PivotBuoy

PivotBuoy

An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind

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D4.6: Recommendations for the installation and operation of floating systems

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including Commission Services)	
CO	Confidential, only for members of the consortium (including Commission Services)	

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Document History

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ACRONYMS

AHT	Anchor Handling Tug
BP	Bollard Pull
DAQ	Data acquisition
EU	European Union
GBS	Gravity base system
KPI	Key performance index
PAT	Portside Acceptance Test
PLOCAN	Oceanic Platform of the Canary Islands
SAT	Site Acceptance Tests
SCADA	Supervisory Control and Data Acquisition
SPM	Single Point Mooring
T&I	Transport & Installation
TLP	Tension-leg Platform
WP	Work package
WTG	Wind turbine generator

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EXECUTIVE SUMMARY

The *PivotBuoy Project: An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind* (referred to as PivotBuoy project) is a project that has developed a prototype, which includes the PivotBuoy system, to reduce the levelized cost of energy (LCOE) of floating wind. The PivotBuoy is an innovative subsystem that aims to reduce the costs of mooring systems and floating platforms, allow faster and cheaper installation and a more reliable and sustainable operation. The system was installed at PLOCAN test site to validate this concept, integrating a prototype of the mooring system in a downwind floating platform developed by X1 Wind.

Deliverable *"D4.6. Recommendations for the installation and operation of floating systems"* is divided into two four sections: (i) introduction to the system and the site, (ii) summary of the results for Work Package 4: *WP4. Installation, testing & monitoring in relevant environment,* (iii) learning providing best practices for the development of future floating wind farms, and (iv) conclusions.

The first section is written to provide a grounding in the PivotBuoy system and its subcomponents. It includes a general description of the system as well as PLOCAN site testing area.

The following section includes a summary of the work performed in work package (WP4), covering the installation, testing and monitoring in relevant environment of the floating wind platform (named 'X30') developed in this project. It is worth clarifying that the PivotBuoy® refers to the patented single point mooring (SPM) technology, which is integrated in X1 Wind's floating platforms.

Then, several best practices for operating, testing and monitoring similar systems are shared with the gathered lessons learned during the different stages that follows the manufacturing: installation of each subsystem (gravity base system, umbilical cable, floater), commissioning, environmental monitoring and operation & maintenance.

Finally, there are some conclusions on the work developed within this work package during the project.

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1 INTRODUCTION

1.1 Document Objective and Outline

This document marks the final deliverable of the 4th work package (WP4) of the PivotBuoy project. Its focus lays on translating the lessons learned in previous deliverables to a general recommendations providing best practices for the development of future floating wind farms.

The current section (Section 1) summarizes the report objective and provides a general description of the PivotBuoy® technology, including its description and the current location of the installed prototype. Hereafter, a summary of the previous work done in WP4 is provided, along with the results and outcome of the installation and operation stage (Section 2). Finally, the main learnings are summarized and discussed in Section 3.

It must be noted that presently there is no commercial scale wind farm development using the PivotBuoy® technology, although an EU-funded project to build a full-scale 6MW pilot using PivotBuoy technology has been recently launched (NextFloat Project). As such, conclusions are based on generic assumptions and might differ per project site due to varying project-specific factors such as environmental conditions, available infrastructure, and local content requirements.

1.2 General description of the PivotBuoy system

The PivotBuoy system is a novel floating wind concept that combines the advantages of Single Point Mooring (SPM) systems (easy installation) with those of TLP platforms (weight reduction and enhanced stability) in order to enable weight reduction compared to current established systems. The light structure allows for relatively simple assembly and installation with local infrastructure. The SPM system is integrated with a downwind wind turbine generator (WTG) that allows the platform to passively weathervane and self-orientate. The conventional turbine tower is redesigned, replacing the traditional tower with a pyramid-like structure resulting in more efficient load transmission and increased flexibility in avoiding resonance in the blade passing frequency range.

Figure 1 shows the “X30 platform”, a prototype project with a Vestas V29 turbine with a power rating of 225 kW, at quayside in the port of Las Palmas, Gran Canaria (Spain). The prototype was launched at the Hidramar shipyard and was towed and connected to the test site of the Oceanic Platform of the Canary Islands (PLOCAN) in 2022. Once installed offshore, the performance of the prototype was monitored over several months period to gather data for further design of larger scale units that will be implemented for commercial offshore wind developments.

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Figure 1. X30 Platform prototype in Las Palmas Port

Figure 2 shows a visualization of the model of the PivotBuoy system. The concept is based on a "design for manufacturing" philosophy, resulting in a highly modular design, aimed at reducing the overall costs and increasing fabrication flexibility. A more in-depth assessment of the different components is given in deliverable D2.3 (confidential) [1].

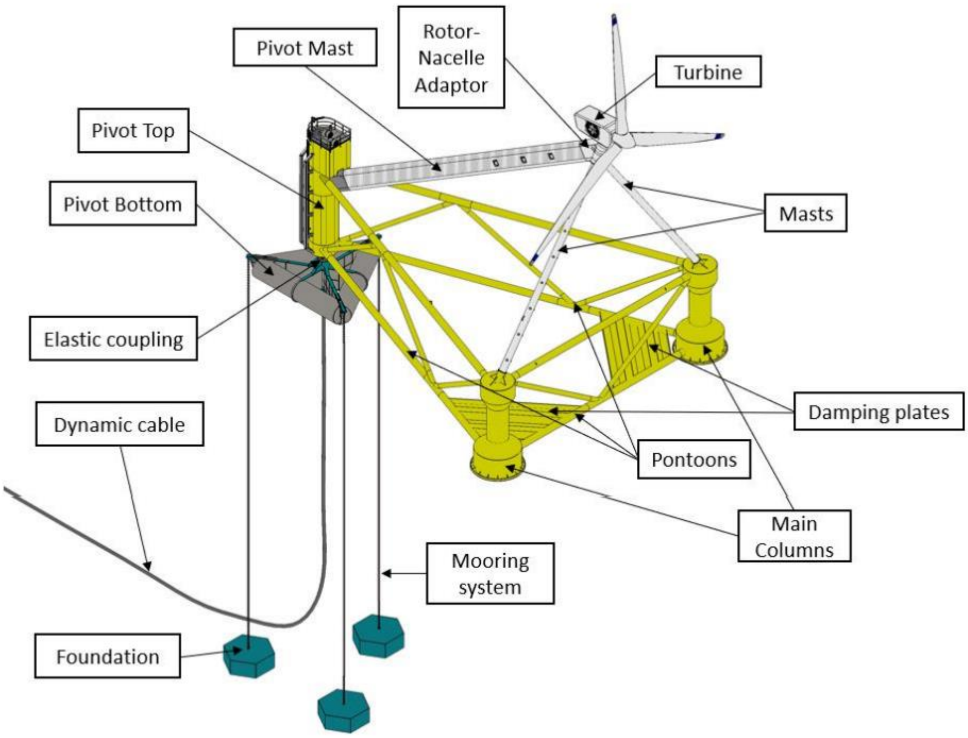

Figure 2. PivotBuoy part-scale X30 design

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The lower body (Pivot Bottom) is an excess buoyancy body moored to a gravity-based anchor through a tensioned three-leg system, where the umbilical cable is also connected. The upper body (Pivot Top) is the connection point of the weather-vaning part of which the remaining structure is assembled at shore and towed to the installation point for connection to the geostationary lower body.

