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

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Executive Summary of TEM#99

Introduction

The offshore wind resource is significant for many countries and is already, or slated to be, a key contributor to the electrical grid production plans of many countries. For some, their coastal waters include extensive regions of shallow depths (less than 60m), where fixed-bottom supports for offshore wind turbine are feasible. However, the majority of the offshore wind resource across the globe is in depths where the only feasible technical approach is to use floating supports.

Much of the research on floating turbines to date has focused on the engineering of an individual turbine and support structure. However, as developers move forward with field trials and plan for larger scale commercial arrays, they will face a new, but common, set of layout issues that did not arise for fixed-bottom offshore wind plants. Some are opportunities, such as shared moorings or anchors, while others are challenges, such as understanding new wake motion dynamics.

Currently, floating offshore wind energy technology is fragmented among IEA Wind tasks, with some aspects being addressed in Tasks 26 (Cost of Wind), 28 (Social Acceptance), 30 (Offshore Code Comparison), 37 (Systems Engineering), and 40 (Downwind Turbines). However, floating offshore wind energy is at the frontier of wind technology and community interest. Many governments, industries, and developers are currently marching forward with pilot or even second-generation floating wind projects, but there are challenges and opportunities that are common to all countries.

The objective of the International Energy Agency (IEA) Topical Expert Meeting (TEM) number 99 was to exchange information and ideas that relate to the opportunities and challenges that are unique to floating offshore wind arrays and do not overlap with other IEA tasks. The IEA Wind program can seize on the momentum for floating wind deployment and address some of these common issues in an international, collaborative setting.

Meeting Overview

TEM#99 on Floating Offshore Wind Array Challenges and Opportunities was organized by IFPEN, NREL, Principle Power and MaREI (UCC) on Jul 15, 17 & 20 as an online meeting. A total of 103 participants from 18 different countries with expertise in the various research areas of floating wind joined in sessions ranging from 33 to 55 people. There was a very good response across research institutes, industry players, wind turbine OEMs and operators but also across government bodies that made discussion rich and exciting.

Due to the online format, live presentations were reduced to a minimum in order to boost interaction during the meeting. Participants had the opportunity to watch pre-recorded videos prior to the meeting to familiarize with the IEA Wind TCP framework and with selected projects that fit into the sessions' topics. In addition, pre-meeting questionnaires helped set the context and get a first feeling of key topics. Introductory slides highlighting each participant's background and interests were available for consultation; a precious document that helped group chairs to steer discussion during break-out sessions.

Each of the 6 meeting sessions started with a short introduction and overview by one of the organisers. After the context had been set and the research topics explained, participants divided into small groups had an hour to discuss and prioritize these topics, identifying also any relevant research project. All participants then gathered again, and each group's note taker briefly summarized the main points that were discussed.

From these notes, the organizing team will seek to identify the key topics and prioritize the research areas for collaborative research, with the aim to reach a consensus on a new IEA Wind Task on floating wind and to propose amendments to existing Tasks.

Main Results

The six sessions of TEM#99 have allowed to grasp the vast range of topics playing a role in the development of large-scale floating wind arrays. Discussion on each research area helped identify important matters for international information exchange and collaboration in the frame of the IEA Wind TCP.

The discussions around mooring and anchoring raised a large and diverse set of research issues at the array level. In particular, the topics of array-level failure risks and mitigation strategies, as well as modeling and design considerations for shared-anchor and shared-mooring arrays generated significant interest. Agreement was reached on the importance of:

- Improving understanding of phenomena such as scour or marine growth;
- Multidirectional anchor loads and new failure modes;
- Standardization and analyses that extend from individual component behavior to the coupled behavior across the entire farm;
- Array-level modeling, anchor evaluation tools and methods, and standardization of design approaches across technologies/materials and layouts.

In the area of cabling and export, modeling and design considerations along with fatigue and marine growth were also identified as key issues, particularly linked to O&M strategies for condition monitoring and maintenance at the array scale. The topic of substation design was tied in to questions of equipment needs and the potential for multi-use platforms. Common priorities across all topics were the following:

- Need for better cable connection/disconnection strategies to ease installation and removal, and to reduce the impacts of failure;
- Opportunity for *mooring-cabling co-design* to produce mooring and cabling solutions better suited to each other.

Participants of the metocean assessment session agreed on the fact that the deep water/far-from-shore environment is sufficiently different from onshore/near-shore conditions that dedicated models, data sets, and validation approaches are required to support commercial scale floating projects. In particular:

- There is a need for mid-fidelity numerical models, joint wind/wave models and data, better characterization of nonlinear, breaking, and low frequency waves, and publicly available, standardized validation data.
- The uncertainty associated with metocean conditions and floating wakes is likely to lead to overly conservative project designs which underutilize the resource.
- This research area has the potential to complement IEA Wind Tasks 30 (OC6), 32 (Wind LiDAR), and 36 (Forecasting).

Farm controls experts noted that there is a true “floating” specificity to be considered in wind farm control approaches at array level, so that floating offshore wind turbines should be co-designed along with the wind farm control strategy. By addressing the interaction between units within the array at the earliest design stage, best dimensioning and wind farm control pairing in terms of reliability and LCOE can be achieved. More generally, the following points should be considered:

- The synergy of this topic with the new IEA Wind Task 44 on “Wind farm flow control” has to be thoroughly studied. A dedicated gateway between the two tasks seems essential.
- An “OCx style” benchmark study on FOWT arrays control and optimization strategies is suggested. Contest-like initiatives could stimulate research in this area.
- Collaborative projects with OEMs would ease an exhaustive access to the turbines and platforms data, and make feasible high-level customization at the turbine controller interface so that generated setpoints at a supervision level could be advantageously taken into account.

Unsurprisingly, comparing the effects of conventional and novel installation, operations and maintenance strategies received the most attention and discussion within the I,O&M session, given the breadth of the topic and the direct impact on project LCOE. Major themes that emerged from the discussions were the needs for:

- A robust, credible analysis to characterize the cost benefit tradeoffs between various installation and O&M strategies;
- A better understanding and quantification of project risk as well as understanding the environmental impact of commercial scale floating wind projects.

The strong recurring theme of the "being a good neighbor" session was Marine Spatial Planning (MSP). MSP has been conducted to greater or lesser extent in various countries for fixed offshore wind developments. In the case of floating farms, there will be a need for:

- Impartial expertise to develop the required GIS data layers for floating wind farms and to assist with their interpretation;
- Coordination between the organisations responsible for MSP in the relevant jurisdictions and addressing pertinent questions arising from their engagement with local stakeholders.

In summary, a strong need for establishing international benchmarks was observed in several domains. For instance, the creation of reference floating arrays is desirable in order to assess different component designs and control or operations methods. Risk and cost assessment would also benefit greatly from international standardization so that the evaluation methods build on a common basis; the use of a similar data format goes hand in hand with benchmarks. Finally, coordination with jurisdictions worldwide is recommended to ensure acceptance and cohabitation of floating farms and the marine environment.

Summary of Sessions

The information in this section provides an overview and selected highlights of each of the sessions that were held within TEM#99.

All meeting material from TEM#99 is available on the IEA Wind website, on the TEM#99 community page. Access for download can be requested from the Task 11 Operating Agent.

General introduction of IEA Wind TCP, Task 11 and TEM#99 goals

As an introduction to TEM#99 and in order to set the context of the meeting, two videos were pre-recorded by the organisers:

- **Cian Desmond from MaREI** introduced TEM#99, the topics covered, its format and goals in a short video available online.
- **Nicolas El Hayek, Task 11 operating agent**, recorded a more general, broader presentation of the IEA Wind TCP and of Task 11 activities. In particular, the benefits for specialists to participate in international collaboration are explained in the video.

