SIMREI

Support Infrastructure for Marine Renewables in Ireland

Project Summary Report

July 2023

Credit: Boskalis

Rockall Research Limited

WaveVenture

MMCC Port Marine Ltd

Executive Summary

The SIMREI project, “Support Infrastructure for Marine Renewable Energy in Ireland”, led by Rockall Research with partners Ocean Wave Venture and MMCC Port Marine has been funded by the Sustainable Energy Authority Ireland under the SEAI Research, Development and Demonstration Funding Programme 2021, Grant number 21/RDD/598. The overarching objective of SIMREI was to use evidence-based research to quantify the port infrastructure and work vessel capability needed to support the rollout of Ireland’s Marine Renewables industry and particularly the development of significant Floating Offshore Wind (FOW) capacity to meet our 70% renewable electricity target in 2030 and to achieve net-zero emissions by 2050.

SIMREI is distinct from other literature on this subject in its use of Ocean Wave Venture’s TEMPEST™ software to simulate several representative scenarios of FOW in Ireland. The software is used to model the Installation, Operations & Maintenance of FOW farms, providing datasets highlighting the requirements for FOW development, in terms of port and wet storage capacity and the number of vessels and their usage. The software enables the identification of key bottlenecks and constraints regarding the deployment and operation of FOW farms in Irish waters. This report represents a condensed summary of the project as a whole.

It is worth bearing in mind that FOW is an emerging technology and there are numerous proposed solutions and various supporting technologies currently being developed. Even within the 1-year duration of this project various novel technologies have been proposed and developed in areas such as larger turbines, concrete floating platforms, shallower draft platforms, smaller platforms supporting smaller capacity turbines and solutions to enable maintenance and/or replacement of large components offshore. Therefore, the findings of this study must be taken into context with the assumptions that are made based on the current technology and information within the industry.

With Ireland’s goal of deploying some 30GW of FOW by 2050, the ports will be kept very busy over the coming decades. Today's benchmark wind turbine is 15 MW and, therefore, we can expect to be operating 2000 FOWTs in our waters by 2050. This study has shown that Ireland must rapidly develop significant port infrastructure in order to assemble, install and operate this number of FOWTs to meet our targets. The maintenance of these units, with the current default ‘tow back to port’ strategy, together with today's failure rate for offshore wind turbines, will pose significant additional challenges in terms of port capacity. Solutions are being developed to allow maintenance and/or replacement of large components to take place offshore. It is suggested that even if these operations could be undertaken in wet storage areas rather than at the quayside it would be a significant step forward, alleviating pressure on the ports.

This project has assessed the suitability of four Irish ports, Cork Harbour, Bantry Bay, The Shannon Estuary and Killybegs, as well as foreign ports, to be used as bases for the installation, operation and maintenance of FOW farms. The high-level results of this analysis are:

Port infrastructure in Ireland must be significantly developed to support the assembly, deployment and maintenance of FOWTs. Current Irish Port infrastructure is not sufficient to meet the Government's target of 30GW of FOW by 2050 and immediate investment to develop port infrastructure is required. This study shows that the required port infrastructure would include: ● Port storage capacity for a minimum of 3 full sets of components needing to be stored in the port before assembly starts. ● Quayside capacity for assembly of a minimum of 3 FOWTs. ● A minimum of 3 ports with the above capacity, working in coordination are required to achieve the 2050 targets. Local constraints and bottlenecks such as water depth, tidal restrictions and marine traffic must be considered. **Maintenance.** This does not include space for FOWT maintenance. particularly with the current default of 'tow back to port' for maintenance.	**Assembly and Installation rates** needed to deploy a 1GW FOW farm in under 3 years is a significant challenge alone, due to the large size and number of units needed, combined with limited port capacity and weather windows. This is of particular concern when reviewing longstop dates, supply chains and requirements for support schemes. With Ireland's goal of some 30GW of FOW by 2050, we expect to be operating 2000 FOWTs in our waters by 2050. Over 20 years (2030 to 2050) that is 100 units per year or 2 per week. This could be achieved using 3 ports with an assembly rate of 1 every 10 days or 2 ports with an assembly rate of 1 every 7 days. However, without significant development of our ports, Ireland will struggle to install and maintain this number of FOWTs, particularly with the current default of 'tow back to port' for maintenance, together with today's failure rate for offshore wind turbines.
Wet Storage is a critical component due to weather conditions off our coasts. With year-round manufacture and assembly in the port, developers will be required to store assembled FOWTs in wet storage areas until a suitable weather window enables the units to be towed out and installed at the offshore farm. Wet storage is also required for FOWTs waiting for repair. Without any wet storage, installation rates for a 1GW FOW farm were found to exceed 8 years, and a wet storage capacity of 10 to 15 would likely be needed per port. This report identifies the Shannon Estuary and Bantry Bay as suitable for wet storage of significant numbers of FOWTs. A more detailed examination of the suitability of wet storage locations in terms of metocean conditions, water depths, ground conditions, FOWT mooring requirements, etc is recommended.	**Weather restrictions mean more vessels are required.** Ireland has a powerful offshore wind resource, however, the environmental conditions offshore make marine operations challenging and this has a significant impact on the installation, operation and maintenance of FOW farms. Employing multiple vessel fleets for offshore operations is required to maximise the use of the available weather windows, in order to reduce the time to install the farm and increase the availability by reducing downtime. It was also found that having vessels available year-round, rather than just in the summer months, had a significant positive impact on both the installation and maintenance of the farm, especially given a limited wet storage capacity.

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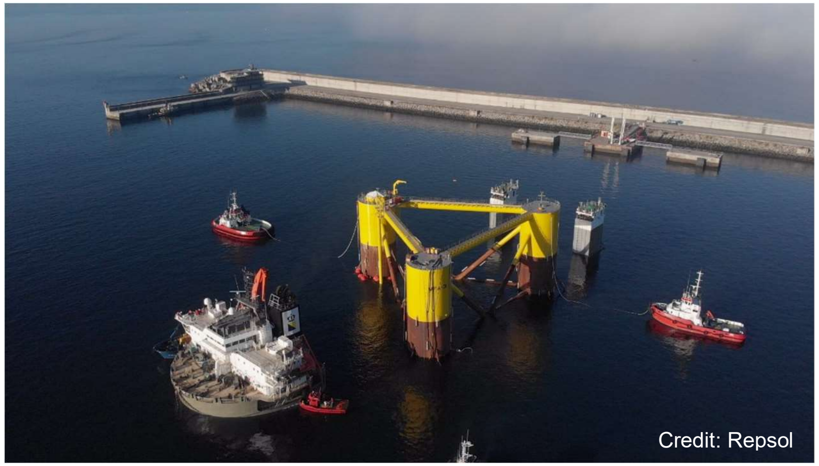
Disclaimer

The SIMREI project was funded by SEAI's Research, Development and Demonstration programme under grant number 21/RDD/598. The views expressed in this report are those of the authors and not SEAI's. Whilst the information contained in this report has been prepared and collated in good faith, the authors make no representation or warranty (express or implied) as to the accuracy or completeness of the information contained herein nor shall we be liable for any loss or damage resulting from reliance on the same.

Introduction

SIMREI, Support Infrastructure for Marine Renewable Energy in Ireland, is a 1-year project funded by SEAI's RDD program under grant agreement 21/RDD/598. The project is led by Rockall Research and has partners Wave Venture and MMCC Port Marine. The overall objective of the project is to provide evidence-based guidance on the required infrastructure to service the Floating Offshore Wind (FOW) industry in Ireland for it to meet the government's installed capacity target of 30GW by 2050.


