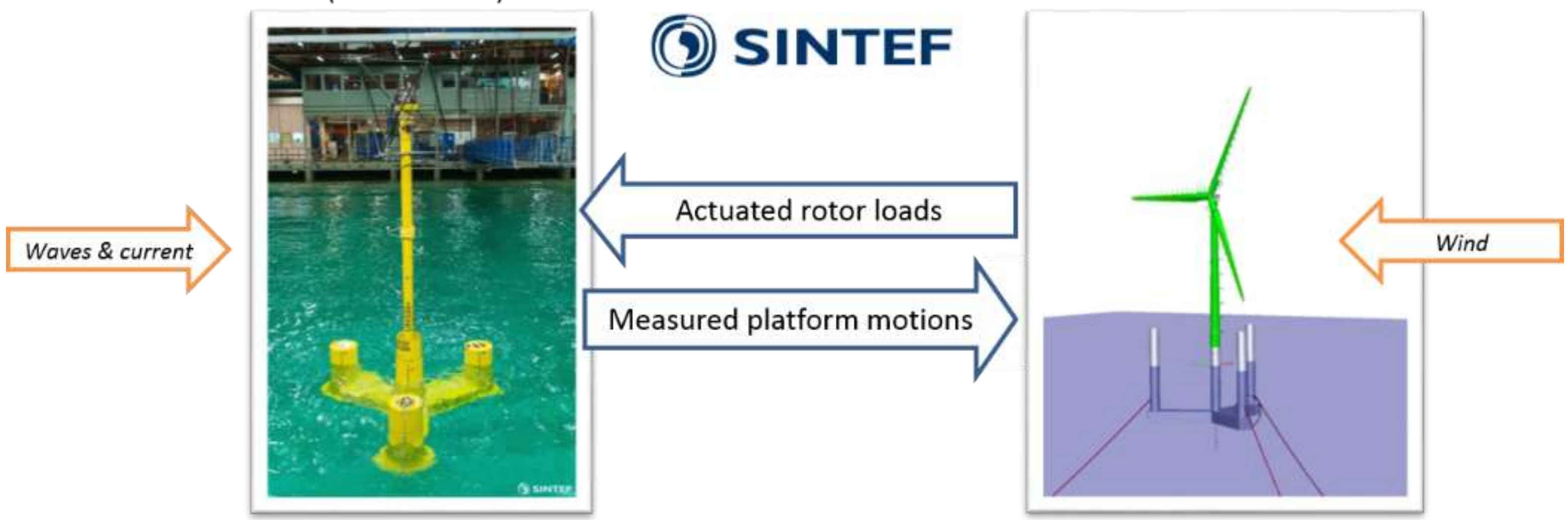
Detailed breakdown of costs and energy losses

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Experimental HIL testing

Model testing
(Ocean Basin)

Aero simulation
(NREL's FAST code)