To become commercially competitive, the prototype is scaled up to higher power ratings. A reference design for a **full-scale** 15 MW turbine configuration is made based on the X140 platform mentioned in the D2.5 report [2] and further scaling calculations. The (approximate) dimensions of the prototype and full-scale X140 platform are listed in Table 1. Note that the X140 platform is expected to undergo several additional design cycles, hence the final dimensions are subject to change. As the recommendations of this report are based on the magnitude of size rather than exact dimensions, these changes will not impact on the overall conclusions in this document.

Table 1. General dimensions of the X30 and X140 platforms

	X30	X140
Power Rating	225 kW	15 MW
Hub height	25 m	138 m
Length	34 m	<100 m
Width	25 m	<100 m

To give a comprehensive description of the PivotBuoy system, a simplified installation sequence is presented in Figure 3. Firstly, the foundation is installed on the seabed. Hereafter, the tendons and Pivot Bottom are installed. Finally, the floater is connected to the Pivot Bottom via a quick connect system, which makes the installation a relatively time-efficient operation.

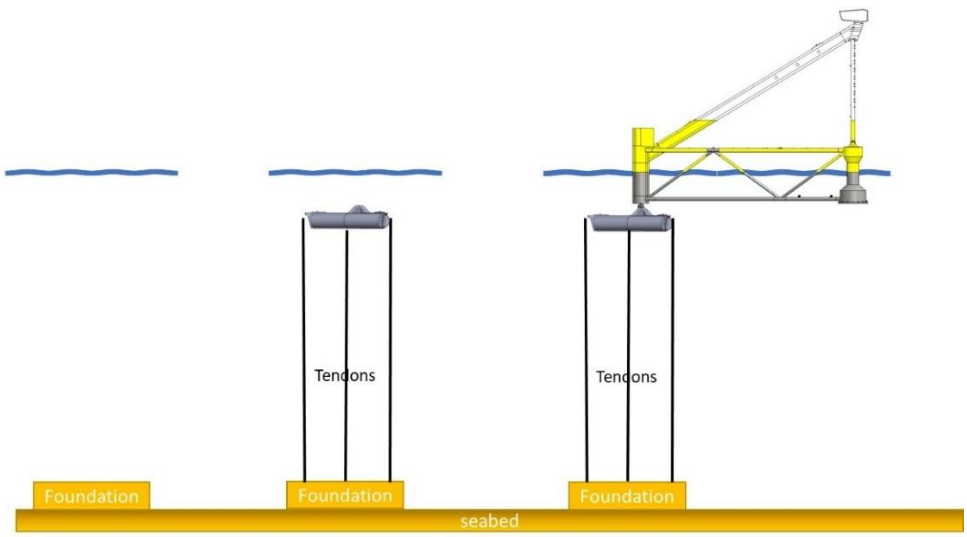

Figure 3. Installation sequence: 1) Foundation, 2) Tendons & Pivot Base, 3) Floater

The floater and the TLP system can be considered as two separate systems, which makes it possible to install all TLP systems prior to the tow-out and connection of the floaters. For both operations the most cost-effective vessel can be selected, reducing installation costs and required time offshore. Once a Pivot Bottom/foundation system is installed at site, the floater is brought into position, ballasted and

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connected to the foundation. Note that this installation sequence differs from the prototype installation, where the Pivot Bottom was attached to the Pivot Top prior to tow out to the project site.

1.3 General description of PLOCAN site

The Oceanic Platform of the Canary Islands (PLOCAN) is a joint initiative between the Spanish and the Canary Islands governments, with the help of the European Regional Development Fund. It represents a multipurpose service centre with land-based and sea-based novel infrastructures to support research, technology development an innovation in the marine and maritime sector. Its mission is to promote long-term observation and sustainability of the ocean, providing a cost-effective combination of services, such as observatories, test site, base for underwater vehicles, training and innovation hub.

PLOCAN has extensive experience in the fields of Ocean and Wind Energy research and development activities. In particular, PLOCAN contributes with the hosting of equipment, devices and marine technologies, for testing, validation and demonstration activities and/or any other necessary experiments in its marine test site. The housing services imply rights and regulated conditions to use the facilities and its marine test area, as well as associated services such as transport, installation, maintenance, monitoring, decommissioning, permits, accommodation, and insurance among others. The facility and test site are located in the North-East coast of Gran Canaria Island, and the platform is integrated in the offshore test site.