Session 1: Anchoring & Moorings, July 15, 13:30 – 15:10 (CEST)

Introduction and Session Overview

Matthew Hall from NREL, chair of session 1, welcomed all participants to this opening session of TEM#99 and outlined the process for the session. He presented a brief overview of the session's topics and then directed participants to small breakout group discussions.

Two prerecorded video presentations were submitted for this session. **Kenji Shimada of Shimizu Corporation** shared his study on the loads of a shared pile anchor within a floating wind array with shared anchors. **Erin Bachynski of NTNU** shared progress in the WINDMOOR project, which explores low-frequency wind and wave loads on floating wind arrays to inform farm design and shared mooring/anchoring/cabling configurations.

Breakout discussion notes

Parallel discussions in seven breakout groups collectively identified the following research needs for each topic of the session, which were briefly identified in a synthesis discussion at the end:

Topic A: Alternative mooring materials, configurations, and layouts, including mooring-cabling integration

- The variety of mooring line configurations and material options, especially with synthetic ropes, calls for standardized methods and requirements to ease comparison and certification across different mooring configurations and material types.
- The impacts of wake effects on mooring loads, such as unbalanced rotor loads due to partial waking, are not well understood.
- Better understanding of the long-term performance of mooring systems is needed. Of particular importance are load changes due to marine growth, and the creep, fatigue, biofouling, and abrasion (whether from connections, seabed contact, sediment, or marine growth) of synthetic mooring lines. This calls for long-term testing and monitoring along with sharing of data from industry.

- The potential for integrated mooring-cabling attachments – such as a combined mooring-cabling connector for a single-point-moored, weathervaning FOWT design – warrants further exploration. Anchor installation is a challenging design consideration for anchor layout in deep water, and optimization approaches are not established.

Topic B: Modeling and design considerations for shared-anchor and shared-mooring arrays

- A modeling capability is needed that looks at loads on individual turbines and also across the array, and is suitable for optimization. Representation of low-frequency wind and wave excitation is important. An ability to simulate line failures and loads after part of the system fails is also needed.
- Trade-off studies are needed to compare shared and independent mooring systems in terms of mooring costs and wake losses for different spacings across a variety of site/design scenarios, considering the potential of larger turbines and installation challenges.
- There is a lack of experimentation, model validation, and empirical data, particularly for inter-array moorings, and floating arrays for which wave tank testing is difficult.
- Shared multi-line anchors is a new loading regime for anchors and research is needed on topics such as the impact of changing multidirectional loads, trenches from multiple lines, and loads in failure cases. Key design questions include anchor sizing for these applications, installation processes, and alternative anchor technologies (e.g. micropiles, torpedos) suitable for different depths and seabed conditions.

Topic C: Anchoring solutions depending on site conditions and array layout, including installation, removal, reuse, and standardization considerations

- Research is needed on high-volume anchor logistics including manufacturing, transportation, storage, and installation, considering how costs and supply chain capacity.
- Anchoring solutions for difficult seabed conditions (e.g. soft soil in shallow water, or bedrock) need further study and characterization in terms of cost, performance and scalability.
- Techniques are needed for predicting and withstanding sediment loss/deposition and erosion for shallow-water anchors. Scour studies are needed.
- Anchor performance under more complex loadings—including cyclic multidirectional loads, multiple lines and associated trenching, and unexpected load direction changes due to mooring failures—is not well understood. Integrated research is needed going from array-level system behavior down to loads and geotechnical details of individual anchors. This should include empirical testing for multidirectional loadings.

Topic D: Interference mitigation depending on depth, mooring type, and array layout, including installation considerations

- Research is needed to anticipate the seabed use impacts, fishing/navigation obstructions, and installation challenges that could arise in a large array, and how different mooring concepts could address these, including footprint minimization.
- Options should be explored for increasing mooring visibility, especially for synthetic lines, to reduce collision risks including for marine life.

Topic E: Dedicated efficient seabed investigation techniques for large floating wind arrays

- Research is needed to find lower-cost solutions for geotechnical investigation at the array scale. Additionally, “big data” analysis techniques are needed to efficiently bring together high-resolution array-level measurements (e.g. 3D soil profile data) to allow optimization of anchor design and cable routing.

- The potential for high-resolution geotechnical wind farm profiles should be assessed to allow evaluation/optimization of each anchor as well as optimized cable route mapping accounting for soil conditions etc.

Topic F: Array-level mooring/anchoring failure risks and mitigation strategies

- Research is needed to characterize mooring/anchor failure modes and associated risks at the array level, to inform practices around safety factors and redundancy. Scenarios of total loss of stationkeeping and potential for cascading failures should be considered. Collaboration with regulators may enable new risk management approaches suited to the lower consequences of wind energy.
- More consideration around anchors in failure situations is needed, including ability to handle side loading and performance during soil liquefaction from seismic events.
- Array-level design to mitigate failure including layouts to minimize risk of cascading failures and potential for fortifying select anchors to mitigate cascading failures or collisions, and turbine control and electrical disconnect responses in the event of failure.
- There is an opportunity to identify key condition monitoring and digital twin approaches to guide maintenance/inspection and reduce failures. With larger arrays come larger datasets and potential to use risk-based approaches. Open data sharing on failures could create a common database to improve reliability for the entire industry.

In summary, the discussions raised a large and diverse set of research issues associated with mooring and anchoring at the array level. Some research needs relate to improving understanding of phenomena such as scour or marine growth given their increased importance to a floating wind array. Other research needs focus on the specific new interactions and complications that arise within a floating array, such as multidirectional anchor loads and new failure modes.

Though topics B and F generated the most discussion, all topics generated significant interest. Common themes that emerged across topics are the need for standardization and for doing analyses that extend from individual component behavior to the coupled behavior across the entire farm. Some distinct gaps were identified in array-level modeling capabilities, anchor evaluation tools and methods, and standardization of design approaches across technologies/materials and layouts.

Session 2: Cabling & Export, July 15, 16:00 – 17:40 (CEST)

Introduction and Session Overview

Matthew Hall from NREL chaired session 2**.** He gave an overview of the topics to be discussed and then attendees went into small breakout groups for further discussion.

Takeharu Yamaguchi from Furukawa Electric provided a prerecorded video presentation on the dynamic power cables for the Fukashima Forward floating wind project. He discussed the dynamic cable configuration, loads analyses and the design process, modeling and comparison to measurement data, fatigue analysis, and impacts of marine growth.

Breakout discussion notes

Parallel discussions in six small groups led to the following research items in each of the topics.

Topic A: Design of dynamic intra-array cables and export cables in shallow and deep water

- More research is needed on cable dynamics including curvature and touchdown-region behavior, considering internal mechanics and interaction between mechanical and electrical aspects, to inform design and improve predictions of fatigue and lifetime.
- Improved configuration solutions are needed for dynamic cables in shallow water and deep water to lower dynamic cable costs.
- Greater understanding of marine growth rates and effects on cables, to plan for in design, is needed.

Topic B: Intra-array cable layout and design of configurations to address interference with moorings

- Moorings and cables are interdependent. Co-design of mooring and cabling systems would allow both systems to be optimally designed accounting for the other.
- The possibilities of fully dynamic cables between platforms or cables mechanically integrated with the mooring system warrant more research to understand trade-offs related to interference, design complexity, and failure risks.

Topic C: Substation design (fixed-bottom, floating, or subsea) and specific equipment for floating farms

- Trade-off studies are needed to explore the range of substation possibilities as a function of site conditions, from minimalistic subsea designs to large multi-functional artificial islands.
- Subsea cables and electrical equipment have unique sensing requirements and O&M constraints that need to be considered.
- Hydrostatic pressure for cable and connections becomes an issue at greater depth, and needs to be accounted for to avoid plastic deformation. Further development of wet-matable connectors rated for high voltages may be warranted, to provide disconnect for both maintenance and emergency cases.