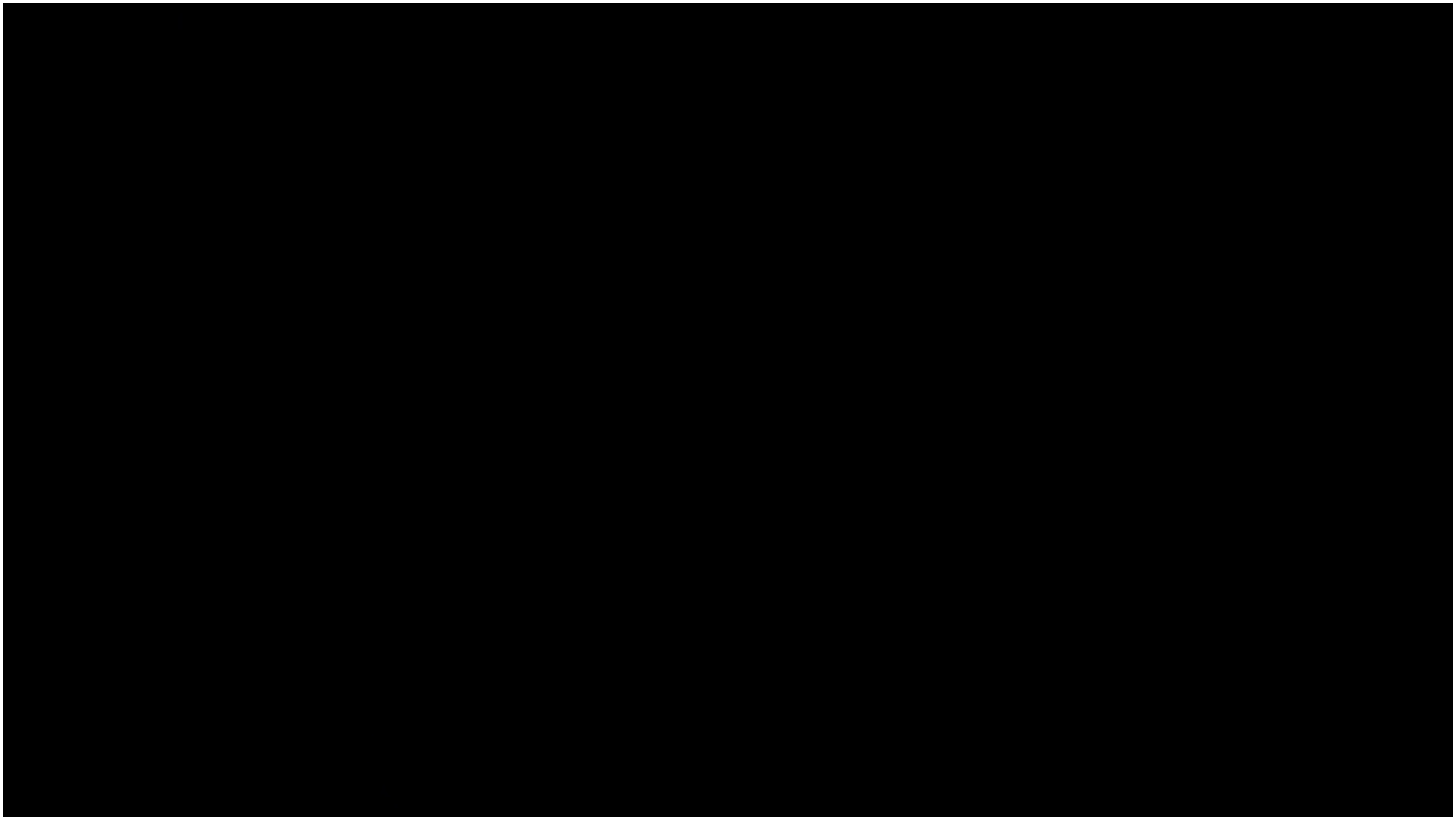


Opposite for wind tunnel, with calibrated hydro model.

POLITECNICO
MILANO 1863

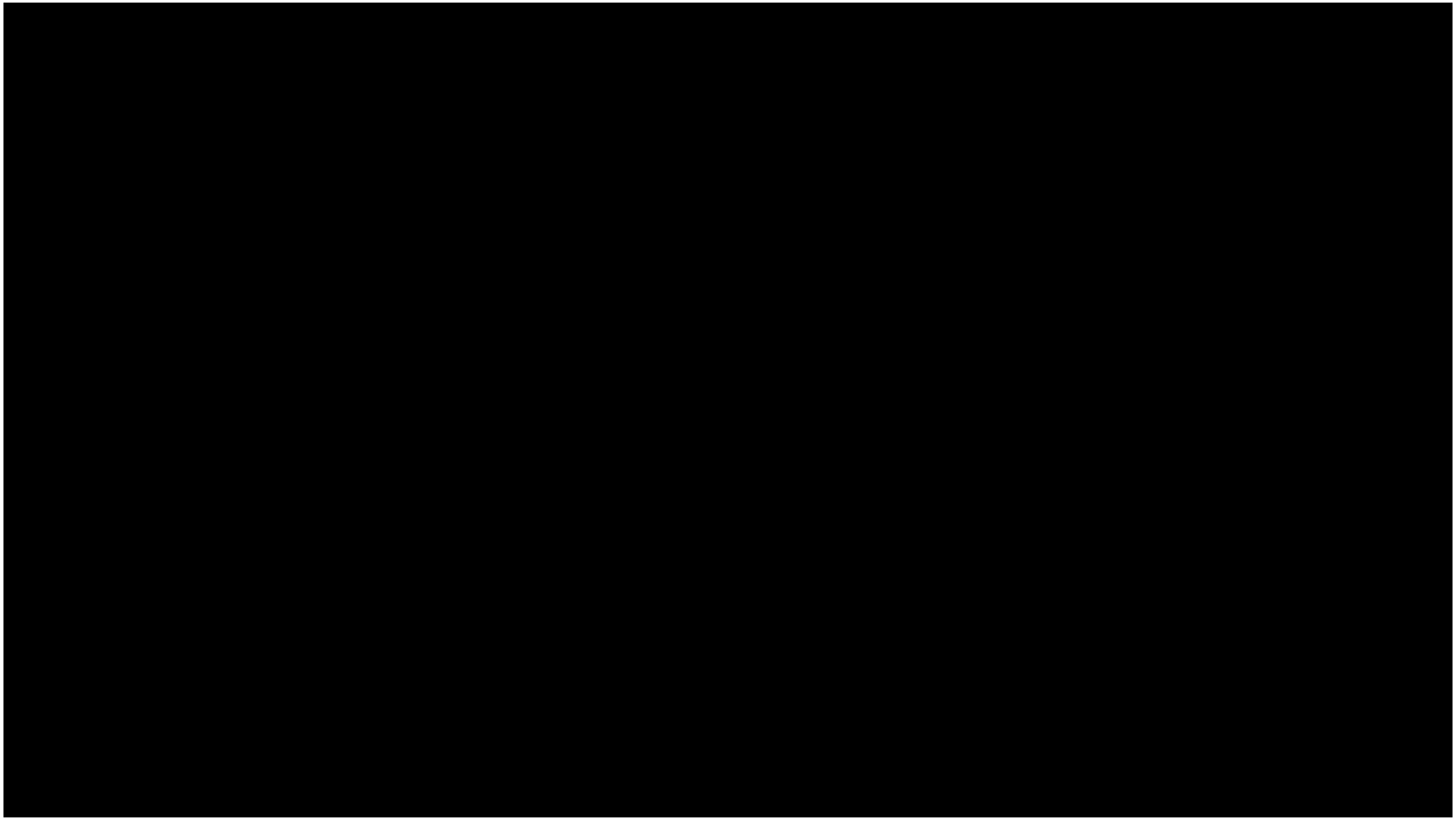
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Wave Basin – SINTEF OCEAN



