PivotBuoy

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

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D6.5: Reliability, Health & Safety and Environmental Considerations for Large Scale Farms of Floating Wind Platforms with Single Point Mooring Systems

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CONTENTS

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ACRONYMS

BV	Bureau Veritas
CRM	Collision Risk Modelling
CTV	Crew Transfer Vessel
D	Deliverable
DNVGL	Det Norske Veritas Germanischer Lloyd
EHS	Environment Health and Safety (same as HSE)
EIA	Environmental Impact Assessment
EU	European Union
FAD	Fish Aggregating Device
FMECA	Failure Mode, Effects and Criticality Analysis
GBS	Gravity Based Structure
HAZID	Hazard Identification
HSE	Health, Safety & Environment
HVAC	Heating, Ventilation & Air Conditioning
INSPIRE	Infrastructure for Spatial Information in the European Community
MEDEVAC	Medical Evacuation
SAC	Special Areas of Conservation
SCADA	Supervisory Control and Data Acquisition
SCI	Sites of Community Importance
SEA	Strategic Environmental Assessment
SOV	Service Operation Vessel
SPC	Special Protection Areas
SRL	Self-retracting Lifeline
TLP	Tension Leg Platform
TTA	Tower Top Adaptor
UXO	Unexploded Ordnance
WP	Work Package
WTG	Wind Turbine Generator

EXECUTIVE SUMMARY

This document presents an analysis on the reliability, health & safety and environmental considerations of commercial scale wind farms with full-scale PivotBuoy floaters. The assessment is divided into three sections: reliability (1), health & safety (2), and environment (3). As the definition of these topics can be very broad, their scope is narrowed down and clearly defined prior to the assessment.

The goal of the reliability assessment is to minimize potential threats to the integrity of the individual systems and of the wind farm as a whole. It highlights critical issues from preceding FMECA and their mitigations. Additional relevant topics for commercial sized wind farms are added. The full system is divided into several individually treated subcomponents, of which the critical risks and proposed mitigations are summarized.

The reliability analysis shows that main identified potential issues of the full-scale systems are related to the increased risk of fatigue damage due to the extended design lifetime compared to the prototype platform. This risk can be reduced to industry-acceptable levels by detailed design including adequate utilization factors, leading to appropriately dimensioned critical components. Furthermore, inclusion of experienced manufacturers and proper fabrication quality control decreases risk. Since the majority of the design comprises relatively simple geometries with little to no dynamic components, no exceptional issues are expected. The novel components such as the quick connector system are thoroughly tested and will be recalibrated for the full-scale design.

Since floating wind platforms are generally unmanned offshore structures, the health & safety assessment during the operational phase is less demanding than for many conventional offshore projects in for example the oil & gas or naval industry. Nevertheless, the health & safety assessment's goal is “target zero”, which means zero serious incidents throughout the entire project lifetime (i.e., incidents resulting in absence from work). The health & safety assessment covers the offshore safety of the full-scale PivotBuoy floater. This includes several aspects of vessel activities in support of the windfarm's operations & maintenance.

In the health & safety assessment the transfer methods for personnel and equipment and the on-board health & safety are discussed. The analysis indicates that it might be beneficial to switch from a CTV transfer to a SOV transfer with motion compensated gangways for full-scale systems as the latter vessels are capable of withstanding more onerous sea states. This will increase workability and overall well-being of the crew, which becomes even more pronounced for commercial sized floating wind farms, which are typically further from shore than conventional sites and will thus require longer offshore stays. With the increased dimensions of the full-scale system, extra measures must be taken to ensure on-board safety during working conditions and emergency situations. The analysis highlights the importance of health & safety in the design and lists considerations for the full-scale design.

One of the major catalysts for the increased interest in the development of (floating) offshore wind projects is the reduction of carbon emission, which is clearly an environmental aspect. However, while reducing carbon emissions, it is important to minimize the impact on other environmental aspects such as flora, fauna, and contamination of soil & water on every level of the ecosystem (benthic, marine,

terrestrial, etc.). The environmental assessment identifies the impact of commercial floating wind farms for the installation, operational and decommissioning phase.

The environmental analysis indicates a reduced environmental impact compared to both conventional (bottom fixed) wind farms and other floating concepts (catenary moorings). Because there is no need to drive piles or support structures into the seabed, the impact on marine flora and fauna is heavily reduced. Additionally, the small footprint of the TLP-GBS foundation will cause reduced disturbance of all marine ecology compared to catenary moored systems. Finally, since the floating wind farms can be located further offshore, the social impact like visual disturbances and interference with recreational/industrial marine traffic is also reduced.

1 INTRODUCTION

1.1 Document Objective and Outline

This document marks the final deliverable of the 6th work package (WP6) of the PivotBuoy project. Its focus lays on translating the lessons learned in previous deliverables to a general reliability, health & safety, and environmental assessment for commercial scale wind farms with full-scale floating wind systems using the PivotBuoy® technology.