Topic D: O&M strategies: array-wide inspection, monitoring, maintenance, and decoupling/disconnect

- Larger arrays and greater experience will allow use of risk-based rather than time-based inspection approaches. New monitoring technologies and strategies will be needed, such

as using many AUVs to fit within weather windows versus resident ROVs, tracking individual cable paths versus the full array footprint, etc.
- Dynamic cables could benefit from improved condition monitoring technologies, including electrical, thermal and mechanical sensing, to provide in-situ condition measurements over the lifetime, especially for fatigue.
- Disconnection is a big issue: how a turbine can be disconnected and removed from the array without interrupting array output, and the trade-offs between doing maintenance on site versus towing a turbine back to shore.

Topic E: Installation: interference with moorings, safe coupling/decoupling, etc.

- Research is needed on better coupling/decoupling techniques, including the possibility of subsea collection systems, integrated mooring-cabling attachment methods at the platform (e.g. through single point moorings), and methods for preserving array connectivity when a turbine is removed.
- The trade-offs should be assessed between an integrated mooring-cabling approach with a specialized vessel and independent approaches with vessels for each.
- As cables cover larger distances in an array and to shore, higher-quality route-mapping may be warranted, and associated standards could be improved. This may be particularly important for floating arrays due to different soil conditions.

Topic F: Failure modes (including from mooring failures) and solutions for mitigation/redundancy

- Research is needed to characterize the many failure modes associated with cabling and export, including dynamic cable fatigue and failures at the seabed which may depend on installation, seabed changes, etc.
- Strategies to mitigate damage from mooring or cable failures at the array scale should be explored, such cables that can tolerate extreme excursions, disconnection points to confine failure to specific locations, means of easily reconnecting after a cable failure, or redundant mooring features to avoid cable damage when one line fails.

In summary, the discussions brought up a variety of research issues across the topics. In Topics A and B, the discussion of dynamic power cables drew parallels with discussion of moorings and anchors in Session 1, looking at modeling and design considerations along with fatigue and marine growth issues. The topic of substation designed was tied in to questions of equipment needs and the potential for multi-use platforms. O&M was raised as an important issue, with discussion of different strategies for condition monitoring and maintenance at the array scale. Installation and failure were also well discussed. A common priority across topics D, E, and F was the need for better cable connection/disconnection strategies to ease installation and removal, and to reduce the impacts of failure. An idea frequently mentioned across many of the topics was the opportunity for *mooring-cabling co-design* to produce mooring and cabling solutions better suited to each other.

Session 3: Metocean Assessment, July 17, 13:30 – 15:10 (CEST)

Introduction and Session Overview

Cian Desmond from MaREI (UCC) chaired session 3 and started with a few logistical items for the online meeting. He then presented the main topics of Metocean Assessment to be discussed subsequently in the breakout sessions.

Breakout discussion notes

Topic A: Combination/validation of remote sensing data from spaceborne and farm mounted sensors

- There is a need for accessible, standardized data in order to benefit model improvement, uncertainty reduction, and ultimately bankability. This could facilitate a systematic data processing methodology (machine learning/AI, digital twins).
- There is a need for joint wind/wave/current data. This especially complex and expensive in the deep water/far-from-shore environments where floating wind arrays will be located.
- The current limitations result in conservative wind resource assessment and ultimately project design.

Topic B: Numerical modelling of the marine boundary layer; coupling atmospheric and oceanic models

- Numerical models developed for land-based projects are less effective for further offshore work. This is particularly evident in mid-fidelity engineering turbulence models, which has been identified in IEA Wind Task 30 (OC6).
- Better coupling of high-fidelity and mid-fidelity is needed, but it is not yet clear if this can address the deficiencies in mid-fidelity models. Higher fidelity models need to properly account for the physical coupling of the wind and ocean.
- Variations within arrays (ie, bathymetry) may significantly impact wakes and loads across a commercial-scale array; this could be addressed with a better mid-fidelity models.

Topic C: Measurement, modelling, and prediction of high loading events

- Better characterization of nonlinear waves, breaking waves, and low frequency drift waves is needed. This is complicated as validation data is unreliable for extreme weather events (measurement equipment is often destroyed).
- The EU can benefit from Asian experience in modeling extreme events such as typhoons.
- The impact of climate change on the frequency and intensity of extreme events needs to be examined, particularly as metocean data for design is obtained from hindcast and may not represent future conditions.
- There is ongoing IEC work in this modeling area.

Topic D: Deployment of floating lidar arrays and associated data processing techniques

- Fukushima floating wind turbines have used floating LiDAR measurements, and have a pending publication.
- Standardized data processing tools are required.
- This topic has a close overlap with other topics in this research area as well as IEA Wind Task 32.

Topic E: Provision of realtime data for predictive control

- A response takes time so predictive control is needed to improve production and safety.
- Realtime prediction of waves is in its infancy, and may be a good link with modeling of the marine boundary layer.
- A better definition of input parameters is required.
- Real time measurements and response prediction will be a challenge, and the cost/benefit tradeoffs are not certain.

Topic F: Wake modelling for floating arrays. Physical and numerical approaches

- Floating wakes will bend with hydrodynamic motions, and the impact of the 6 degree of freedom motions on the wake and the inter-array impact needs to be understood.
- A strong potential for yaw instability exists.
- Moving structures and wakes make layout optimization particularly challenging.
- Uncertainty around wake effects is likely to reduce installation density and thus underutilize the resource.
- Lack of validation data makes this a particularly challenging research area; laboratory experiments using atmospheric boundary layer tunnels or HiL systems may address this need.
- Significant ongoing research exists in this area.

In summary, the deep water/far-from-shore metocean environment in which floating arrays are likely to be deployed is sufficiently different from onshore/near-shore conditions that dedicated models, data sets, and validation approaches are required to support commercial scale floating projects. In particular, there is a need for mid-fidelity numerical models, joint wind/wave models and data, better characterization of nonlinear, breaking, and low frequency waves, and publicly available, standardized validation data. The uncertainty associated with metocean conditions and floating wakes is likely to lead to overly conservative project designs which underutilize the resource.

This research area has the potential to complement IEA Wind Tasks 30 (OC6), 32 (Wind LiDAR), and 36 (Forecasting).

Session 4: Control of Floating Farms, July 17, 16:00 – 17:40 (CEST)

Introduction and Session Overview

Fabrice Guillemin from IFPEN chaired the "Control of Floating Farms" session. He welcomed all participants to this 4th session of TEM#99 and outlined the process for the seance. He presented a brief overview of the topics to be addressed, discussed and selected and then directed participants to small breakout group discussions.

A pre-recorded video was submitted for this session by **Ali C. Kheirabadi from the Control engineering Laboratory at University of British Columbia**. He outlined his doctoral research, which subject and objective is "Maximizing power production in floating offshore wind farms using wind farm control". As an alternative to power derating and wake steering strategies, he studied the potential and feasibility of a "yaw and induction-based turbine repositioning" approach in order to mitigate wake effects in the farm. He worked on steady state evaluation and optimization of the turbine setpoints, and studied the sensitivity to various parameters such as farm size, farm orientation, moorings size and moorings orientation with regards to incoming wind direction. He implemented and tested a distributed control strategy on a dynamic wind farm model.

Breakout discussion notes

Parallel discussions in six breakout groups collectively identified the following research needs for each topic of the session, which were briefly identified in a synthesis discussion at the end.