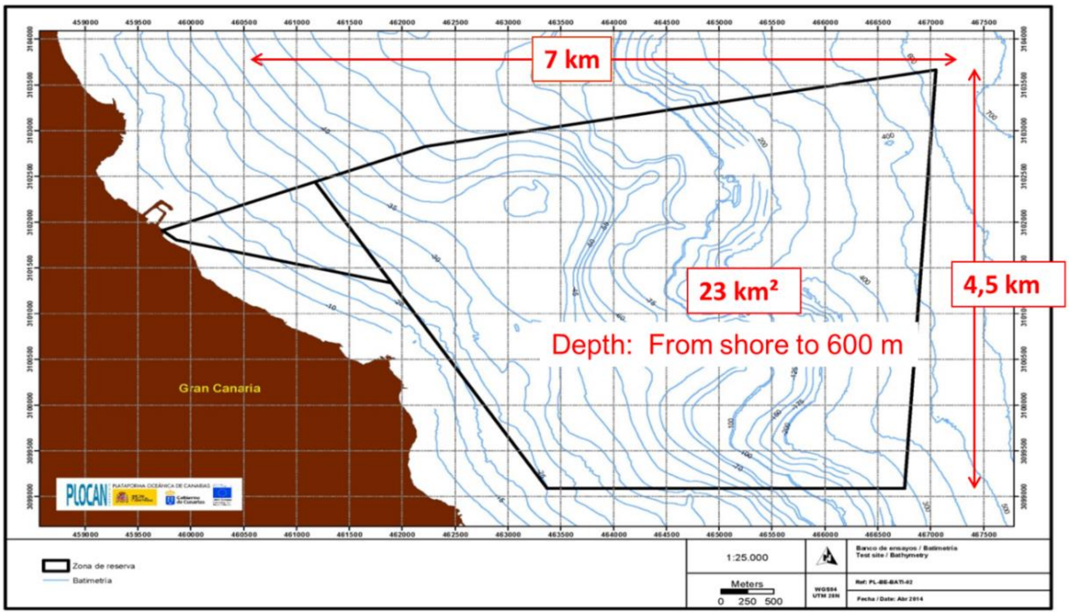

Figure 4. PLOCAN test site.

The test site encompasses the publicly owned area of sea and land off the north-east coast of Gran Canaria. It is an area of approximately 23 km^2, reaching maximum depths of 600 metres. It has its own electricity and communications infrastructure to feed power and data from the devices on trial at the test bed. The general objective of the test bed is to provide companies and research groups with a chance to demonstrate how the technologies they develop work before marketing them.

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After an exhaustive assessment taking into account the environmental conditions described in deliverable D.4.2 [3], the location of the selected deployment area is shown in Figure 5, and some of its specifications have been detailed in Table 2.

Table 2. Selected site specification details

	Selected site specifications
Coordinates	UTM X: 462359.65 / Y: 3102659.52
Depth	≈ 48 m
Slope	0 to 5º
Type of seabed / sediments	Fine sand
Distance to PLOCAN platform	≈ 850 m

The selected site is at around 48 m water depth, which is a depth providing an adequate behavior for the TLP mooring system, with a mild slope of 0 to 5° and fine sand which is adequate for a gravity base anchor. The distance to the PLOCAN platform, where the electric cable will be connected, is around 850 m straight.

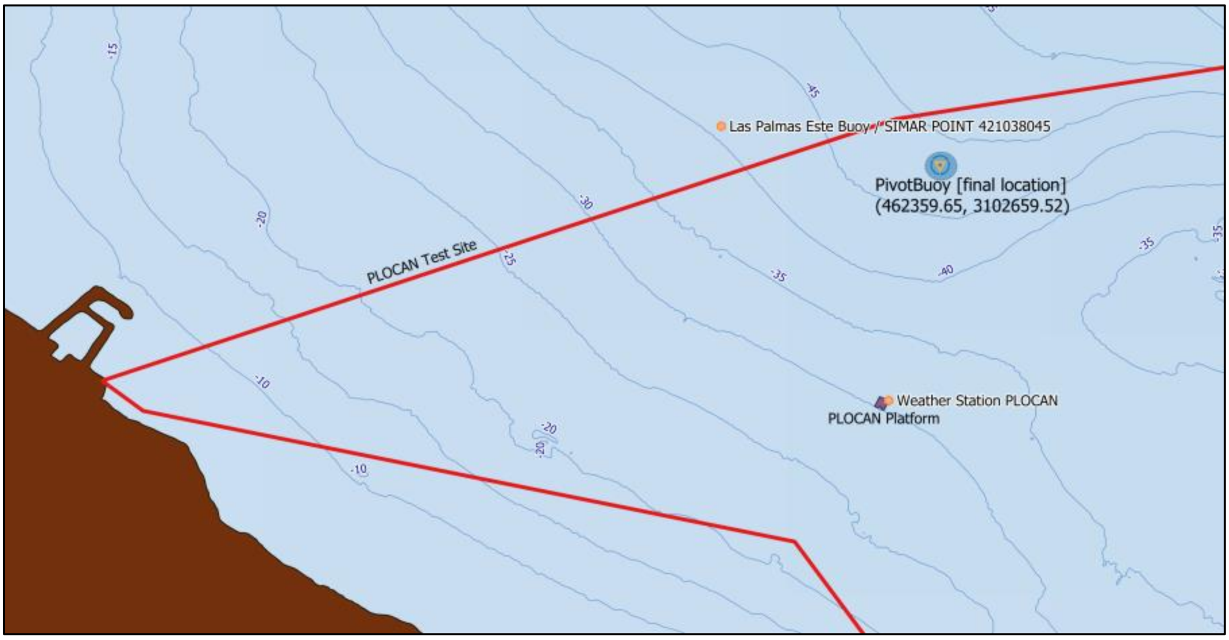

Figure 5. Selected site map, showing also bathymetry and platform location

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2 WORK PACKAGE 4 SUMMARY & RESULTS

2.1 Previous work done in WP4

Work Package 4 (WP4) covers the installation, testing and monitoring in relevant environment of the floating wind platform ('X30' – 225kW turbine) developed in this project. It is worth clarifying that the PivotBuoy® refers to the patented single point mooring (SPM) technology, which is integrated in X1 Wind's floating platforms.

In this work package, only two deliverables are publicly available: D4.1 and D4.6. Both can be found on the PivotBuoy® website (https://pivotbuoy.eu/documentation/). Although the work package is based on the 225 kW X30 pilot project, lessons learned can still serve as valuable input to the commercial wind farm development using full-scale floating units. The previous deliverables are summarized below:

D4.1 – Test site environmental conditions [4]

This deliverable presents the data to characterize the test site environmental conditions, including metocean data (waves, wind and currents) as well as bathymetry, seabed conditions and other relevant information for the design of the system.

D4.2 – Installation plan (confidential) [3]

This deliverable presents an initial step-by-step planning of the installation process, including the different main three stages: the deployment of the anchor and mooring system, the umbilical cable lay and finally the towing and connection of the platform.

D4.3 – Site test plan (confidential) [5]

This deliverable presents an initial testing plan to be carried out during the installation, commissioning and operation of the platform once it is at PLOCAN test site.

D4.4 – System installed & commissioned (confidential) [6]

This deliverable summarizes the installation and commissioning of the PivotBuoy system (and 'X30' platform) and other subsystems at PLOCAN test site. The report includes an explanation of the followed steps and pictures taken during the subsequent operations as well as a final section including the lessons learned for next potential installations.