Credit: Repsol

Overall, it is clear, and widely accepted, that Ireland does not have the port infrastructure in place to meet the needs of this industry. Significant investment must be made to develop the ports and a national strategy is needed as it is likely that the ports will be required to work together to support FOW farm projects.

SIMREI employs a novel approach to provide the evidence base by using marine operations simulations of the installation, maintenance and decommissioning of FOW in Ireland. The simulations cover each operation through the life of a Floating Offshore Wind Turbine (FOWT) from the in-port assembly of FOWT units, tow to wet storage and installation at the farm. Failures and subsequent maintenance are modelled, and the probability of failures is based on a FMECA for the FOWT. The repair involves either maintenance of small components at sea or tow back to port/wet storage for maintenance of larger components. Finally, each unit is decommissioned after its operational lifetime.

Project objectives

The overarching objective of the SIMREI project is to clearly identify which Irish ports are suitable to service the future Offshore Renewables Industry and outline the requirements and capability for the local infrastructure. The unique selling point of the SIMREI project is that assumptions and recommendations have been simulated, analysed and tested with respect to the actual development targets as specified by Ireland's Climate Action Plan. The project's approach rigorously simulates varying development plans and projects, to better assess the actual impact and value of the infrastructure and resource requirements.

The key project objectives are:

- Accurately define marine renewable energy stakeholder requirements and model inputs.
- Assessment of current port infrastructure and recommendations of future development options, based on stakeholder requirements.
- Simulation of Ireland Offshore Renewables in scenarios from 2030 to 2050.
- Dissemination of evidence-based recommendations for future Irish port development.

The project centres around gathering information for building operations and maintenance models of Ireland's future marine renewables installations. The model has been used to assess in detail the suitability of Irish ports and the impact their capacity will have on the future development of marine renewables in Ireland.

The SIMREI Approach

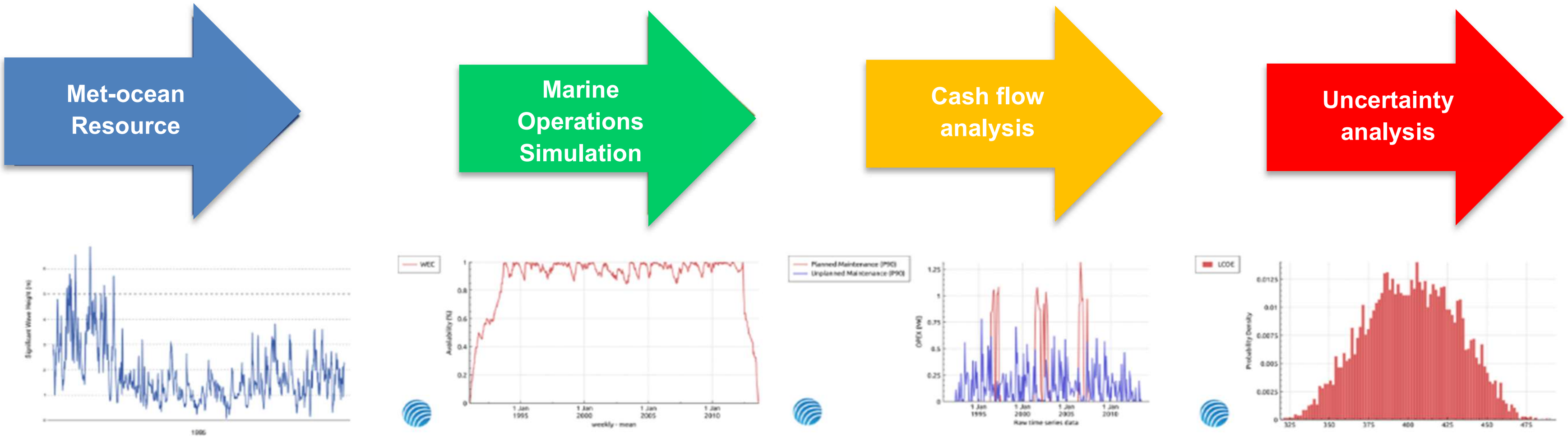
The simulations replicate a highly detailed start-to-end lifecycle of a wind farm including all marine operations, from the deployment of the moorings, assembly and installation of FOWTs, maintenance of failed FOWTs, all the way to the decommissioning of the FOWTs. The analysis considers weather restrictions by utilising hindcasted metocean data over the length of a typical project. The hindcast data is input and analysed as a time-series, allowing the use of actual weather windows in the metocean data for the completion of tasks in the I, O&M of the wind farm.

All the inputs used in the simulations defining port characteristics, onshore and offshore storyboards, and vessel requirements have been contrasted with high-calibre reports and experts in the field, to maximise the quality of the outputs. Since the future of FOW in Ireland is not written, parametric studies have been used analyse different future scenarios and give justifications for where the main near-future efforts and investment should be focused.

Simulation software

The *Wave Venture TEMPEST™* software is an integrated engineering and financial analysis package, specifically designed for the needs of offshore wind energy technology development. The simulations used in SIMREI calculate the progress of marine operations in installation, operations and decommissioning in the context of realistic vessel and task-level weather windows. Planned maintenance schedules are included and unplanned maintenance activities are simulated using random failures derived from equipment FMECA type reliability data.

The simulation calculates the energy productivity in the context of time series resource data and the bottom-up estimates of installation/decommissioning progress and operational availability. A financial analysis module allows a versatile discounted cash flow analysis with costs and revenue coherently linked to other aspects of the simulation. Key outputs are the installation progress, operating availability, energy productivity, failure counts, vessel usage/waiting times, CAPEX, OPEX, DECEX, Revenue, LCOE, NPV. All are calculated in the context of realistic weather windows and equipment reliability characteristics. In addition, the software includes powerful parameter studies that allow the user to run variations on a base simulation and to graph and interrogate the results to gain insights and performance improvements.



Simulations

The objective of the simulations is to obtain insightful numerical and graphical results regarding the installation and operation of floating wind turbines using the current and future infrastructure of Irish ports. The default simulations analyse the installation and operation of a 1 GW wind farm composed of 67 FOWTs rated at 15 MW each. Some of the most relevant results focus on the full commissioning time of the farm, the port capacity to install and operate the wind farm, vessel usage and the impact of the capacity of a wet storage area between the port and offshore site.


Credit: Principal Power

The simulations emulate every action that is taken on each FOWT, from its manufacturing until it is time for it to be decommissioned after 25 years of service in the open ocean. This includes detailed tasks describing: the import of components and materials, the assembly of the turbine in the port, the use of a wet storage area to increase the port capacity, the installation of each device, and the maintenance operations carried out both for turbine failures and scheduled servicing. The vessels required and their capability to perform each of the marine operations are also modelled and analysed as well as the effect of the met ocean conditions.

Since the future of Irish ports and the floating wind market is not scripted, the simulations modelled for SIMREI do not just show the results for a single scenario, but a range of possible realistic future scenarios.