Topic A: Control objectives and performance targets

- The control objectives should consider profitability and reliability aspects, by taking explicitly into account: lifetime, maintenance, failures occurrences and repair planning, in addition to AEP.
- A tradeoff methodology needs to be implemented to prioritize the several objectives to be addressed: AEP maximization, structures fatigue minimization (moorings, blades, tower, cable), actuators solicitation and components (gearbox, transmission) failures mitigation.
- Power management objectives (frequency fluctuations mitigation, …) need to be defined in the floating farm context, at farm and turbine scale.

Topic B: Integration of structural and dynamics specificities in farm / turbine control design

- It is quite a community consensus that mechanical coupling (moorings) role on the controls is not well known. Thus, thorough studies are needed to understand and quantify added-value and potential synergies between passive/active moorings features and farm level supervision and control.
- Interaction between turbine motions and wake presence need further investigation and understanding. Adapted instrumentation, subscale experiments and high-fidelity modeling should help.
- Many "floating specific" degrees of freedom open the way for new control mechanisms:
    - Vertical wake steering and/or wake mixing, through axial induction control and induced platform tilting
    - Active Moorings (winches or turbines themselves) for load balance and/or repositioning (though repositioning deemed to be logistically difficult)
    - Intra/inter array controllable mooring systems
    - Impact of platform intrinsic yaw on control strategies
- Links to "cabling & moorings" research areas need to be drawn carefully in the task design.

Topic C: Operation optimization at farm scale

- This area of research suffers a big lack of experience on floating array behavior. It is thus still early to evaluate accurately floating wind farm dedicated control strategies.
- New sensors and actuators on blades are envisioned to better capture their behavior and possibly control wake mixing locally, that would lead to “Smart Blades” concepts. Though, cost trade-off introducing additional sensors must be examined, pro/cons balance can be questionable.
- The integration of LIDAR systems as inputs for control systems in FOWT (Floating Offshore Wind Turbine) arrays is a topic that should be precisely addressed. A link to IEA Task 32 could advantageously help to proceed on the analysis and feasibility of solutions adapted to FOWT arrays (accuracy capacities, use with data-based models, maturity for array commercial stages, …).
- Existing hardware may be used to improve wind field estimation (*e.g.* load sensors).
- Understanding of the surrounding wind field is extremely important for reliable optimization studies. There is potential for collaboration using the “Digital wind farms” concept from the IEA Task 43 project.

Topic D: Validation and certification framework

- There is a need for high-fidelity simulation tools for validation and certification procedures.
- Data-driven techniques can be used in the certification process. An adapted methodology has to be developed.
- FOWT arrays validation and certification practices can be designed starting from fixed-foundation wind farm control certification framework.

Topic E: Data and physics combination into control design

- The model-based framework needs to connect the “farm scale” to the “component scale” through a system level modeling of key components (mooring lines, gearbox, …) and array-scale mid-fidelity control-oriented models.
- Practices to validate mid-fidelity and data-driven models with high-fidelity tools are missing. There could be a link with IEA Task 43 for this topic. Some research projects addressing data-driven models in the context of FOWT farm control could be envisioned.
- There is room for improvement and further research in high-fidelity simulation tools with control systems in the loop.
- Experimental data has to be gathered to build accurate understanding of (far-)offshore floating arrays behavior.
- Subscale testing should provide support for hybrid (data+physics) modeling approaches
- FOWT arrays-oriented research projects addressing the best ways to access and combine neighboring turbines information (SCADA and wind conditions) for control purposes will bring up high valuable knowledge to the industry.

Topic F: Farm state access

- Valid models for evaluating AEP are a prerequisite before setting objectives and targets. It is necessary to capture accurately the behavior of the floating array first. Analytics, machine learning and physics-based approaches can provide answers

New topic: **Co-Design of FOWT and wind farm controllers**

- A new topic has been proposed, that aims at establishing the Co-Design of platform and turbine along with the wind farm control strategy, so that the Interactions between units in the array are addressed at the earliest design stage. This is expected to achieve the best dimensioning and wind farm control pairing, in terms of reliability and LCOE.

Additional general comments

- One way to promote the research in control systems for wind arrays could be to create contests like the Offshore Wind Accelerator (OWA) initiatives to stimulate projects in this area. An "OCx style" benchmark study on FOWT arrays control and optimization strategies is also suggested.
- The synergy of "floating arrays control" work package with the new IEA Task 44 on "Wind farm flow control" has to be thoroughly studied. There is a true "FOWT" specificity to be considered in wind farm control approaches, and also a strong bond between Task 44 and the future "Floating Wind Arrays" task. Thus, a dedicated gateway between the two tasks seems essential.
- It is suggested to build some collaborative projects with OEMs on board, in order to ease an exhaustive access to the turbines and platforms data, and make feasible eventual high-level customization at the turbine controller interface, so that generated setpoints at a supervision level could be advantageously taken into account.

Session 5: Installation, Operations & Maintenance (Marine Logistics), July 20, 13:30 – 15:10 (CEST)

Introduction and Session Overview

Matt Shields from NREL chaired session 5. He outlined the process for the session, presented a brief overview of the session's topics and then directed participants to small breakout group discussions.

In addition, **Marie Schwarzkopf from Ramboll** presented a summary of ongoing research into optimised O&M strategies and installation techniques under the COREWIND project funded under the EU Horizon 2020 Research and Innovation programme. Her presentation discussed the importance of new turbine access methods and a requirement to better understand wave constraints, the challenge of evaluating tradeoffs between floating and jack-up vessels for installation and major component repairs, and novel approaches to innovations designed to reduce cost.

Breakout discussion notes

Parallel discussions in five breakout groups collectively identified the following research needs for each topic of the session, which were briefly identified in a synthesis discussion at the end.

Topic A: Comparing the effects of conventional and novel installation and operations and maintenance (O&M) strategies on project cost, performance, availability, weather window utilization, and risk for a range of project characteristics (distance to shore, metocean conditions) and other sensitivities.

- The floating wind industry is faced with a **myriad of project design questions** surrounding the selection of platform type, vessels, cable/mooring disconnections, maintenance strategies (including tow-to-port vs in-situ), fixed vs floating operations, and project planning/sequencing. Although the industry is familiar with these questions, there is a **lack of quantitative, published analysis** describing the tradeoffs between different design decisions.
- The use of **digitalization, digital twins, risk-based decision making, and operability by design** present an opportunity to reduce O&M costs through innovation.
- Optimization of installation and (particularly) O&M strategies is **limited by the lack of available data** on failure rates, repair requirements, accessibility, vessel parameters, etc. A public data repository would be helpful, although it is difficult to collect this type of data.
- A **detailed and robust sensitivity analysis** (or analyses) could offer valuable insights to the industry by providing:
    - A reference wind farm(s) for cost comparison
    - Cost sensitivities to platform type, geospatial parameters, installation/O&M strategies, etc
    - Mapping cost effective O&M strategies to project/metocean conditions
    - Quantifying commissioning and O&M risk and
- In order for this type of sensitivity analysis to be credible it will require collaboration and **engagement with developers, technology providers, marine warranty surveyors, contractors, and researchers**.

Topic B: Characterizing how port and local assembly constraints (laydown area, crane capabilities, wet storage, etc) drive installation timelines, vessel fleet requirements, and required port upgrades/costs for commercial-scale projects using different platform technologies.

- **Port constraints drive installation and O&M strategies**, meaning that this topic is coupled with Topic A

- There is value in **characterizing the main port characteristics, limits, and constraints** needed for commercial scale floating wind; however, this may be a **difficult research topic to generalize** as the results may be port- or region-specific and will vary for different types of substructure.
- Offshore installation may be less of a challenge than the **ability to fabricate, assemble, and load-out at commercial scale.**

Topic C: Evaluating the techno-economic potential of commercial scale projects relative to pilot or demonstration scale projects

- **Standardization is a key part** of progressing to commercial scale but it is not clear when these benefits may be realized.
- There may be value in **exploring funding streams to develop preliminary demonstration projects** as part of commercial leases, which would likely involve some government/commercial cost-share.