D4.5 – System testing and monitoring results (confidential) [7]

This deliverable assembles the generated data (performance, reliability and environmental) obtained with instrumentation as well as other devices installed on both the prototype and PLOCAN test site area. The report includes a summary of the steps followed and pictures taken during the testing and monitoring stage. Thus, different tests and periodic on-site visits were carried out to validate assumptions, validate the technology and cover a diverse range of O&M activities. By the end of the report there is a final section including the lessons learned for operating, testing and monitoring similar systems in the future.

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2.2 Outcome

The main outcome of this work package is having the full system installed and tested at PLOCAN test site. Deliverables D4.1, D4.2 and D4.3 are prior to the installation, and all are planning and preparation for the different stages; they also contributed as inputs during the design and manufacturing phases, so the installation strategy could be considered during those prior stages. Thus, the result of the work package is explained step-by-step in the last two deliverables: D4.4 and D4.5. In the following two subchapters a summary of those deliverables is provided.

2.2.1 System installed and commissioned

The installation procedure was divided into four stages, depending on the systems to be installed. Afterwards, the commissioning and site acceptance tests (SAT) were performed. In this way, it can be differentiated between the following, chronologically arranged:

PLOCAN subsystems. Before proceeding with the different systems installation, PLOCAN had to set up their platform and facilities so that the prototype could be connected to it, both electrically and mechanically.

Gravity-based anchor installation. The 3 concrete blocks were first installed in PLOCAN area before laying the umbilical cable.

Umbilical cable installation. Only after PLOCAN prepared its platform for receiving the cable and also once the concrete blocks were installed, the umbilical cable could be laid.

Platform towing & Hook-up. The PivotBuoy platform (also known as X30) could be towed to PLOCAN site area, hooked-up to the gravity-based anchor and connected to the umbilical cable.

Commissioning & SAT. They were performed to ensure that the systems were working as intended and to validate the platform in operational offshore conditions.

2.2.1.1 PLOCAN subsystems

Before proceeding with the different systems installation, PLOCAN had to set up their platform and facilities so that the prototype could be connected to it, both electrically and mechanically.

Thus, in order to install the power cable (medium voltage umbilical cable), several holes were made on the platform concrete structure to route the cable through to the connection point. Also, a set of anti-friction rollers were installed underwater in several places on the platform to facilitate the cable installation, avoiding the friction of the cable with the concrete structure, protecting the cable from overbending, etc.

Furthermore, PLOCAN developed a smart grid control system and upgraded its electrical facilities to be able to manage the power input from the different devices connected to the marine platform. This system creates a stable electric grid for several prototypes to connect to it.

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2.2.1.2 Anchor installation

First the foundation, a gravity-based anchor which is formed by three concrete blocks, was installed in PLOCAN area, along with their auxiliary elements (tethers for connection, shackles, etc.) that connect them with the X30 platform once the prototype is in the final site, so it is firmly attached to the seabed.

Before being towed to PLOCAN test site, each block was laid and stored on the seabed in a selected available area at Las Palmas port. Then, VB BEVER tugboat, a 70-ton BP vessel that was available at that time at Las Palmas port, picked and towed one block per day till to PLOCAN site.

Also, TRAMES UNO was used as an auxiliary vessel for the placement of the blocks since the tugboat couldn't lay them with the needed accuracy. TRAMES UNO is a local workboat that can provide support during the operations to install the X30 platform, perform the cable lay or assist other vessels; its base port is Taliarte, the closest to PLOCAN.

Figure 6. BEVER – AHTS vessel (left). TRAMES UNO – workboat (right)

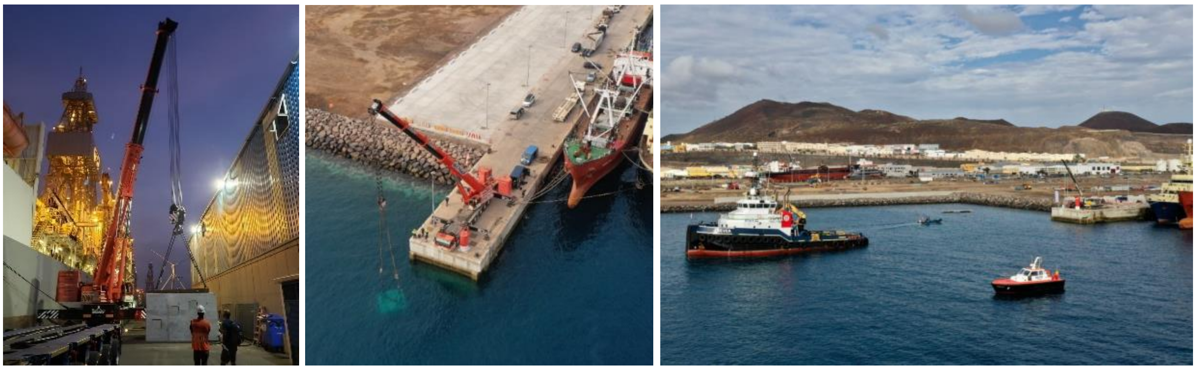

Figure 7. Gravity anchor installation

The operation took three consecutive days (one day per block) since each operation took the full journey daylight hours.

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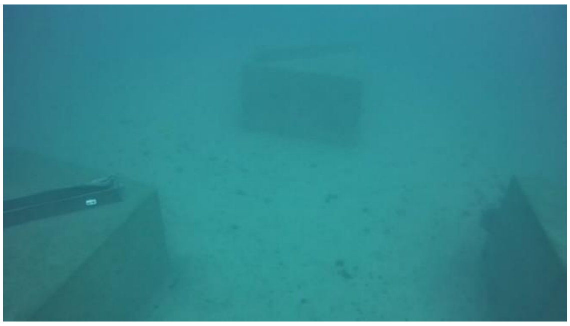

Figure 8. Three blocks positioned on the seabed at PLOCAN test site

2.2.1.3 Umbilical cable installation

Only after PLOCAN prepared its platform for receiving the cable and once the three concrete blocks were installed, the umbilical cable could be laid. The cable was initially spooled onto a reel, which was loaded on TRAMES DIEZ vessel. This workboat was similar to TRAMES UNO, which was previously used as an auxiliary vessel during the anchors installation and had a drum holder installed on its deck.

Several appurtenances, needed for the installation and correct operation, had to be assembled on the cable before its installation while the vessel was moored at Taliarte port. Thus, some components were installed on the vessel deck before its departure to PLOCAN site area for the cable installation. Others were prepared and left ready for being assembled on a cable section during the cable lay operation. Additionally, some pending appurtenances were fixed to the cable in the last meters of the cable lay operation.