Baseline inputs

In order to study each port under the same conditions, some standardised inputs are used across all simulations. These include using the same FOWT model, hiring the same vessels and sharing an identical strategy for installation and maintenance. The wind turbine selected to power Ireland with floating offshore wind, is the Vestas V236, rated at 15 MW. The platform selected to hold the wind turbine is an 86m x 86m triangular-base semi-submersible, three-column floating platform with a 12m draft based on the WindFloat, developed by Principal Power, a collaborator on SIMREI. An FMECA for the FOWT utilised in the model has been taken from SPARTA's 2020/21 Portfolio review, where the average major repairs per turbine are provided. These major repairs are defined as those that require the turbine to be towed back to port for an extensive repair operation. The failures sum up to approximately 0.009 average monthly repairs per turbine, which is equivalent to a FOWT being affected by a major failure once every 9 years on average.

Vessels


Credit: Principal Power

Vessels play a key role in any open ocean project, as they are responsible for the transport of devices and are needed during any offshore task. The vessels used in the simulation have two main responsibilities, in port manoeuvring and offshore operations.

Port manoeuvring covers any action between the port's quayside and wet storage, where harbour tugs will tow the fully assembled FOWT back and forth during installation and O&M. The harbour tugs will not be used for open ocean actions, always working in the area sheltered from large waves. Their manoeuvrability and small draft compared to bigger fleets, make the tugs an ideal option to tow FOWTs through the narrow and shallow areas of some Irish ports.

When it comes to offshore operations a more robust type of ocean-going vessel is required to tow the large FOWTs in the open sea, where both wind and wave conditions are not as favourable as in the port. Anchor handlers are usually selected for these kinds of tasks since they can both tow the FOWT from wet storage to the wind farm and perform the connection of the device to the preinstalled mooring and electrical cable. All these operations require additional smaller vessels, like escort tugs and patrol vessels, as support for the anchor handlers. In the simulations, this spread of vessels has been considered as the fleet which has been selected for each task as appropriate.

Metocean data

The simulations carried out in this project are time series-based calculations, the time-series metocean resource data drives the energy production modelling and, critically, the calculation of the marine operations access windows. The resource data used to run the simulations were primarily from ECMWF's ERA-5 dataset and the Irish National Tide Gauge Network. Daylight and nautical twilight were also included with input from several harbour authorities to accurately simulate harbour access restrictions.

Wet Storage Areas

With year-round FOWT assembly and production in the port required, developers will be required to store several assembled FOWTs in wet storage areas until a suitable weather window is forecast to allow installation. It is thus imperative that wet storage areas be in sheltered, coastal waters, outside of areas strongly influenced by waves and tidal currents, and ideally in proximity to existing assembly ports and offshore array areas.

A major fundamental requirement will be the monitoring of these units while in wet storage and this will be based on relevant criteria set out by the Harbour Master/Port Authority, Department of Marine Surveyors, Insurance industry and P&I Clubs. These criteria will also include the mooring system type and capacity dependent on the number of units to be moored at the wet storage area. It may also be necessary for the units in the wet storage area to have a power supply or onboard power. Therefore, it would also be prudent, if possible, to have the wet storage area adjacent to the assembly area/port due to the availability of suitable vessels in the event of a failure of mooring equipment and particularly to be available on standby during adverse weather conditions.


Credit: Balmoral Group

As part of this project, areas around the Irish Coast that may have partially sheltered bays and inlets with the required suitable depth of water and area to accommodate several FOWT units and mooring systems were reviewed and selected. It is worth noting that there are additional and more detailed selection criteria such as local met-ocean conditions, ground conditions, proximity to port facilities, consenting constraints, mooring & anchoring options, and supply chain considerations that are beyond the scope of this project.

FOWT spacing in wet storage.

The wet storage draft requirements have been influenced by operational drafts of the semi-submersible FOWTs known to the industry. As the temporary storage of these units will be required to withstand various sea states, the draft requirements will need to allow for rolling, pitching and heaving of the substructures without grounding. Furthermore, the water depth requirement will also be driven by the mooring design, which again will be based on the FOWTs design parameters, as well as the metocean and ground conditions at the site.

A centre-to-centre (or tower-to-tower) spacing of 600m between FOWTs moored in wet storage has been assumed and is based on a 15 MW turbine with a rotor diameter of 236m. Turbine spacing within wet storage must also consider failure consequences and vessel access. Lifeboat access between units with safety margins is also a key consideration when gaining consent in other countries and the spacing should also allow for the access of CTVs and tugs.

Accounting for the above, a 600m distance between turbines has been selected for the simulations and corresponds to 2.5 rotor diameters (590m). Alternatively, the minimum distance could be defined as 2 * (the hub height + blade length). The hub height we are using is 150m and the rotor radius is 118m, therefore: spacing = 2 * (150 + 118) = 536m. Therefore, each turbine sits in a 600 x 600m box, having an area of 360,000m2 or 0.36km2 or 36 hectares. The figure below shows the typical centre-to-centre spacing of the FOWTs in wet storage.

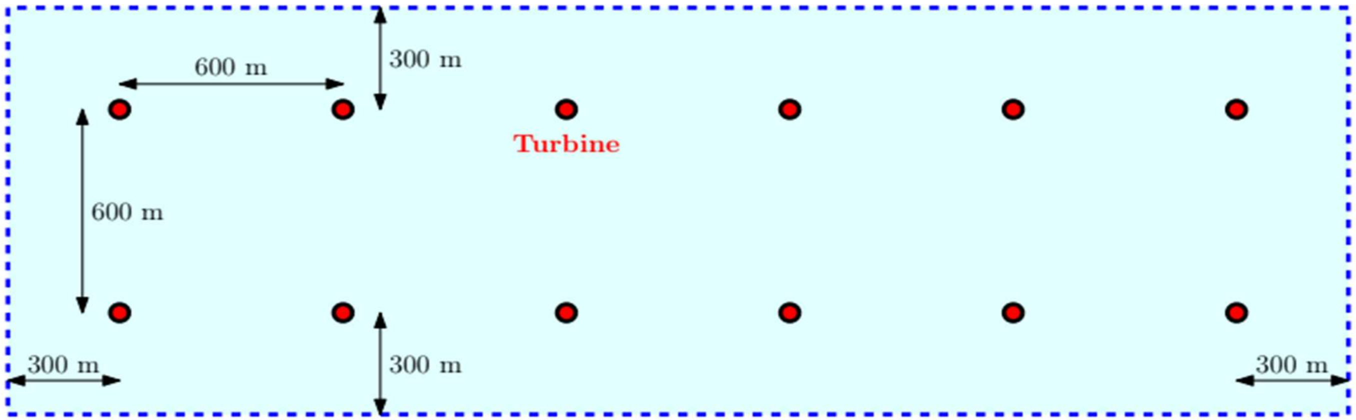


Figure 1: Plan view example of the 600m spacing of wind turbines in wet storage.

Model Description

The figure below shows a representation of the steps that are included in the model that was used to simulate the installation and maintenance of FOWTs from Irish ports.