Topic D: Designing floating wind plants with decommissioning in mind to reduce lifecycle costs and streamline environmental permitting processes.

- **Funding or cost-planning for decommissioning** needs to be considered early in the project life.
- The **environmental impact of decommissioning** is not clear - for example, artificial reefs could develop during the lifetime of floating wind farms which would be removed by decommissioning.

Topic E: Defining key performance indicators or other metrics that can be used to compare different installation and O&M methodologies

- There is a need to **evaluate qualitative project impacts**, such as risk, environmental impacts, carbon payback, or site evaluation, which could benefit from the development of relevant KPIs. Still, **LCOE remains the most critical metric**.
- Environmental impacts have been known to cause **delays for developers** and a more rigorous approach based on KPIs at early project stages could be beneficial.
- A better approach is needed to **incorporate project risk into LCOE**.

In summary, Topic A received the most attention and discussion - this is unsurprising due to the breadth of the topic and the direct impact on project LCOE. A major theme that emerged from the discussions was a need for a robust, credible analysis to characterize the cost benefit tradeoffs between various installation and O&M strategies. Secondary themes included a need to better understand and quantify project risk as well as understanding the environmental impact of commercial scale floating wind projects.

Session 6: Being a Good Neighbor, July 20, 16:00 – 17:40 (CEST)

Introduction and Session Overview

Cian Desmond from MaREI (UCC) had the pleasure of chairing the last session of TEM#99. This session focused specifically on the environmental, economic and social challenges and opportunities associated with the development of floating wind arrays. During the introduction presentation, the natural synergies with existing IEA Tasks (particularly Tasks 26, 28 and 34) were highlighted. The point was made to delegates that the focus of discussions in this TEM were to identify areas in which the existing and this proposed task could collaborate or produce complementary work specific to the development of floating wind arrays.

Pre-recorded video: Laura Serri from RSE provided a pre-recorded video presentation summarising provisional results from a techno-economic assessment of future floating offshore wind arrays in Italy. The scenario-based work uses a simplified Levelized Cost of Energy model and indicates that floating wind energy will be economically viable for deployment in Italian marine areas by 2030.

Breakout discussion notes

A total of 34 experts worked together across 5 break out groups to discuss the 6 proposed research topics. A high-level summary of the points discussed in each of these areas is provided below along with a brief conclusion detailing the most pragmatic way to advance work in this Research Area.

Topic A: **Requirement:** Establish the need for utility-scale floating arrays in relation to meeting climate change targets in different national contexts.

- A joined-up approach is required across the national plans to optimise deployment globally
- A collaborative international approach is required to establish a supply chain and ensure that offshore floating wind is deployed in the optimal locations for all stakeholders.
- Similar challenges in the USA with states operating independently rather than collectively to deliver the optimum solution in terms of return on investment and carbon mitigation.
- A clear message on the required level of development and the regional benefits of floating wind is required. The narrative is too fragmented at present.

Topic B: **Planning:** A review of planning processes in relevant jurisdictions to find the balance between providing a voice for host communities, other stakeholders and development risks.

- Acceptance of offshore wind is heavily dependent on the host community.
- A collective project with several relevant countries involved is required in order to develop collective guidelines.
- Social acceptance is far from assured even if the turbines are out of sight.
- Impact on navigation in and out of port, particularly during inclement weather conditions, needs to be examined.
- Best practice guidelines would be practical and useful in this area. Common regulations are not feasible.
- The right groups need to be engaged to examine the constraints for fixed wind and these need to be examined in the context of deeper water and larger farms. This can be done "quickly and easily" and have a significant impact.

Topic C: **Economic impact:** Investigate the economic benefits of floating wind, including supply chain / local production opportunities, jobs and port facilities.

- Will floating wind actually create jobs locally or will it be a market dominated by a few international players.
- Is there an appropriate level of local supply chain requirement to create local economic benefit without impacting the viability of a proposed development? How can this be assessed?
- The economic impact of the transmission infrastructure should not be overlooked. Large infrastructure projects can be used to stabilise an economy and provide significant future returns.
- Who benefits is the key question when it comes to stakeholder engagement. Will it just be large faceless international consortia or will the host communities, existing and future users of the marine environment benefit.
- Economic benefit is less certain for coastal communities with floating wind. This may offset the increased acceptance due to visual impact. This will depend strongly on the host community.
- A study on job creation potential could be built around data from exiting demonstration floating farms.
- The larger scale of these floating farms provides great potential for regional collaboration. How can this be planned / facilitated?
- The transferability of jobs from oil and gas needs to be examined.
- The reduction of jobs due to automation and the increased reliability of turbines needs to be factored in. These technologies will be required for projects to make economic sense in remote / harsh environments. How will this impact local benefit?
- Optimisation of regional port infrastructure development is required.

Topic D: **Fisheries consultation:** Development of recommendations for best practice consultation and compensation policies for commercial and recreational fisheries, including compatibility of various fishing techniques within the boundaries of the wind farm.

- Fishing communities have the strongest existing tie to the marine environment.
- These groups often work individually with a degree of commercial secrecy / sensitivity.
- Co-design from an early stage is essential. Groups need to be engaged at a stage when they can meaningfully influence the design / location of a project. The best technical solution will not necessarily be the most acceptable.
- Fisheries have been more influential than visual impact objections in the US.
- Collaborative GIS mapping is key to resolving conflicts.
- Concerns vary widely depending on the type of fishing gear used (e.g. trawling v pot based).
- There may be an engagement coordination role for the IEA as impartial experts.
- Can inter array fishing be conducted safely?
- Can turbine mounted sensors / artificial reefs provide a benefit to fishing communities?

Topic E: **Marine Protected Areas:** Explore legislative, technical, and environmental barriers in relation to the designation of marine protected areas and the possibility of co-existence with floating wind.

- With the EU targeting 30% of oceans designated as MPA we need a better understanding of what this designation means and if floating wind can co-exist.
- This is a Marine Spatial Planning Issue.
- It is likely that R&D projects will be better accepted in these areas.
- Increased fouling in biodiverse areas may be a problem for moorings and cables.

Topic F: **Multi-use strategies:** Explore benefits and drawbacks of innovative multi-use strategies, such as aquaculture and solar arrays.

- Solar, hydrogen, fisheries and tourism were identified as possible co-locationed technologies.
- Use of multiple generation / storage technologies will be required to enable decoupling from the grid. This may be important for remote deployments in deep water far from grid infrastructure.
- Biofouling may again be a problem with aquaculture.
- Sharing the costs and the benefits of multiuse will be a challenge.

There was a degree of interest in all 6 research topics, however, most interest was gained by topics relating to:

C: Economic assessment of the benefit of floating wind;

D: Consultation with fisheries

F: The potential use of multi-use.

Having reviewed the notes of the discussion the strong recurring theme is Marine Spatial Planning (MSP). MSP has been conducted to greater or lesser extent in various countries for fixed offshore wind developments, as we move to repeating this exercise for floating farms, there will be a need for impartial expertise to develop the required GIS data layers and to assist with their interpretation through analysis and/or stakeholder workshops.

A role for this task would be to engage with the organisations responsible for MSP in the relevant jurisdictions and act as a coordinator of the international research effort to address pertinent questions arising from their engagement with local stakeholders.