The first stage of the cable installation, once it was at PLOCAN test site area, was to pull-up the end of the cable through PLOCAN offshore platform; from the seabed to PLOCAN's deck where it would be connected to the electrical devices already prepared there. The initial step was to introduce the cable end through the holes of the concrete wall. Once inside the concrete platform, the cable was hooked and lifted to the electrical equipment deck so it could be connected to its corresponding electrical cabinet. By the end of this operation, which took around 4 hours, the umbilical cable was ready and connected at PLOCAN side, so its lay could start on the other end of the cable.

Within the same day, the installation vessel proceeded with the cable lay, which consisted in slowly dropping the cable from the reel on the installation vessel, to the seabed. This operation was done at a very slow speed of the vessel while the cable was unrolled and released through the stern of the ship. The installation vessel had up to 3-4 anchors that were used to position the vessel by dropping and raising them along to the path imitating in this way the movement of the spider legs, so some were in front while others behind the vessel. For this operation an auxiliary vessel was responsible of the anchors' repositioning.

Although in a straight line there are 850 meters from PLOCAN to X30 platform, the cable had to follow a L-shape route to surround a restricted area PLOCAN had reserved for other project purposes, so the cable length had to be longer than the two connection points. Furthermore, the cable had to follow a big loop near X30 installation point, so that there would be enough length for the cable end to lift it up to the X30 platform once installed.

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The cable lay operation took around 9 hours, which along with the elements' installation in the last section of the cable on X30 floater side, submerging the cable and picking up the vessel mooring lines to returning to port, took the full day.

Figure 9. Cable installation

Finally, before proceeding with the X30 platform installation, during the following days after the cable laying, an inspection with a ROV was performed in all the cable path, starting at PLOCAN offshore platform and finishing at X30 side.

2.2.1.4 Platform towing & hook-up

Afterwards, the X30 floating platform was towed and hooked-up on the previous installed subsystems. The X30 platform installation was performed in two stages, each one being a 1-day operation.

On the initial day, two maneuvering vessels unmoored the platform from the quay and guided the platform through Las Palmas port until the structure was hooked to the two vessel that performed the towing operation. The main tugboat was the VB BALEAR and the auxiliary vessel the VB ALEGRANZA, the latter was connected to the platform through an auxiliary line tied from the stern of the platform to the vessel's bow. This vessel also served to transport the team from Las Palmas to PLOCAN while supervising the towing.

The tow-to-site took nearly 3 hours. In parallel to the above operations, that same morning TRAMES DIEZ vessel was pre-moored at the expected X30 floater position at PLOCAN, waiting for the floater's arrival. Once the floater was at the installation point, TRAMES DIEZ took the command of the operation; so the floater was connected to it, and the vessel set the X30 platform swung to its expected position while it was still connected to the main tug (VB BALEAR). Once in position, the two towing vessels (main & auxiliary) went back to Las Palmas port; so the X30 floater was only hooked by TRAMES DIEZ, which performed the rest of the operation, connecting the floater to the tendon of each of the three gravity base blocks previously installed.

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Figure 10. X30 platform being towed to PLOCAN

Figure 11. Hook-up

The second day the cable pull-up was performed. The end of the cable, which was laid during its installation, was hooked and approached to the lower part of the Pivot Bottom, where there was a hole to enter it throughout the yaw axis and up to the Pivot Top. Then, the cable was pulled up with a winch until the mechanical room and once there, the electrical wires of the cable were inserted in the slipring. Thus, X30 floater was ready for electrical connection and the second journey of the towing and hook-up operation finished.

Figure 12. Cable pull-up

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2.2.1.5 Commissioning

Afterwards, during the following weeks and months after the installation was finished, commissioning and site acceptance tests (SAT) were performed to ensure that the systems were working as intended and to validate the platform in operational offshore conditions. The most relevant results are those proving the weathervane of the system and the stability conditions of the platform. Most of these tests were performed remotely thanks to the wide variety of sensors installed in the platform, the SCADA and the Data Acquisition System (DAQ).

Figure 13. X30 floater installed and commissioned

2.2.2 System testing and monitoring results

Once each subsystem was installed and commissioned, the testing campaign at PLOCAN to validate the project key performance indicators (KPIs) started. Thus, performance, reliability and environmental data were obtained with both X30 platform instrumentation, instruments deployed by PLOCAN for onsite monitoring and periodic visits. This data is crucial for the validation of the simulation models for WP5, and it can be split into the following three groups: performance data, reliability and maintainability O&M data and environmental data.

Also, different tests covering a diverse range of O&M activities were carried out to validate assumptions regarding weather windows and expected periodic O&M activities.

2.2.2.1 Performance data

The performance of the X30 platform was very satisfactory. Several variables were analyzed to show the performance of the platform during operation. The aspects covered are weather-vaning, stability in adverse conditions, the climate in the nacelle and the control room, the deformation in the Pivot Mast, the radial and axial movements of the yaw shaft with the tide and the accelerations in the platform.

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Weather-vaning. Validating the platform as a weathervane system is one of the key aspects of the project. As can be seen from the graph below, the alignment with the wind of the platform has been great, especially at speeds. The graphs show a 2D histogram of the wind alignment and the wind speed over the 4 months the X30 has been in PLOCAN in PLOCAN. Most of the data is located under 10 m/s due to the weak winds in PLOCAN during winter.

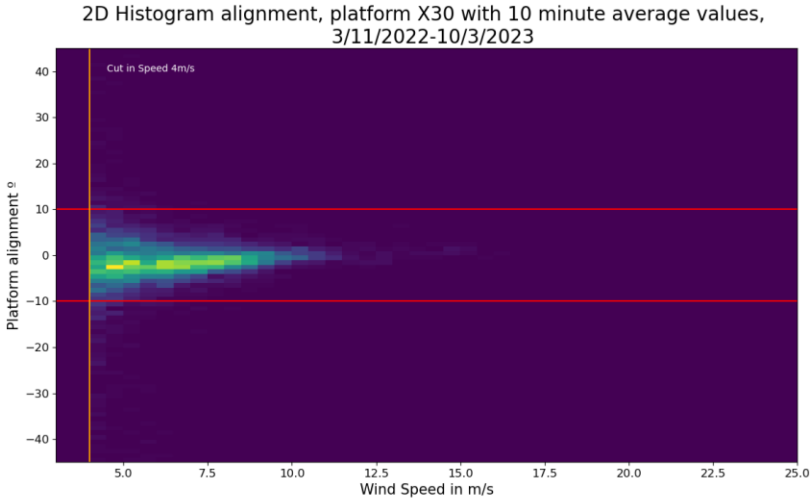

Figure 14. Histogram alignment, X30 platform 10-minute average values from 03/11/2022 to 10/03/2023

The data shows that the platform aligns very well with the wind, validating one of the key assumptions of the PivotBuoy design.