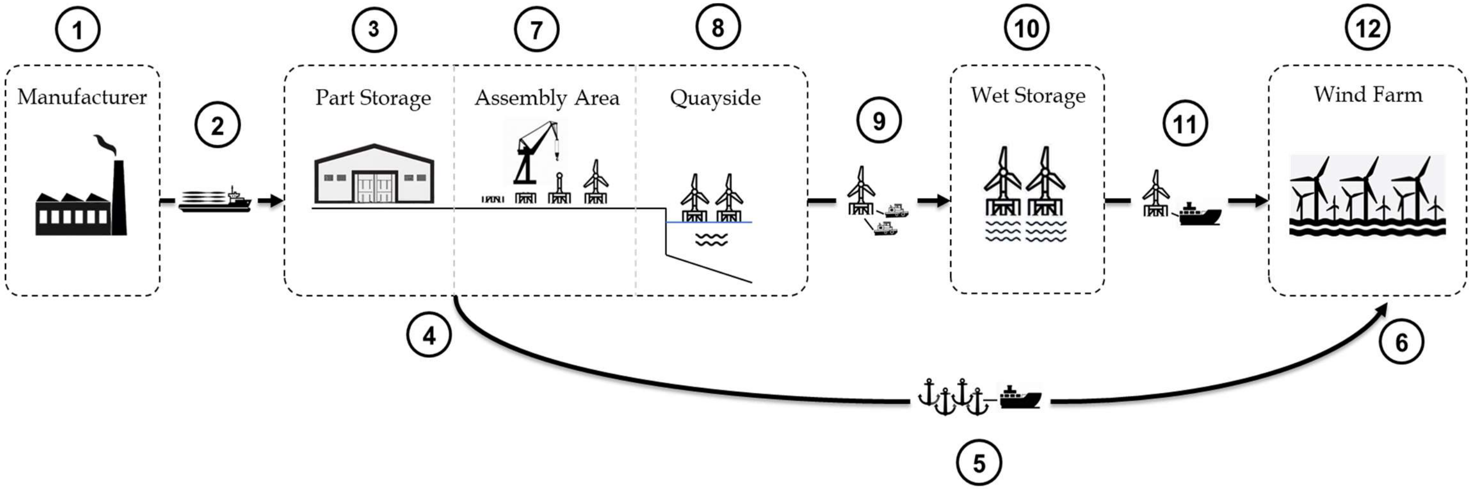


Figure 2: Illustration of simulated operations

On assembly, the FOWTs are towed to a designated area that has been prepared as wet storage where they can wait in relatively benign conditions until they can be towed out for installation. The time it takes to moor the FOWTs in the wet storage and to disconnect the moorings before the tow to the farm can be set as marine operations which are then simulated. The number of FOWTs that can be held in wet storage simultaneously can also be set within the TEMPEST™ software.

A FOWT is towed from wet storage to the farm location when a weather window opens that is long enough to safely tow the device (subject to maximum wind speed and wave height permits) and connect it to its moorings. Towing speed, maximum tow wave height and wind speed restrictions can be defined in the software. The tow and the installation at the wind farm are performed by a small fleet of vessels consisting of an anchor handler and 2 or 3 tugs, as required. The speed at which the fleet returns to wet storage to pick up the next device can be different from the towing speed and the number of towing fleets has been set to either be 1 or 2. FOWT units fail based on the FMECA inputs and are towed back to wet storage when a weather window allows, the unit is then taken from wet storage to the quayside for repair. Once repaired the installation process is repeated.

In order to balance the initial level of detail, while ensuring insightful results, the initial analysis used the following baseline inputs:

- No restrictions were implemented based on the wind speed and waves in the port. This means that assembly and tow between the port and wet storage can continue in any weather conditions. Adverse conditions at harbour entrances and shallows based on tidal flow and swell are not considered.
- There are no environmental restrictions placed on actions at the wet storage. So, restrictions on operations due to wind and waves are not considered in the sometimes-semi-exposed wet storage areas.
- The floating platforms are assumed to be assembled at the port at a rate of 1 every 10 days.
- The quayside capacity is shared between devices being assembled and devices being maintained/repaired, e.g., if quayside capacity is 3 and 1 FOWT is in port for maintenance, only 2 new FOWTs can be worked on for assembly.
- A maintenance wet storage with a capacity to hold 3 FOWTs was used for each port. The ‘maintenance’ storage is part of the main wet storage and the ratio of outgoing to incoming FOWTs can change based on changing requirements throughout a project.

Simulation Results

The following sections summarise the results of the analysis of the installation and maintenance of FOW farms from each of the four Irish ports considered, Cork Harbour, Bantry Bay, the Shannon Estuary and Killybegs, as well as from foreign ports such as Milford Haven.

Cork Harbour

In order to facilitate FOWT installation and maintenance from Cork Harbour, significant upgrades to the infrastructure are required. These include suitable quayside space with sufficient water depth where FOWTs can be assembled and sufficient storage space where turbine substructures and other parts can be stored before assembly. The scenarios modelled in this study have an assumed quayside space for 3 FOWT units which is in alignment with Doyle Shipping Groups' future plans for the development of Cork Dockyard.

Wet storage of sufficient capacity cannot be facilitated within the port and is therefore modelled outside the harbour entry at Roches Point as proposed in previous studies. However, the disadvantage of locating the wet storage outside the harbour is that it is potentially too exposed to environmental conditions and the area is relatively shallow. Confirmation of the suitability of this site for wet storage requires a more detailed assessment and is beyond the scope of the current project.

Access to Cork Harbour is restricted for vessels with a deep draft. The shallowest water depth in the port at Lowest Astronomical Tide is 11m at the Spit Bar turn. Towing a device with a 12m draft requires 13.2m water depth (draft plus 10% under keel clearance), so a tidal level of +2.2m would be required. This was found to be an excessively restrictive condition and therefore a less restrictive 1.5m level was used in this study, under the assumption that some mitigating options are implemented, e.g., dredging or shallower draft FOWT units.

Cork Harbour is a busy commercial port with scheduled traffic and large tankers/bulk carriers requiring regular entry. Some of these vessels will compete for access at high tide that allow towing FOWTs from the quayside to beyond Roches Point or vice versa when coming in for maintenance/repair. This clash between commercial shipping and the requirements of the FOW sector will inevitably lead to a requirement for prioritisation from Whitegate Oil Refinery and bulk cargoes of animal feed imports into Ringaskiddy, scheduled container services to the USA and Caribbean, ferry schedules and large cruise vessels. There are other unscheduled vessels requiring high water arrival and departures and certainly should the port require unopposed traffic during the towage movement of a FOWT, it would lead to serious commercial pressures from different sides. This issue will be relevant to all commercial ports. These restrictions have not been considered in the model but could have a significant impact on farm installation time and available maintenance/repair windows.

Figure 3 illustrates the simulated installation timeline for 1, 2 and 3GW floating offshore windfarm deployment with favourable constraints i.e., 2 install fleets always available, largest wet storage simulated and night towing allowed etc. There are significant challenges for installation and maintaining high availability particularly as the number of installed turbines increases. The plot shows that all three farms suffer from a loss of availability when FOWTs are taken back to port, but more importantly, shows that the port is incapable of installing and maintaining a 2 or 3GW farms as the full installation is not met. This strongly evidences the need for a significant increase in port capacity and the need for multiple ports to be developed.