An MSP Work Package would (depending on feedback from national planners) incorporate topics across all 6 TEM #99 Research Areas and would play an important role in maximising the impact of the international research effort as we move to the development of large arrays in deep water.

Conclusions & Next Steps

The IEA Wind TEM#99 has been an insightful meeting during which the exchange of results and experiences in large-scale floating arrays among the participants shed light onto the multidisciplinary aspects of array-scale floating wind turbines. The novelty of the online format was a challenge for the organizing team, but the approach chosen for the six sessions proved to be efficient and fruitful. A great success for this first ever online IEA Wind Topical Expert Meeting; the Task 11 OA would like to warmly thank the organizing committee for their great commitment.

A large number of participants expressed interest in the formation of a new IEA Wind Task tackling the technical, longer-term science challenges and research needs of array-scale floating offshore wind. Based on the notes from the individual sessions, the organizers were able to identify several topics of interest for international collaboration which could be addressed transversely in the following topics:

- Reference sites
- Reference farms
- Risk assessment methods
- Marine spatial planning and Innovations

Work packages will be shaped around the abovementioned topics and reviewed by the interested countries and organisations. Discussions among the many interested parties will be led by IFPEN, NREL, Principle Power & MaREI (UCC), with the goal of presenting a proposal at the autumn online Executive Committee meeting (ExCo 86, October 12-16, 2020).

APPENDIX ONE – TEM#99 Introductory Note

INTRODUCTORY NOTE

IEA WIND TASK 11 TOPICAL EXPERT MEETING # 99

ON

FLOATING OFFSHORE WIND ARRAY CHALLENGES AND OPPORTUNITIES

Matt Shields, Garrett Barter, Matt Hall – National Renewable Energy Laboratory

Alana Duerr – U.S. Department of Energy

Aaron Smith, Nailia Dindarova – Principle Power

Cian Desmond – University College Cork

Pauline Bozonnet, Daniel Averbuch – IFP Energies nouvelles

Matt Lackner – University of Massachussets

BACKGROUND

The offshore wind resource is significant for many countries and is already, or slated to be, a key contributor to the electrical grid production plans of many countries. For some, their coastal waters include extensive regions of shallow depths (less than 60m), where fixed-bottom supports for offshore wind turbine are feasible. However, the majority of the offshore wind resource across the globe is in depths where the only feasible technical approach is to use floating supports.

Much of the research on floating turbines to date has focused on the engineering of an individual turbine and support structure. However, as developers move forward with field trials and plan for larger scale commercial arrays, they will face a new, but common, set of layout issues that did not arise for fixed-bottom offshore wind plants. Some are opportunities, such as shared moorings or anchors, while others are challenges, such as understanding new wake motion dynamics.

MOTIVATION

Currently, floating offshore wind energy technology is fragmented among IEA Wind tasks, with some aspects being addressed in Tasks 26 (Cost of Wind), 30 (Offshore Code Comparison), 37 (Systems Engineering), and 40 (Downwind Turbines). However, floating offshore wind energy is at the frontier of wind technology and community interest. Many governments, industries, and developers are currently marching forward with pilot or even second-generation floating wind projects, but there are challenges and opportunities that are common to all countries. The IEA Wind program can seize on the momentum for floating wind deployment and address some of these common issues in an international, collaborative setting.

OBJECTIVES

This topical expert meeting is intended for participants to exchange information and ideas that relate to the opportunities and challenges that are unique to floating offshore wind arrays and do not overlap with other IEA tasks. These opportunities and challenges would also be shared by researchers or developers across the globe. Topics that form the base of a new IEA Task proposal and that will be discussed include:

- Anchoring and Moorings: reduce cost, optimise performance through sharing of moorings, reusable anchors, installation efficiencies at scale, etc.
- Cabling and Export: inter-array cabling, export, umbilical design, export systems, HVDC, installation efficiencies at scale, etc.
- Metocean Assessment: meso to micro modelling, increasing accuracy, impact of climate change, risk of extreme conditions, etc.
- Control of Floating Farms: control algorithms designed specifically for floating assets, response to extreme conditions, opportunities to alleviate loading through whole wind farm control, etc.
- Installation, Operations and Maintenance: increasing weather windows, reliability-based design, predictive maintenance, access to floating assets, etc.
- Being a Good Neighbour: co-location of industries, avoiding conflict with shipping/fisheries, increasing social acceptance, etc.

INTENDED PROGRAM

Preliminary Remarks

TEM#99 will be the first online organized IEA Wind TEM and will take place over three days: Wednesday, July 15 – Friday, July 17 – Monday, July 20. Each day will be dedicated to specific topics, and participants will have to sign up for the sessions they wish to attend. The sessions will be structured as follows:

- Presentations (20 minutes)
- Discussion in small groups (60 minutes)
- Synthesis (20 minutes)

In order to facilitate discussion in groups of 6-8 people, a draft of the IEA Wind Task proposal will be sent out to invitees prior to the meeting, and they will be given two weeks' time to submit comments on the document. It will be used as a base for the group talks.

Participants are encouraged to contribute actively either by presenting, chairing a small group discussion or taking notes for the group. They can volunteer using the registration form.

Tentative Agenda

Monday, June 29

Registered experts receive an explanatory presentation + a link to a survey to indicate their interest for each Research Area & Topic. To be watched and filled until July 6.

Wednesday, July 6

Presenters and note takers are informed, a 2nd survey for prioritization of topics is circulated

Tuesday, July 14

Registered experts receive an invitation for each session, with an overview of the participants & a link to the community page for 1-slide introductions and pre-recorded videos can be found

All times hereafter are indicated in Central European Summer Time (CEST, UTC+2).

Wednesday, July 15

13:30 -15:10 Session 1: Anchoring & Moorings

16:00 - 17:40 Session 2: Cabling & Export

Friday, July 17

13:30 - 15:10 Session 3: Metocean Assessment

16:00 - 17:40 Session 4: Control of Floating Farms

Monday, July 20

13:30 - 15:10 Session 5: Installation, Operations & Maintenance

16:00 - 17:40 Session 6: Being a Good Neighbour

INTENDED PARTICIPATION

- Wind turbine OEMs
- Offshore wind turbine owners and operators
- Offshore wind component suppliers
- Offshore wind turbine service and repair providers
- Marine economy unions and advocates
- Marine wildlife and environmental experts
- Research institutions
- Funding agencies

EXPECTED OUTCOMES

A report will document the proceedings of the meeting. This report will provide:

- The state of existing floating offshore wind array planning
- Challenges and opportunities for offshore wind arrays common to all developers
- Scope for proposed IEA Task for submission to IEA Executive Committee

PRACTICAL DETAILS

Individual Outlook invitations will be sent separately for each session, including the meeting link and the list of participants. Please accept these invites to confirm your presence.

A community page on the IEA Wind Platform will be set up shortly before the meeting. All introductory slides as well as pre-recorded presentations will be available there.

APPENDIX TWO – IEA Wind Task Proposal Synopsis

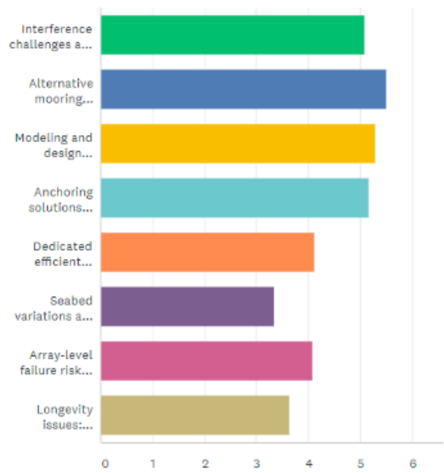
IEA Task 99 Proposal: Floating Offshore Wind Array Challenges and Opportunities

This survey outlines a preliminary list of topics to be discussed and prioritized during IEA TEM99. The topics listed in each research area have been developed to specifically focus on commercial scale challenges and opportunities of floating wind arrays, which may complement or build upon work being covered in other IEA Tasks. The major focus of the TEM will be to prioritize the topics in each research area to develop appropriate Work Packages for a Task Proposal. The goal of this survey is to refine the preliminary list of topics to be a comprehensive and relevant list of challenges and opportunities facing floating wind arrays from the perspective of international experts in the field.