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

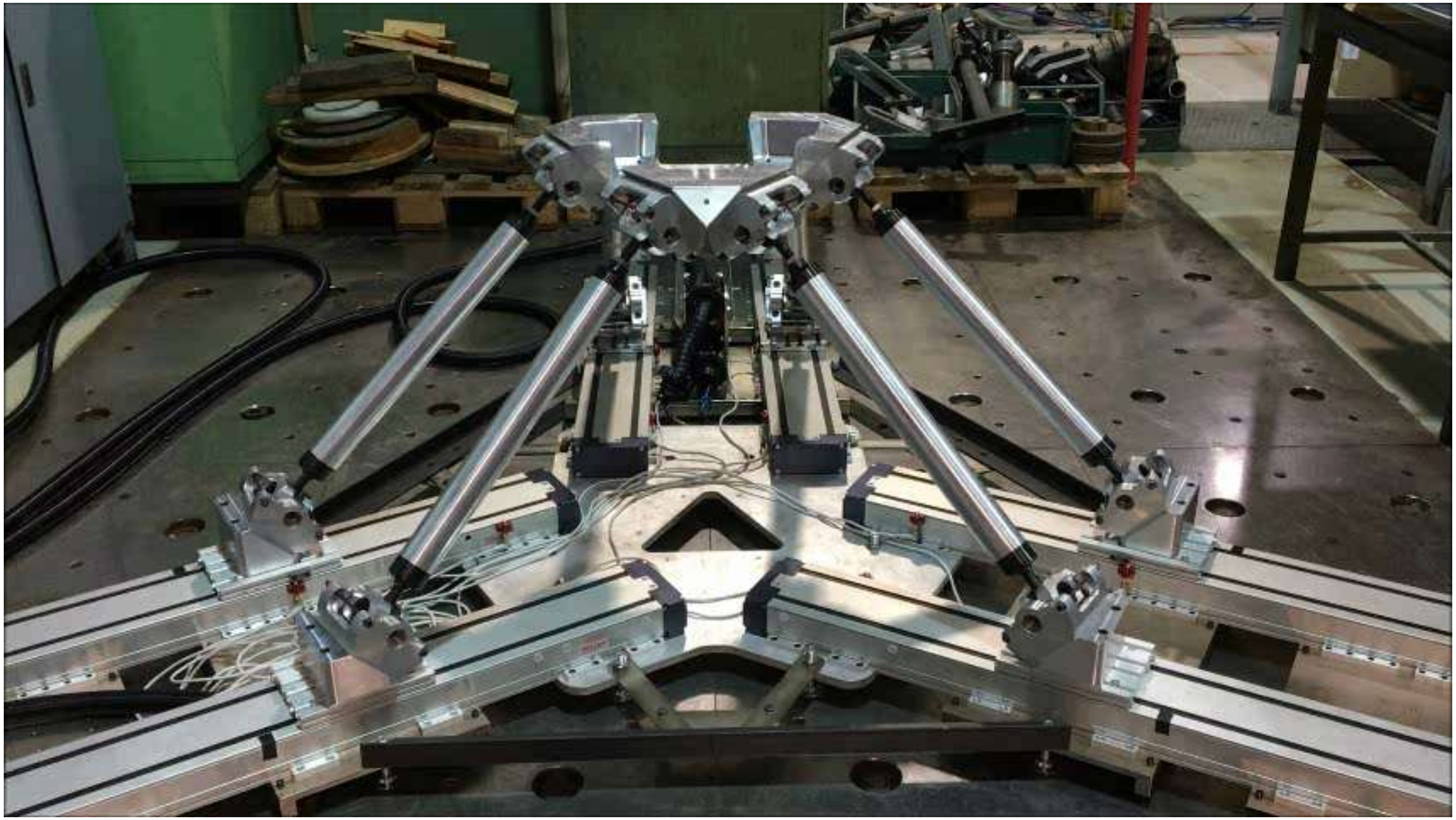
Wind Tunnel - POLIMI



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

HexaFloat Robot

6-DoF Robotic Platform for Wind Tunnel Tests of Floating Wind Turbines



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Thank you for your attention!

Questions?

Contact:

mdeprada@irec.cat

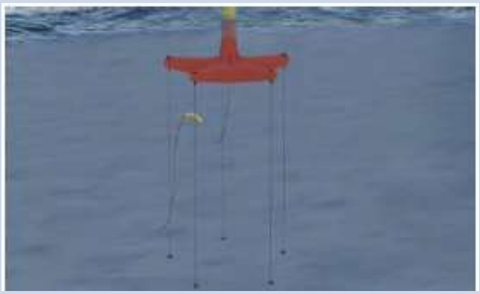
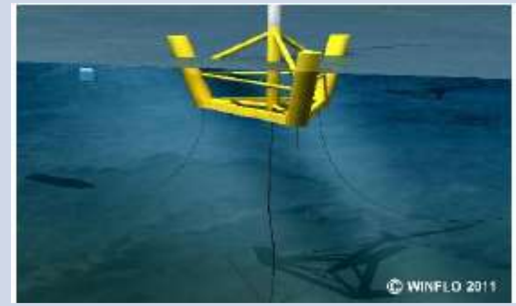
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Back-up

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Mooring systems

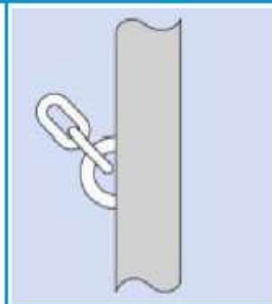
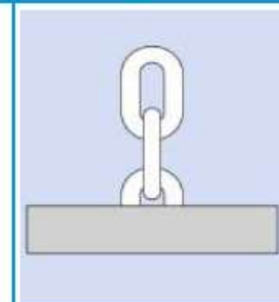
Taut-leg	Catenary
 *Example: Glosten PelaStar*	 *Example: DCNS SeaReed*
▪ Synthetic fibres or wire which use the buoyancy of the floater and firm anchor to the seabed to maintain high tension for floater stability.	▪ Long steel chains and/or wires whose weight and curved shape holds the floating platform 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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the art