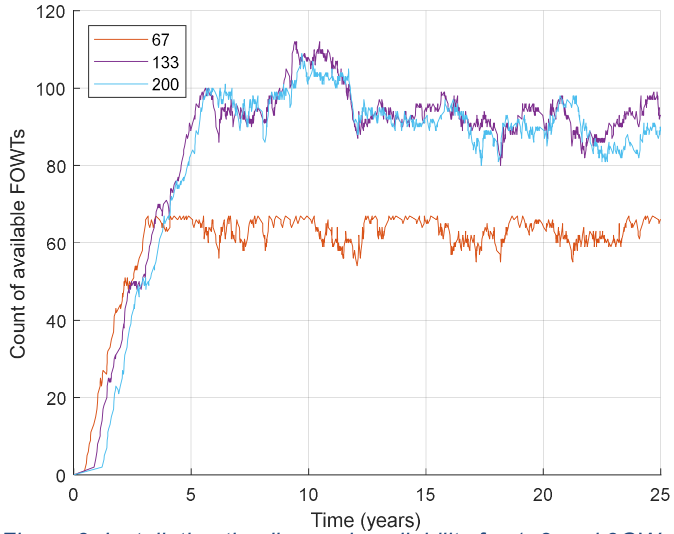


Figure 3: Installation timeline and availability for 1, 2 and 3GW FOW deployment using Cork harbour.

The main conclusions regarding the feasibility of FOWT farm installation and maintenance from Cork Harbour based on the modelling performed with the assumptions described above are:

- Availability of installation vessel fleet(s) has the largest impact on installation rate. Year-round availability of vessels is required to achieve a reasonable installation rate.
- A wet storage area with the capacity to hold 5 or 6 fully assembled FOWTs appears to be sufficient for installation and some maintenance activities. However, a detailed analysis of the proposed wet storage area outside of the port is required to confirm its suitability.
- Farms consisting of more than 70 FOWTs will be difficult to maintain by ‘tow back to port’ given the assumed annual failure rate of 1/9 turbines per year and quayside capacity of 3 FOWTs. Maintenance and repair might have to be performed at a location other than the quayside (e.g., offshore or in wet storage).
- Installation of a 1GW farm (67 FOWTs) can be achieved in 2.5 - 3 years. Increasing the quayside assembly rate can potentially shorten this but this will most likely also require greater availability of installation vessels (due to limited space the quay cannot be extended so the rate could only be increased by faster assembly.
- All results presented for Cork Harbour are only valid for the assumption that the tow between quayside and wet storage can be performed at a tidal level of LAT +1.5m. If higher tides are required, all installation and maintenance results will be significantly adversely affected.

Bantry Bay

In order to facilitate FOWT installation and maintenance from Bantry Bay, a final design, planning permission and construction of an extended new quay at Leahill is required. The first stage development of 500 metres is proposed to have quayside space for 3 FOWT units.

Bantry Bay provides an excellent sheltered deep-water area for a port capable of assembling/servicing FOWTs and has significant scope for wet storage of units.

Conditions off the West Coast of Ireland differ significantly from those in the Celtic Sea, subsequently reducing the number of suitable weather windows for operations outside of the bay. This more onerous climate will also affect the installation and operation of FOWT farms from the Shannon Estuary and Killybegs.

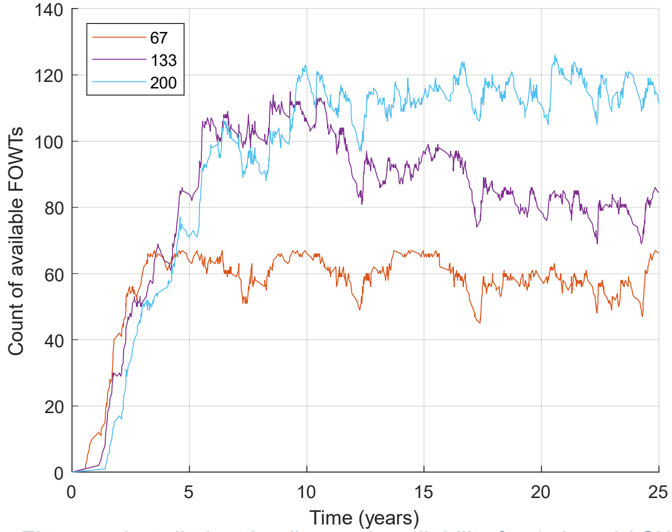


Figure 4: Installation timeline and availability for 1, 2 and 3GW FOW deployment using Bantry Bay

Figure 4 illustrates the simulated installation timeline for 1, 2 and 3GW floating offshore windfarm deployment with favourable constraints i.e., 2 install fleets always available, largest wet storage simulated and night towing allowed etc. There are significant challenges for installation and maintaining high availability particularly as the number of installed turbines increases. The plot shows that all three farms suffer from a loss of availability when FOWTs are taken back to port, but more importantly, shows that the port is incapable of installing and maintaining a 2 or 3GW farms as the full installation is not met. This strongly evidences the need for a significant increase in port capacity and the need for multiple ports to be developed.

The main conclusions regarding the feasibility of FOWT farm installation and maintenance from Bantry Bay based on the modelling performed are:

- The installation rate is improved more by increasing installation fleet availability than by increasing wet storage capacity. Fleet availability can be increased in two ways, by adding more fleets and by having the fleets available all year round instead of only in the summer months.

- A wet storage area with the capacity to hold ~15 fully assembled FOWTs appears to be sufficient for an install rate of 300-400 MW per year combined with some in-port maintenance activities.
- The analysis of the operating phase has shown that Bantry Bay, subject to completion of the proposed 500m quay and drydock, has enough storage space and could be capable of accommodating 3 FOWTs stored along the quayside at one time. (Quayside storage of 3 units was used throughout the study and an assembly rate of 1 FOWT every ten days or 500 MW per annum).
- Assuming tow to port for preventative and corrective maintenance on components, the port shows an ability to repair around 16-17 FOWTs yearly at maximum port capacity. However, this number cannot be seen separately from the current assumptions in the model:
    - Scheduled, preventative maintenance is performed on each FOWT once every 5 years with a 7-day maintenance time in port.
    - Unscheduled, corrective maintenance is performed when large failures occur and a failure rate of 1 out of every 9 FOWTs per year is assumed with 20 days repair time in port.
    - While the quayside has the capacity to accommodate 3 FOWTs, only a single device can be completed with a heavy lift crane at any time.

  This result suggests that the configuration for the Bantry port as modelled, will have the capacity to simultaneously deploy approximately 300 to 400 MW per annum (based on an assembly rate of 500MW per annum) and operate as a repair facility for a 1.5 GW wind farm (100 x 15 MW FOWTs). However, advances in the FOW sector, such as offshore maintenance, will likely reduce these constraints in the future. Moreover, Bantry as modelled here, with quayside space for 3 FOWTs, represents a minimum port development and this location could have facilities with double the quayside space. Clearly, as Ireland moves towards its target of 30GW, ports like Bantry will need to operate at a higher capacity, handling more FOWT units per year, but this is beyond the scope of this current project.
- Installation of a 1GW farm (67 FOWTs) can be achieved in 2.5 - 3 years. Increasing the quayside assembly rate can potentially shorten this but this will most likely also require greater availability of installation vessels.
- The results presented here are for the installation of a farm 60 km from Bantry. As can be seen in the section on foreign ports, Bantry's location may well see it used for deployment and servicing FOW farms in the Celtic Sea. The distance to these farms is greater, which increases towing time, but the onsite conditions for installation are less severe than on the west coast. Additional modelling is required to determine how these parameters trade off against each other.

The Shannon Estuary

In order to facilitate FOWT installation and maintenance from the Shannon Estuary, significant upgrades to the infrastructure are required. These include suitable quayside space at Moneypoint and Foynes Island with sufficient water depth where FOWTs can be assembled and sufficient storage space where turbine substructures and other parts can be stored before assembly. The scenarios modelled in this study have an assumed quayside space for 3 FOWT units.