Research area 1: Mooring and anchoring

This research area explores the challenges and innovation opportunities related to stationkeeping systems at the array level, including issues related to scalability, footprint and interference, array-wide variations, and shared intra-array components. Topic areas will be considered in relation to cost, scalability, reliability, environmental impact, etc.

1. Interference challenges and solutions as a function of depth, mooring type, array layout, etc., including installation considerations
2. Alternative mooring materials, configurations, and layouts, including mooring-cabling integration
3. Modeling and design considerations for shared-anchor and shared-mooring configurations
4. Anchoring solutions depending on site conditions, array design, etc., including issues of installation, removal, reuse, and standardization
5. Dedicated efficient seabed investigation techniques for large floating wind arrays
6. Seabed variations and resulting stationkeeping design and loading differences across the array
7. Array-level failure risks (collisions, cascading failures, production interruptions) and mitigation
8. Longevity issues: fatigue, corrosion, biofouling across the array, farm-wide condition monitoring strategies

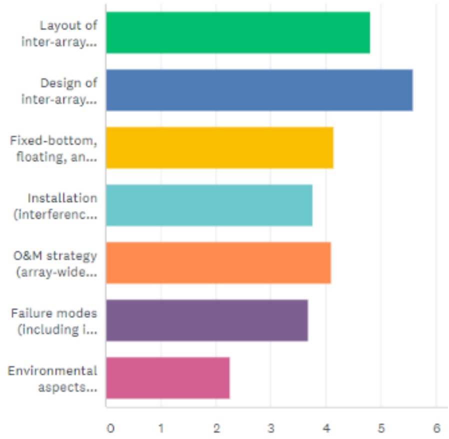


Research area 2: Cabling and export strategies

The electrical cabling in a floating wind farm is composed of two kinds of cable: the inter-array cables, connecting the wind turbines together and to the sub-station, and the export cable, carrying the electricity to shore. A unique aspect of floating wind is the dynamic part of the cables, which is subject to environmental dynamic loading and floater movement. Based on this description, the following sub-topics are identified as sources of technical and scientific challenges and innovation opportunities.

1. Layout of inter-array cables and design of cable configurations including interference with moorings
2. Design of inter-array cables (fatigue, possible variation throughout the wind farm, mid-depth and deep dynamic cable configurations) and export cables in both shallow and deep water

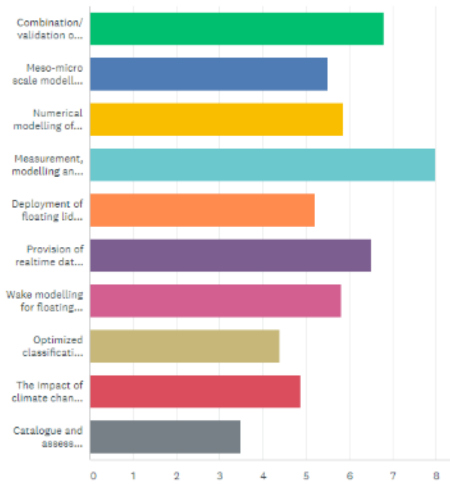
3. Fixed-bottom, floating, and subsea sub-station design, and specific equipment for floating wind farms
4. Installation (interference with moorings, safe coupling/decoupling)
5. O&M strategy (array-wide inspection, monitoring, and maintenance strategies; decoupling and disconnect processes)
6. Failure modes (including in the event of mooring failures) and redundancies/safeguards for ensuring array output
7. Environmental aspects (heating, electromagnetic fields, soil conditions, etc.)



Research area 3: Metocean assessment

As we move to the commercial deployment of floating wind we will see large arrays developed in far offshore locations. This presents a significant challenge to the meteorologist or oceanographer when attempting to characterize the wind and wave resource in order to provide data for design processes and to provide inputs for control algorithms once farms are operational. These challenges are across a wind range of both spatial and temporal scales and are compounded by a lack of in situ validation data covering the development zone. Potential topics include:

1. Combination/ validation of remote sensing data from spaceborne and farm-mounted sensors.
2. Meso-micro scale modelling of wind farm scale weather systems.
3. Numerical modelling of the marine boundary layer; coupling atmospheric and oceanic models.
4. Measurement, modelling and predication of high loading events.
5. Deployment of floating lidar arrays + associated data processing techniques.
6. Provision of realtime data for predictive control
7. Wake modelling for floating arrays. Physical and numerical approaches
8. Optimized classification of the far offshore metocean conditions for design code integration.
9. The impact of climate change on long-term conditions.
10. Catalogue and assess uncertainty of existing far from shore databases.

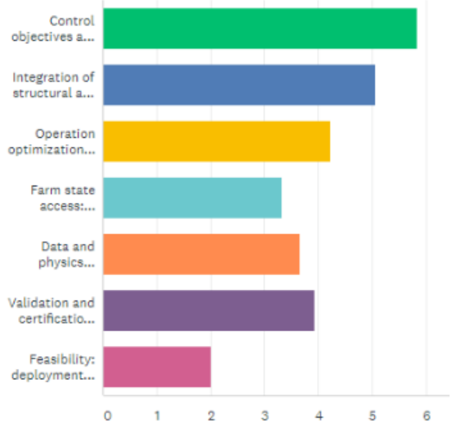


Research area 4: Control of floating farms

Although several “proofs of concept” studies have been successfully conducted regarding control strategies that manage aerodynamic interactions between turbines (such as wake steering or axial induction control) , the industrial feasibility and evaluation of these solutions is still ongoing, especially in on-shore applications. This is even more challenging in floating off-shore context, as the assets go under more complex solicitations (hydro-aero coupling, noticeable nacelle and platform motions, larger farms with larger turbines, lower site roughness, ...), and higher uncertainties on performance evaluation.

In this context, here is a non-exhaustive list of significant topics that can be addressed and discussed during the upcoming TEM#99:

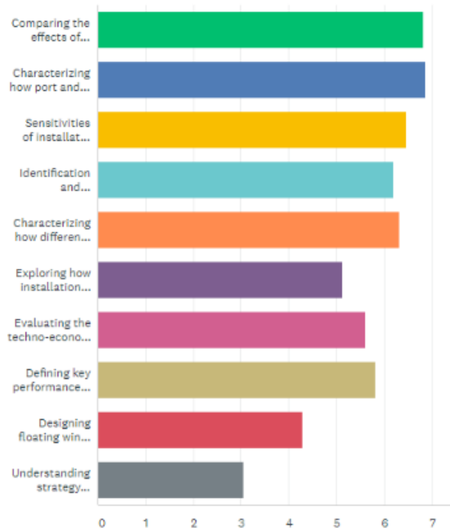
1. Control objectives and performance targets: AEP, efficiency, structure elements fatigue mitigation, grid requirements, O&M conditions, etc.
2. Integration of structural and dynamics specificities: dynamic layouts, cables and moorings constraints, platform compliance, yaw stiffness, damping devices (active or passive), etc.
3. Operation optimization at farm scale: coupled (through wakes) assets supervision and multivariable control issues
4. Farm state access: production and loads measurement accuracy, variables of interest observability, required vs achievable levels of data certainty, etc.
5. Data and physics combination into control design: handling uncertainty levels of measurements and models
6. Validation and certification framework: simulation platforms representativeness and realism needs, relevant design loads cases, computations costs, etc.
7. Feasibility: deployment impact on wind farm hardware and instrumentation