Stability. Another key aspect of the PivotBuoy is to validate the behavior of the platform during challenging meteocean conditions. The biggest extreme weather conditions were faced during a storm (December 27th, 2022) that had the following characteristics:

- Hs = 3,78 m
- Hmax = 6,72 m (equivalent to Hmax = 20,16 m for an equivalent 1:1 scale platform)
- Wind speed max. = 18 m/s

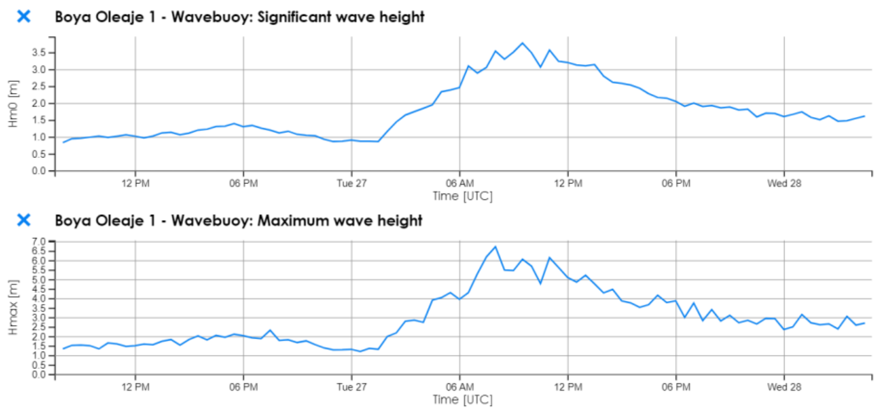

Figure 15. Weather conditions on December 27th, 2022

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During that day, X30 floating platform behaved well, as it can be seen in pitch and roll degree values shown in Figure 16. More information on the data for model and platform behavior validation can be found in WP5.

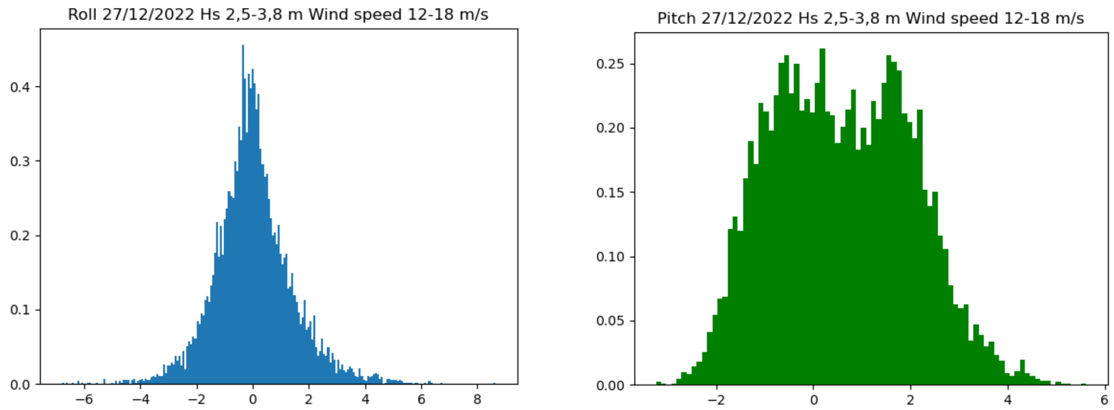

Figure 16. Pitch and roll during December 27th, 2022.

Figure 17. X30 floating platform during December 27th, 2022.

Power Production. Finally, once the Smart Grid at PLOCAN test site was ready, on March 3rd started the last phase of the testing plan which is the system validation with power production which will last until May (see video of the turbine commissioning). Initial results show very good power performance with excellent alignment with the wind (as in the previous tests without production), low accelerations and pitch angle during operation, and power output above the V29 power curve at equivalent wind speeds for existing onshore wind turbines. The data is being used to validate simulation models and will be integrated into the final report to EC due in May 2023.

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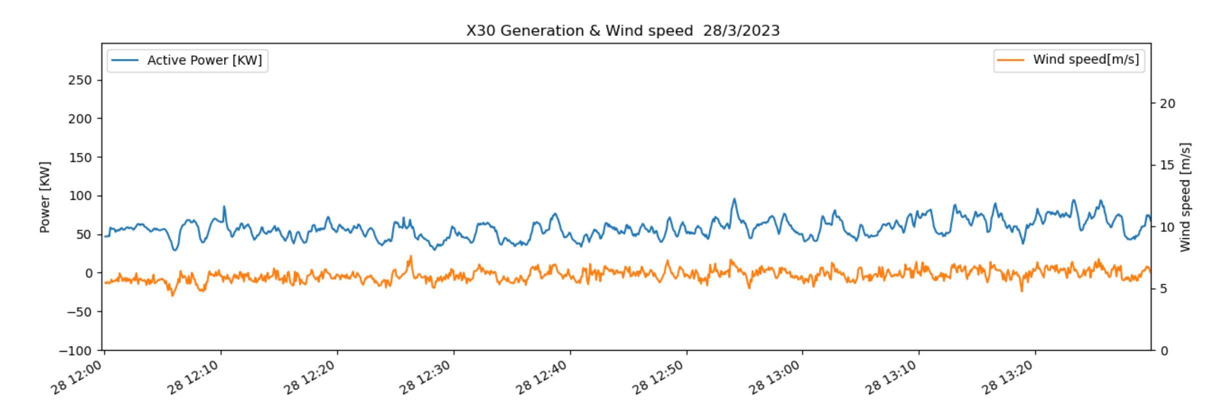

Figure 18. Power output reading X30 platform SCADA on March 28th for 6 m/s mean wind speed.

Climate nacelle. Keeping the environment inside the platform as dry as possible and in reasonable range of temperatures is key to keep the electric equipment in good conditions, minimize the need for corrective actions and undesired down times. Dehumidifiers were installed for that task.

Climate control room. The control room is another space with sensible electrical equipment. To protect them a dehumidifier has been installed. Additionally medium voltage equipment such as the switchgear and the transformer are significant heat sources. In the low voltage circuit, the converter, when active, is another significant source of heat. To prevent overheating a ventilation system has been installed.