The Shannon Estuary's strategic location with an expansive estuary on the west coast of Ireland, means that the port has access to sheltered facilities inside the estuary with good water depth and port services. The estuarial port provides shelter once inside the entrance at Kilcredaun Head with deep water of 20m, availability for wet storage and proximity to west coast wind resources. Like all expansive estuary ports, with narrowing port entrance navigation channels, issues arise following adverse weather conditions as it meets ebb or flood tides. An example of this occurs at Kilcredaun Head where the river Shannon flows into the Atlantic Ocean. Occurrences of adverse conditions due to a combination of wave and tide and their effect on available weather windows for towing have not been considered in the simulations.

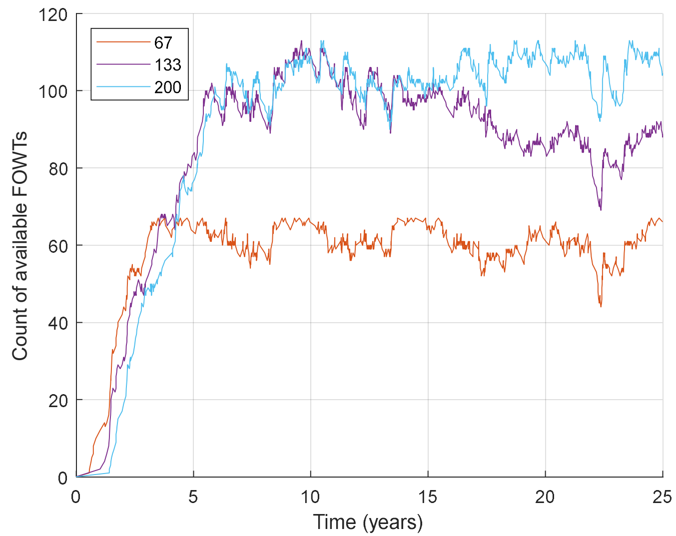


Figure 5: Installation timeline and availability for 1, 2 and 3GW FOW deployment using the Shannon Estuary

Figure 5 illustrates the simulated installation timeline for 1, 2 and 3GW floating offshore windfarm deployment with favourable constraints i.e. 2 install fleets always available, large wet storage simulated and night towing allowed etc. There are significant challenges for installation and maintaining high availability particularly as the number of installed turbines increases. The plot shows that all three farms suffer from a loss of availability when FOWTs are taken back to port, but more importantly, shows that the port is incapable of installing and maintaining a 2 or 3GW farms as the full installation is not met. This strongly evidences the need for a significant increase in port capacity and the need for multiple ports to be developed.

The main conclusions regarding the feasibility of FOWT farm installation and maintenance from the Shannon Estuary based on the modelling performed, with the assumptions described above, are:

- The installation rate is improved more by increasing installation fleet availability than by increasing wet storage capacity. Fleet availability can be increased in two ways, by adding more fleets and by having the fleets available all year round instead of only in the summer months.
- A wet storage area with the capacity to hold ~15 fully assembled FOWTs appears to be sufficient for an install rate of 300-400 MW per year combined with some in-port maintenance activities.
- Assuming tow to port for preventative and corrective maintenance on components, the port shows an ability to repair around 16-17 FOWTs yearly at maximum port capacity. In this report, wet storage of assembled bases that may be towed/transported to other ports for turbine/blade integration was not modelled and should be taken into account in future work. However, this number cannot be seen separate from the current assumptions in the model:
    - Scheduled, preventative maintenance is performed on each FOWT once every 5 years with a 7-day maintenance time in port.
    - Unscheduled, corrective maintenance is performed when large failures occur. A failure rate of 1 out of every 9 FOWTs per year is assumed with a 20-day repair time in port.
    - While the quayside has the capacity to accommodate 3 FOWTs, only a single device can be worked on at any time.

  The result suggests that the configuration for Shannon Estuary port as modelled, will have the capacity to simultaneously deploy approximately 300 to 400 MW per annum and operate as a repair facility for a 1.5 GW wind farm (100 x 15 MW FOWTs). However, advances in the FOW sector, such as offshore maintenance, will likely reduce these constraints in the future. Similar to Bantry, this location could have facilities with double the quayside space (6 FOWTs). Clearly, as Ireland moves towards its target of 30GW, ports like the Shannon Estuary will need to operate at a higher capacity, handling more FOWT units per year, but this is beyond the scope of this current project.
- Installation of a 1GW farm (67 FOWTs) can be achieved in 2.5 - 3 years. Increasing the quayside assembly rate can potentially shorten this but this will most likely also require greater availability of installation vessels.
- Contrary to the situation in Cork Harbour, the wet storage in the Shannon Estuary does not empty completely over summer in most years. This indicates that the installation process from wet storage to wind farm site cannot be completed fast enough, introducing additional installation delay. The key difference here is the more severe metocean conditions of the West Coast limiting the weather windows in which operations can take place.

With the average dimension of the floating bases of 100m x 100m and +12m draft plus UKC (under keel clearance), there is the potential of a clash between towing a FOWT outward from Foynes new development, most likely during daylight hours, and commercial shipping where there will inevitably be a requirement for prioritisation. The Shannon Estuary is a busy commercial port with many sectors requiring high water considerations including Aughinish Alumina, bulk cargoes of animal feed, other cargoes into Foynes and Limerick, and fuel for Shannon Airport. Depending on the development at Moneypoint and its strategic stand-by requirements and oil/fuel imports this will also add to congestion. This issue will be relevant to all commercial ports. As part of its "Vision 2041", should it realise its ambition as a trans-shipment port for the container sector and other products such as bunkering and hydrogen/ammonia, then "prioritisation" and inevitable clashes will occur.

Killybegs

Killybegs received less attention than the other Ports in this study which is mainly due to its significant distance from the current proposed FOW farm sites. Killybegs offers huge potential to have a significant role in this industry, serving projects off the North West of Ireland from Mayo to Donegal and around the Northern Irish coast as far as Belfast. As part of the growing trend of ports considering developments in the FOW sector, due to its natural depth of water it can play a role in the potential deployment of FOW off its coastline, in the North West region. The Bay is exposed to the prevailing SW winds and Atlantic storms, and has a rapidly shoaling coastline with inevitable reflection off the cliffs. It may be difficult to maintain multiple FOWT units in wet storage in the bay over the expected 4-5 winter months while awaiting a weather window of deployment. The wet storage area selected for this specific location is an initial observation and requires a more detailed assessment to confirm its suitability.