Research area 5: Marine logistics and lifecycle

The goal of this research area is to explore the design space of port and marine logistics associated with installing, servicing, and decommissioning a commercial scale floating wind project. Potential goals include evaluating the relative merits of different strategies and examining the conditions under which they may be applied. Major themes to explore include:

1. Comparing the effects of in-situ and tow-to-port operations and maintenance (O&M) strategies on project costs, performance, and availability
2. Characterizing how port and local assembly constraints (laydown area, crane capabilities, wet storage, etc) drive installation timelines and vessel fleet requirements for commercial-scale projects using different platform technologies.
3. Sensitivities of installation and O&M strategies to project characteristics, such as distance to shore and metocean conditions
4. Identification and characterization of novel methodologies, such as simultaneous towing of multiple turbines or determining the impact of shared mooring systems on installation time
5. Characterizing how different installation and O&M strategies allow projects to maximize available weather windows and how these strategies can be optimized when installing/servicing large numbers of turbines
6. Exploring how installation and O&M strategies impact project risk characterization and financing/investment decisions
7. Evaluating the techno-economic potential of commercial scale projects relative to pilot or demonstration scale projects
8. Defining key performance indicators or other metrics that can be used to compare different installation and O&M methodologies
9. Designing floating wind plants with decommissioning in mind to reduce lifecycle costs and streamline environmental permitting processes
10. Understanding strategy constraints, service costs, and required upgrades for commercial scale floating wind ports.

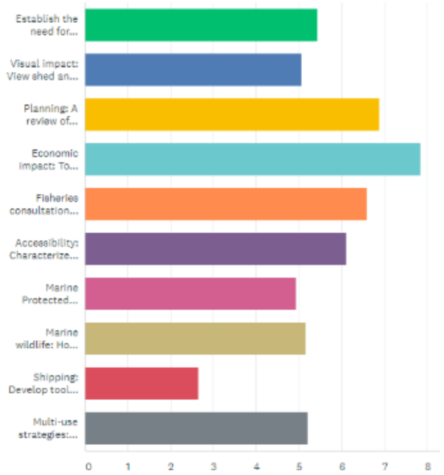


Research area 6: Being a good neighbor

If the opportunity of floating wind energy is fully realized, arrays will be deployed over vast areas of our seas. The effects on existing and future users and stakeholders of these ocean areas, including coastal communities and fishing fleets will need to be carefully considered. Moreover, these stakeholders will need to be engaged in the planning process early on with decision makers. Marine Spatial Planning and consultation processes also will likely be key to ensuring avoidance and mitigation of potential risks to marine life as well as helping to engage the broad range of offshore stakeholders across regions. Results and lessons learned from IEA task 28 and task 34 will be considered in these discussions wherever appropriate.

This research area aims to consider some aspects of these research and engagement areas early in the industrialization of floating technologies and to identify specific opportunities to integrate the social and environmental science priorities with the engineering aspects in order to lead to more holistic design and development processes (e.g., the choice of anchors and mooring lines may be related to environmental considerations in addition to reliability and costs). This will be achieved by collaborating across national borders with key stakeholders to develop specific best practice guidelines that incorporate the needs of developers, co-located industries, regulatory bodies and the public. Lessons learned from the existing offshore wind (and oil and gas) markets in different regions will be considered wherever possible. Potential topics include:

1. Establish the need for utility-scale floating arrays in relation to meeting climate change targets in different national contexts.
2. Visual impact: View shed and visibility analysis along with community workshops to assess social acceptance and provide recommendations.
3. Planning: A review of planning processes in relevant jurisdictions to find the balance between providing a voice for host communities, other stakeholders and development risks.
4. Economic impact: To investigate the economic benefits of floating wind, including supply chain / local production opportunities, jobs, and port facilities.
5. Fisheries consultation: Recommendations for best practice consultation and compensation policies for commercial and recreational fisheries, including compatibility of various fishing techniques within the boundaries of the wind farm.
6. Accessibility: Characterize vessel transit requirements between floating turbines/mooring/cabling systems for various co-located industries to inform the assessment of environmental impact.
7. Marine Protected Areas: Explore legislative, technical, and environmental barriers in relation to marine protected areas.
8. Marine wildlife: How will wildlife behavior be impacted or benefited by the development of large arrays, and how can this impact be quantified and mitigated?
9. Shipping: Develop tools to assess the overall impact of rerouting shipping to accommodate the development of floating arrays.
10. Multi-use strategies: Explore benefits and drawbacks of innovative multi-use strategies, such as aquaculture and solar arrays.



APPENDIX THREE - Meeting Participants

In total, 103 participants & observers were registered to TEM#99, coming from a record number of 18 countries due to the online format of the meeting! Participation to each session ranged from 33 to 55.
The detailed list of participants for each session is available on the TEM#99 community page.

A deck of introductory slides to 51 of the participants was put together, highlighting their background and research interest. This precious document is available for download at this link.

IEA Wind TEM#99 – Session 1: Anchoring & Moorings

IEA Wind TEM#99 – Session 2: Cabling & Export

IEA Wind TEM#99 – Session 3: Metocean Assessment

IEA Wind TEM#99 – Session 4: Control of Floating Farms

IEA Wind TEM#99 – Session 5: Installation, Operations & Maintenance (Marine Logistics)

IEA Wind TEM#99 – Session 6: Being a Good Neighbor

APPENDIX FOUR - IEA Agreement

International Energy Agency Agreement

Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems (IEA Wind)

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977 and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 26 contracting parties from 22 countries, the European Commission, and Wind Europe, participate in IEA Wind. Austria, Belgium, Canada, CWEA, Denmark, the European Commission, Finland, France, Germany, Greece, Ireland, Italy (two contracting parties), Japan, Republic of Korea, Mexico, Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, United Kingdom, the United States and WindEurope are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Three Subtasks

The task includes three subtasks.

The objective of the first subtask is to develop recommended practices (RP) in collaboration with the other IEA Tasks.

The objective of the second subtask is to conduct Topical Expert Meetings (TEM) in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, TEMs are arranged four times a year. Additional TEM types that would allow shorter reaction times, broader audience and augmented visibility are currently being researched.

The objective of the third subtask is to provide room for exchanges within the wind energy expert community. This is done through the IEA Wind platform with online communities.

Documentation

Since these activities were initiated in 1978, more than 90 volumes of proceedings have been published. In the series of Recommended Practices, 20 documents were published and six of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task. Some documents are publicly available one year after first publication.

Operating Agent

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COUNTRIES PRESENTLY PARTICIPATING IN TASK 11 (2020)	
COUNTRY	**INSTITUTION**
Belgium	Government of Belgium
Canada	Natural Resources Canada
Denmark	Danish Energy Authority
Finland	Business Finland
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
Ireland	Sustainable Energy Authority of Ireland (SEI)
Italy	Ricerca sul sistema energetico (RSE S.p.A.)
Japan	New Energy and Industrial Technology Development Organization (NEDO)
Mexico	Instituto de Investigaciones Electricas (IIE)
Netherlands	Ministry of Economic Affairs
Norway	The Norwegian Water Resources and Energy Directorate (NVE)
Republic of China	Chinese Wind Energy Association (CWEA)
Republic of Korea	Korea Institute of Energy Technology Evaluation and Planning (KETEP)
Spain	Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT)
Sweden	Energimyndigheten - Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy (SFOE)
United Kingdom	Offshore Renewable Energy CATAPULT
United States	The U.S Department of Energy (DOE)