Strain gauges. Pivot Mast deformation is measured by strain gauges. It can be seen that it increases in adverse meteocean conditions. Even so, through operation Pivot Mast deformation has been within the expected values.

Yaw movements. The axial shaft movements are within the tolerances. At low tide the shaft moves more than at high tide.

Accelerometers. There are four accelerometers installed on the platform: one in the Nacelle, one in the gearbox, one in the Pivot Mast and one in the control room. The data gathered with those accelerometers has been used to validate the model in Orcaflex as it would be explained in deliverable D5.5 and to monitor that the accelerations are within permissible values.

The performance of the turbine was also satisfactory. During the power delivery to PLOCAN the stability of the platform was not affected by the power production and both pitch and roll remained within the acceptable ranges as expected.

2.2.2.2 Reliability and maintainability data

To minimize the amount of access to the platform O&M and testing, tasks were classified by priority level. Also, the maintenance of the platform was divided between preventive and corrective O&M.

Preventive. Several O&M tasks were conducted during the operation of the X30 platform: tightening yaw bolts to ensure they had the required torque, the ballast system pumps were activated periodically to ensure that they would work when needed and a visual inspection with divers was conducted in all the submerged parts. The results were very satisfactory. No signs of wear were observed in any of the critical systems.

Corrective. Several corrective O&M operations took place after installation to solve different issues with sensors, computers and EHS equipment, as can be expected in a prototype deployment.

2.2.2.3 Environmental data

One environmental monitoring campaign was completed before the X30 prototype installation at PLOCAN's test site, and a second one is being carried out during the prototype operation phase. Each environmental monitoring is composed by the following activities:

- Hydrographic characterization (water quality assessment)
    - In situ
    - At laboratory
- Characterization of habitats and benthic communities
- Characterization submarine noise
- Characterization of birds, turtles and cetaceans

2.2.2.4 Tests

Different tests covering a diverse range of O&M activities were carried out to validate assumptions regarding weather windows and expected periodic O&M activities.

Access. Up to three different vessels were used and evaluated to access the X30 platform. The accesses performed allowed us to classify them into categories that range from very easy to very complicated. Given that experience some access conditions depending on the vessel used were defined.

Active ballast. For the 50-year storm survival the active ballast should compensate for the change in tide. An in-house control system has been developed and tested. Note that this tide compensation system is not necessary for full scale systems, it was only needed here due to the extreme tidal range considering the scale of the unit.

Marine environment survivability. Visual inspections of the equipment installed inside the control room show no significant corrosion due to the offshore environment. Also, two segments of the same small steel chain were installed, one outside and one inside the prototype. The one inside is still like new while the one outside is completely corroded by the offshore environment.

Pitch run up test with no load. A ramp up of the turbine was done to validate excitation modes in the Pivot Mast. A specific test was conducted to assess the effects of that phenomenon. The sensor located in the middle of the Pivot Mast was responsible for gathering the data.

Stability test. A stability test was done to validate the stability of the platform and its center of mass. The observed values were within the expected range and the centre of mass position was verified.

Yaw excursion. A digital gauge was intalled to validate yaw axial movements. The observed values were the expected ones.

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3 BEST PRACTICES & LESSONS LEARNED

Several lessons learned for operating, testing and monitoring similar systems in the future have been gathered during the described stages of the document.

3.1 Installation & commissioning

The lessons learned regarding the transport and installation (T&I) process of the X30 platform.

3.1.1 Gravity-based anchor installation

During the gravity-based anchor installation many lessons were learned. It was the first offshore operation for X1 Wind and thus we had the counseling of CoreMarine and Intecsea with far greater knowledge and experience.

The main learning was that a combination of Dyneema and steel lines can be tricky. Dyneema lines shall be carefully protected to ensure their integrity. Also, operations with more than one line require careful and precise execution to avoid lines tangling.

Other validated lessons were that having undersea ROVs was extremely helpful to understand and follow the operation. Positioning of an AHT with a system of preinstalled anchors in good sea conditions while monitoring the position with GPS can be very accurate.

From a logistical perspective, another lesson learned is that in the port passenger and freight transport have priority over special operations and therefore those maneuvers shall be executed if possible during low activity times and in close communication with the port control to avoid surprises.

3.1.2 Umbilical cable installation

The most important lesson learned from the cable installation was that offshore works shall be minimized as much as possible. All the precise outfitting of the cable shall be installed, when possible, onshore in a controlled environment. Customized offshore reels with several sections (partitions) allow that option. Cable laying is a standard operation. However extra attention must be given to the last touchdown point of the cable and the beginning of the lazy 'S' to ensure an easy pull in and pull up.

3.1.3 Floater towing & hook up

The towing, the hook up and the final electrical connection took 3 days as expected. The operation was preceded with exhaustive preparations and contingency measures were developed to prevent improvisation. Moreover, the lessons learned in the previous operation were very valuable and the team applied them in this one.

Hook up & towing

The most important lesson learned from the hook up and towing was that tide can be a friend but also an enemy, particularly for TLP systems. Tide limitations in general reduce the amount of weather windows and restrict operations, adding complexity. Other lessons learned were that length adjustment system in mooring system could help reduce operational risks and that sensors monitoring

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all key variables increase the visibility of the operation leading team, reducing risks and improving decision making during the operation. To have a contingency shall be studied to sustain no power moments in the floater.

Pull in and pull up

The day after the hook up was completed, the pull up and pull in took place. The most important lesson learned was that, if possible, bigger tolerances shall be considered to account for deformation in the cable and its outfitting's, marine growth and other unexpected events.

3.1.4 Commissioning

As with other operations, the main lessons learned is that onshore and port preparations shall be as thorough as possible to reduce offshore works because they are more complex and expensive and limited by the availability of weather windows. Remote control and access to all the equipment is an enormous advantage. Visual contact with the turbine also helps the commissioning team to perform the operation.

3.1.5 Best practices

During the T&I of the X30 platform, the team learned to apply the right procedures to ensure that the operations are conducted safe and executed as planned. Therefore, designs with detailed planning and contingency analysis shall be done. It's very important to involve marine contractors in the early phases to design operations that are safe and executable.

Before the operation starts, a briefing meeting shall be done to ensure that every stakeholder knows its responsibilities. Concerns shall be raised during the discussion and doubts clarified to guarantee that everybody is comfortable with the execution plan.