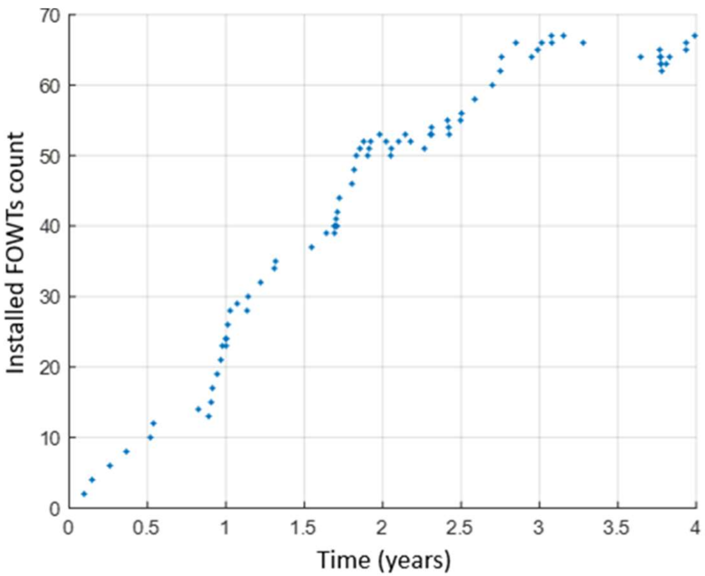


Figure 6: Installation timeline for 1GW FOW using Killybegs harbour

With the average dimension of the floating bases of 100m x 100m and +12m draft plus UKC (under keel clearance), there is a potential clash between towing a FOW outward from Killybegs South Quay area, most likely during daylight hours, and the extensive fishing fleet and commercial shipping. There will inevitably be a requirement for prioritisation as other unscheduled vessel arrivals and departures, and certainly should the port require unopposed traffic during the movement of a FOW turbine, would lead to serious commercial pressures from the fishing industry. This issue will be relevant to all commercial ports.

Figure 6 illustrates the simulated installation timeline for a 1GW FOW farm with favourable constraints i.e. 2 install fleets always available, the largest wet storage simulated and night towing allowed etc. Note that a larger number of turbines were not assessed for the Killybegs site.

The main conclusions regarding the feasibility of FOWT farm installation and maintenance from Killybegs based on the modelling performed are:

- Following substantial investment in port infrastructure, there is enough storage space for all components of 3 FOWTs to be worked on / stored along the quayside at one time. Depth at the quayside is sufficient for the assembly of FOWTs.

- Due to the severe environmental conditions outside the port, it is essential to have 2 installation vessel fleets, which are available all year round, to achieve installation of a 1GW farm in under 3 years.

- There is only a relatively small benefit in having a wet storage capacity greater than 5. The reason for this is that the weather windows for installation are by far the biggest bottleneck for this port. These weather windows are limited throughout the year, and it is therefore rare that the wet storage is completely emptied, even with a relatively small capacity of 5 units.

- Due to its location, the port can play a part in the assembly, installation and maintenance of floating units for farms in the northwest region. Towage of assembled units from ports further south would be very much Atlantic weather dependent even over the summer months.

Foreign ports

In order to assess if the installation (and potentially maintenance) of FOWT farms in Irish waters from foreign ports is viable, a study was performed that used similar port configurations as used for the Irish ports in terms of rate of assembly, quayside and wet storage capacity, etc. The main difference is in the distance from the port to the farm. This was varied from 100 - 600 km (55 to 325 NM), which means farms in the Celtic Sea could be reached from ports in northern France and the UK from Liverpool to Bournemouth. Equally, this study can be used to look at the viability of servicing FOW farms in the Celtic Sea from Irish ports at the same distances.

The main conclusions regarding the feasibility of FOWT farm installation and maintenance from foreign ports based on modelling performed with the assumptions outlined are.

- Installation only from ports up to 300 km away could be viable, in terms of time to install, when vessels are available all year and from ports up to 200 km when vessels are only available in summer (Figure 7 highlighting 200km contour for proposed Inis Elga FOW farm). It should be noted that other ports (and vessels), foreign or domestic, are required to perform the maintenance and repair activities.

- Including maintenance and repair significantly increases installation time. For the ports 100 and 200 km from the farm, installation takes between 0.75 - 1 year longer when repairs must be performed, at the same port, on FOWTs that were already installed while installation is ongoing.
- When maintenance and repair are included, ports further away than 200km are no longer viable options under the restrictions used. Overall, it is likely that Milford Haven is the only foreign port from where large-scale installations in Irish waters can be performed within reasonable timescales, e.g. 1GW within 3 years. However, if suitable infrastructure is developed there before it is in any Irish port, it could be an attractive port to service the entire Celtic Sea

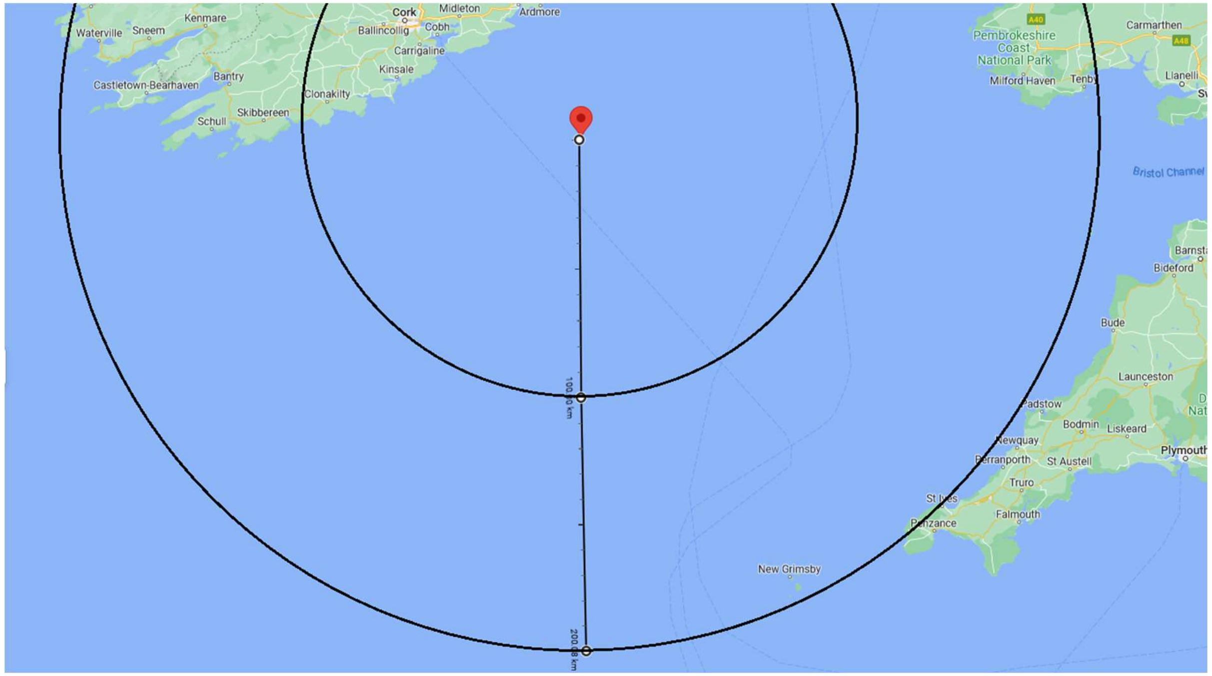


Figure 7: Approximate site location for Inis Ealga FOW farm with 100 and 200km distance indicated

Summary of Results

The key findings of this study can be summarised as follows:

- **SIMREI methodology.** An operations and maintenance tool was used to simulate the installation, operations and maintenance of Floating Offshore Wind (FOW) farms in Ireland in order to determine the requirements of the sector in terms of port infrastructure, vessels and wet storage capacity. This methodology has allowed the most accurate quantification of these requirements and has identified constraints and bottlenecks such as water depth and tidal restrictions, weather windows and marine traffic, which must be considered in the context of Ireland's ambition to deploy 30GW of FOW by 2050.

- **Current infrastructure for FOW.** Floating Offshore Wind is a key factor in the race for green energy for power generation in Ireland and the current Irish port infrastructure is incapable of delivering the rollout of FOW and unless urgent action is taken Ireland will fail to capitalise on this new FOW opportunity. This study has highlighted the scale of the task and the constraints that exist.