Anchoring systems

Project and site specific, often dictated by the seabed conditions

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-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 mainteanance activities on FOWT
  - ➢ Better understanding of loads and motions acting on FOWT and increased operation will decrease uncertainty

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

State of the Art

- Major research projects:
  - Lifes50plus
  - INFLOW
  - Fukushima FORWARD
  - DeepWind
  - 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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

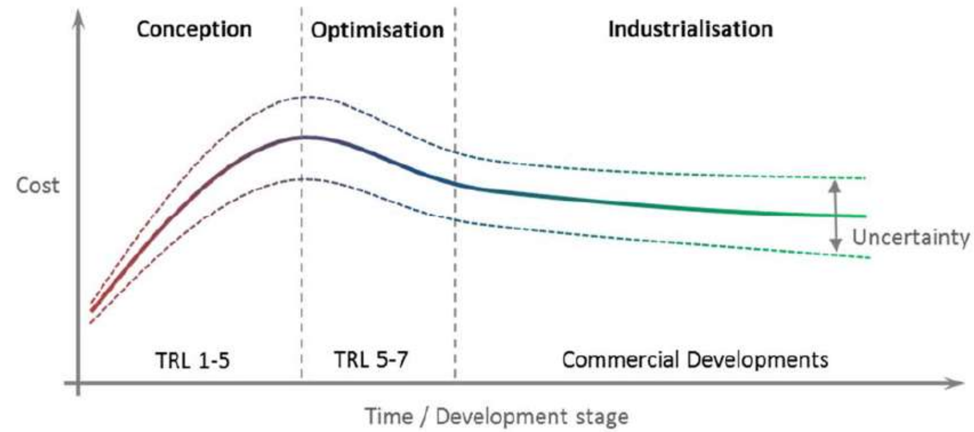
Cost Competitiveness of Floating Wind

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

incite

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Key challenges and opportunities

Installation challenges

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

incite

Source: Carbon Trust

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318