Communication channels shall be defined in advance to ensure that information flows according to plan. A responsibility matrix shall be defined as well as a decision matrix to clarify who will take the final decisions and avoid discussions during the operation.

During the operation every person involved shall be able to stop it whenever a danger is spotted. This ensures that operations are conducted in a safe manner.

3.2 Environmental monitoring

From the environmental monitoring campaigns carried out to date (March 2023), it can be concluded that the X30 prototype has not significantly impacted the existing conditions.

In any case, it is advisable to conduct a comprehensive environmental monitoring assessment during the three phases of the project: before the prototype installation, during its operation and after its decommissioning. Having a long-term time horizon for these monitoring activities would provide a wide range of data to assess the real impact on the environment.

As lessons learned from this monitoring campaign that can be extrapolated to other projects, it can be highlighted the importance of an accurate and realistic planning of the monitoring activities, providing sufficient time to gather relevant information in the main three phases (before the prototype installation, during its operation and after its decommissioning). Additionally, taking into account the weather windows to conduct the required activities at sea is also key when planning these activities.

From the submarine noise characterization, it can be concluded that the recorded frequencies are below the established limits, corresponding the highest values to the transit of vessels in the study area. Furthermore, it is important to highlight the relevance of making use of proven analysis software and experts able to identify submarine noise produced by the prototype itself and its mooring/anchoring system, and noise from external anchoring systems, equipment, etc.

3.3 Operation & maintenance

To monitor the protype an in-house SCADA and DAQ system have been developed. Through them the protype can remotely operate and the data retrieved allowing the team to have a full picture of the platform behavior at every moment.

All the systems including the turbine can be operated and rebooted remotely. However, for certain events the team needs to access the protype to carry out O&M operations or testing campaigns.

Careful planning and detailed problem visibility through remote control and monitoring increase the efficiency of O&M operations and the testing campaigns.

Several preventive and corrective O&M operations have been conducted in the X30. Offshore access to floating platforms is tricky and very limited due to adverse meteocean conditions. In order to find the right boat to do the operation, access with different boats were conducted.

So far, the X30 has been accessed with three boats:

1. Whally (from TRAMES) → It can be positioned with the bow against the boatlanding but is very small and nervous, it is very affected by any type of waves and gives a lot of feeling of instability.

Figure 19. Accessing to X30 with Whally vessel

2. PLOCAN 3 (from PLOCAN) → The transfer has to be done on the side because it has the anchor in the bow, which complicates the operation a lot.

Figure 20. PLOCAN 3 vessel

3. Kaiser (from REPROSUB) → It can be positioned in the right way and is not affected so much by the waves because it is larger.

Figure 21. Kaiser vessel

The Kaiser has been the safest and easier boat to access the prototype and therefore the one used since that conclusion was reached. It gives maneuverability due to its reduced size while being big enough to feel stable to do the transfers. It also provides a bigger capacity to carry technicians, equipment and tools.

With the right vessel and extensive personnel training, the meteocean conditions for access became less restrictive. Also, the PivotBuoy being a TLP mooring makes the operation easier.

3.4 Associated risks

During this final stage of the project, the following challenges were overcome. Given the size of the project and the location of the installation there was a lack of adequate vessels to execute the operations. On top of that, the local climate has two very distinct seasons, one reasonably good and another one really bad to conduct offshore operation due to adverse its meteocean conditions.

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3.4.1 Local vessels

Limited availability of local assets to execute offshore operations is an important risk that all the offshore projects face. In locations such as the North Sea the risk is mitigated by the range large quantities of offshore support vessels of every size. However in places such as the Canary Islands those vessels are scarce in the spot market and most of the times they just pass by to change crew, do minor repairs or prepare for campaigns in west Africa. Bringing offshore support vessels for specific short projects involves a significant mobilization and demobilization spending compared to the budget of the project and therefore is not a feasible option.

Therefore, the only option is to wait for the right opportunity and secure the affordable vessels despite their packed agendas, risking the project timeline while ensuring its affordability.

3.4.2 Weather windows

The climate in the PLOCAN region is benign. It has weather windows during most of the year. However, during summer months the probability of having the adequate weather windows required for the X30 platform installation and/or on-site O&M is very low, as presented in the table below.

	18 h | Hs 1,5 m			*18 h | Hs 1,2 m*			*24 h | Hs 1,5 m*			*24 h | Hs 1,2 m*		
	Average	P50	P90	Average	P50	P90	Average	P50	P90	Average	P50	P90
JUNE	26,7	26,4	19,6	16,6	16,3	8,1	19,2	19,2	13,4	12,2	12	5,3
JULY	18,2	19	10,2	8,4	7,1	1,2	12,8	12,2	7,4	5,3	3,6	1
AUGUST	22,7	20,5	16,8	11,6	10,1	6,4	16,1	14,2	11,8	7,5	7	2,8
SEPTEMBER	31	32,5	23,3	22,5	23	14,1	22,5	24	16,4	15,9	16,8	7,6

Figure 22. Summer probable weather windows required for on-site activities while X30 is at PLOCAN

Therefore, planning operations for summer increases the risk of suffering a significant delay.

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4 CONCLUSIONS

This deliverable summarizes all the work done in WP4 related to the installation, testing and monitoring of the protype. This Work Package has contributed to the success of the PivotBuoy® project by providing a detailed explanation and steps of the installation, commissioning and testing stages of the X30 platform unit, during its installation and all the operational stage. Furthermore, WP4 deliverables provide best practices and valuable input for the development of installation and operational tests plans for future full-scale floating wind farms.

The main content of this WP final report is divided into two sections: WP summary and results (1), and best practices for the development of similar future floating wind farms (2).

A summary of all the work performed in WP4 is done; covering the installation, testing and monitoring in relevant environment of the floating wind platform developed in this project. Up to six deliverables have been submitted, although only two are public. A brief explanation on the content of each report is shared. Also, further information and several pictures of the installation and testing stages are shared, these are high level summaries of deliverables D4.4 and D4.5 respectively.

With the gathered lessons learned during different stages, best practices for operating, testing and monitoring similar systems in the future are shared. It can be differentiated between installation and commissioning of each subsystem (gravity base system, umbilical cable, floater), environmental monitoring and operation & maintenance. Also, some associated risks concerning the local vessels and weather windows are assessed.

It is recommended that WP4 deliverables are used as guidance for future development of floating platforms and their subsequent subsystems during the installation, commissioning, environmental monitoring, operation and maintenance stages.

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