- **Suitable FOW Port Locations in Ireland.** The significantly large size of FOWT units means that only a small number of ports are suitable to handle them. The most restrictive factors are water depths, channel width, space (onshore & quayside) and wet storage capacity. The presence of significant marine traffic in these ports, some of which will compete for high tides, is also an issue in some cases. This assessment concluded that Ireland has three ports, The Shannon Estuary, Bantry Bay and Cork Harbour that initially could be capable of supporting the rollout of FOW. The Shannon Estuary and Bantry Bay would be capable of installing FOWTs with current typical semi-sub drafts, however, Cork Harbour currently has significant water depth restrictions. In any case, considerable development and investment is required, with consideration of physical and commercial constraints. The fourth port of Killybegs, with the correct development strategy, could also be suitable.

- **Wet Storage is a critical component** in the supply chain due to winter weather conditions off our coasts. With year-round manufacture and assembly in the port, developers will be required to store assembled FOWTs in wet storage areas until a sufficient weather window is forecast to enable the units to be towed to their final position in the offshore farm. Units coming back to the port for repair may also spend time in the wet storage area. While this study did identify locations which could be used for wet storage of FOWT units in close proximity to each of the four ports, it is worth noting that a much more detailed assessment, including metocean conditions, ground conditions, consenting restrictions etc. is required to confirm their suitability. This is particularly relevant to wet storage sites selected for Cork Harbour and Killybegs which are relatively exposed locations. The sheltered inlets of The Shannon Estuary and Bantry Bay have space for considerable numbers of FOWTs.

- **Large-scale port development plans** are required to increase quay lengths, port laydown area for storing, assembling and deployment, wet storage areas and facilities for O&M. Significant capability and capacity are needed in the ports and supply chain to facilitate FOW. The deployment and operation of 30GW of FOW (2000 x 15MW units) represents a significant challenge requiring substantial development of multiple ports to service this industry. Installing 2000 FOWTs in 20 years (2030 to 2050) is 100 per year or 2 per week. This could be achieved using 3 ports with an assembly rate of 1 every 10 days or 2 ports with an assembly rate of 1 every 7 days.

- **Farm capacity installation rates.** To meet the installation rates to deploy a 1GW FOW farm in under 3 years is a significant challenge. This is of particular concern when reviewing longstop dates and requirements for support schemes. If Ireland is to implement similar longstop requirements as the UK imposes on their schemes it will be very difficult to achieve the required install rates. Significant investment into and coordination of ports and infrastructure will be required to meet the Irish government's targets.

- **Vessels requirements.** In this study, the simulations included 3 harbour tugs for in-port operations and 2 fleets of vessels for installation and deployment. This was found to be the minimum requirement to achieve installation rates of under 3 years for a 1GW FOW farm. The final number of vessels in port will be at the discretion of the harbour authorities.

- **Weather restrictions mean more vessels are required.** Ireland has a powerful offshore wind resource, but the offshore environmental conditions make marine operations challenging, which has a significant impact on the installation, operation and maintenance of FOW farms. Weather windows are rarer on the Atlantic west coast as opposed to the Celtic Sea off the south coast. However, both environments are challenging, and it has been shown that employing multiple vessel fleets for offshore operations is required to make use of the available weather windows, in order to reduce the time to install the farm and increase the availability by reducing downtime.

- **Tow to Port for Maintenance** is onerous in terms of the space and time required for FOWTs to be in the port. Proposed solutions for facilitating offshore maintenance would alleviate this bottleneck but with Ireland's relatively extreme offshore climate, it may be prudent to consider developing solutions to allow maintenance of FOWTs in relatively sheltered and large-capacity wet storage locations. However, this high level of activity may also be seen as a significant long-term business case for Irish Port and vessel operators.

- **Marine operations limits** can have a significant effect on farm availability and installability, the weather access permits for towing and hook-up are key risk areas. The impact of significant wave height limitations on sensitive installation activities can delay the time to fully install the farm by several years and dramatically reduce farm availability.

- **Other marine traffic.** Unopposed traffic during the towage movement of a FOWT is a challenge faced by already busy ports and will lead to commercial pressures from different sides. This issue will be relevant to all commercial ports.

- **Quayside congestion**. During the operational phase, bottlenecks occur in the port assembly area. This is particularly challenging when installation and O&M overlap. Three ports (Cork Harbour, Bantry Bay, & The Shannon Estuary) in future developed scenarios were analysed with an operational/maintenance phase and were shown to have the capacity to simultaneously deploy approximately 300 to 400 MW per annum (based on an assembly rate of 500MW per annum) and operate as a repair facility for a 1.5 GW wind farm (100 x 15 MW FOWTs). However, recent advances in the FOW sector, such as offshore maintenance, will likely reduce constraints in the future, thereby reducing bottlenecks in the port assembly area.

- **Coordinated Ports.** It is most likely that the ports will need to coordinate their work, with large ports handling the FOWTs and large components (assembly, servicing, etc.), and smaller ports focusing on ancillary services such as moorings, cable laying, inspection, and crew transfer.
- **Foreign Competition.** This study has shown that foreign ports could service the FOW industry in Ireland, most notably Milford Haven which has ambitions to redevelop as a hub for FOW and is ideally placed to operate as a base for FOW farms in Irish waters in the Celtic Sea. Therefore, the significant opportunity that the FOW industry represents to the Irish economy will be lost to foreign ports if inward investment is not made.

Recommended Future Work

Work within the SIMREI project and stakeholder engagement have identified the following areas of future work:

- **The industry and FOWTs are changing**, for example, Ireland is now targeting 30GW of FOW, a 16MW turbine has been installed in China, shallower draft FOWT units of ~9m are being proposed, and offshore maintenance solutions are being investigated. Discussions of cooperation between the ports are ongoing and could see ports such as Shannon-Foynes handling all the manufacturing/integration tasks for the west coast and final integration/assembly taking place in Bantry Bay for the south coast. These developments change the inputs and thus the results of this study and it would be very prudent to continually update and rerun the models in order to ensure an optimal holistic solution to delivering and maintaining 30GW of FOW in Irish water is developed.
- **Modelling 30GW of FOW in Ireland**. As Ireland's targets have increased it would be prudent to develop a model capable of simulating the deployment and operation of 30GW (~2000 x 15MW FOWTs) and use this to identify key bottlenecks and vessel requirements. This could include multi-farm and multi-port models.
- **The availability of suitable vessels** is a well-known and significant challenge. Identifying the needs of the industry early in order to ensure the availability of such vessels when required could significantly de-risk the sector.
- **Secondary ports and smaller vessels** will handle a large amount of work in terms of cable laying, mooring installation, smaller maintenance tasks, inspection, crew transfer etc. Modelling these aspects would create a fuller picture of the requirements (ports/harbours, vessels, workforce) of the industry in Ireland and create business cases for investment and development.
- Determine the **suitability and capacity of wet storage areas** in proximity to Irish ports. This assessment must include a detailed description of the requirements for wet storage of FOWT and the collection of assessment criteria. The study must also include a detailed assessment of metocean conditions, ground conditions in relation to anchoring, consenting issues and any other constraints.
- Use models to **assess the benefits of maintenance in offshore or wet storage locations**.
- **Financial and cost-benefit modelling** would bring understanding to the financial impact and requirements for FOW development and the required infrastructure.

Contact Details

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