The current section (Section 1) summarizes the objective of the previous work done in WP6. Furthermore, the definition and project scope of the topic *'reliability, health & safety, and environmental considerations for commercial scale wind farms'* is defined. Hereafter, the 3 main topics (reliability (Section 2), health & safety (Section 3) and environment (Section 0)) are assessed in independent sections. Finally, the main learnings are summarized and discussed in Section 5.

It must be noted that there presently is no commercial scale wind farm development using the PivotBuoy® technology, although a 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. Where possible and needed, confidence intervals are provided to increase the general applicability of this deliverable.

1.2 Previous Work in WP6

WP6 covers the risk assessment of floating wind systems equipped with the PivotBuoy® technology. This risk assessment includes reliability, health & safety and environmental considerations. 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, throughout this deliverable.

As opposed to other WPs, the entire WP6 is publicly available, and its full documentation can be found on the PivotBuoy® website (https://pivotbuoy.eu/documentation/). Most of the work package is based on the 225 kW X30 pilot project; however, 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:

D6.1 – Initial Identification of Failure Modes and Reliability [1]

This deliverable presents the initial HAZard IDentification (HAZID) and potential failure modes, reliability, health & safety, and environmental assessment of the PivotBuoy® **prototype** system. The document was primarily based on the initial Failure Mode, Effects and Criticality Analysis (FMECA) conducted with consortium member experts.

D6.2 – Update of Reliability, Health & Safety and Environmental Assessment [2]

This deliverable presents an updated version of D6.1 including proposed measures to 'design out' earlier identified possible critical failure modes. Modifications in the design required reassessment of the FMECA for the individual components.

D6.3 – Final Reliability, Health & Safety and Environmental Assessment [3]

This deliverable is the final update of the HAZID and FMECA analyses including feedback from installation and initial operation of the prototype system.

D6.4 – Optimal Maintenance Strategies for Single Point Mooring Systems [4]

This deliverable assesses the impact of different possible maintenance strategies on cost and loss of energy yield (downtime). The relative infancy of the proposed technology results in uncertainties and limited amount of data. The influence of various key factors is assessed through a sensitivity analysis and the results are input to the final design of the system.

1.3 Project Scope

The title of this deliverable names three distinct main topics: reliability (1), health & safety (2) and environment (3). As the generality of the definition of these topics leaves room for a broad range of interpretations, it is important to narrow down and clearly define the scope per topic. The current subsection will define the scope by listing the general goal and the investigated fields per topic. Prior to this, a definition of a ‘commercial scale wind farm’ as assumed in this deliverable is presented.

1.3.1 Commercial Scale Wind Farm

Throughout the PivotBuoy® project, the platform design developed from a 225 kW prototype platform, named the X30 platform, to a full-scale X140 platform designed for 14-15 MW turbines. Naturally, to support larger turbines, the dimensions of the floater will need to increase. However, due to the excellent scalability of the concept, the required material per MW significantly decreases with increasing turbine power rating. A more elaborate discussion on the scalability is given in *“D2.5 – Preliminary Design for 10-20 MW Systems”* [5].

With the goal of being competitive in future energy markets, all conclusions in this deliverable are based on commercial sized wind farms with power ratings exceeding 500 MW in the European region. It is assumed that the individual turbines will produce approximately 14-20 MW and the dimensions of the floaters will be at least as large as the X140 dimensions. This means that a full-scale wind farm will require 25 or more full scale floating systems. The (preliminary) dimensions of a full-scale X140 platform are listed in Table 1. Note that these dimensions are still subject to change as more design loops are to be carried out. However, these changes are not expected to influence the conclusions made in this deliverable.

Parameter	
Turbine Capacity	14 MW
Hub Height (from water level)	138 m
Length (between axes of columns & Pivot Top)	~100 m
Platform width (between column axes)	<100 m

Table 1 Main Dimensions of the X140 Platform Models [5]

1.3.2 Reliability Scope

Following the Cambridge Business English Dictionary, the term 'Reliability' is officially defined as *"how well a machine, piece of equipment, or system works"*. As earlier stated, this definition leaves room for a broad range of interpretations and can be applied at any stage of the project lifetime. As the fabrication process for commercial scale wind farms up until final quayside commissioning checks is already discussed in the publicly available deliverable *"D3.5 – Industrialization Plan for Serial Production of Large Farms"* [6], this document will only assess the reliability of the full system from these final quayside commissioning checks up until decommissioning.

The goal of the reliability assessment is to minimize potential threats to the integrity of the individual systems and of the wind farm as a whole. The reliability assessment highlights critical issues from preceding FMECA and their mitigations. The analysis showed little new or increased reliability risks for a large number of floating units compared a single floating system. Most identified risks, such as collision between floaters, ultimately result from the failure of an individual system. As such, this section will mainly focus on the reliability of a single full-scale unit.

1.3.3 Health & Safety Scope

Since floating wind platforms are generally unmanned offshore structures, the health & safety assessment during the operational phase is less demanding than for many conventional offshore projects in for example the oil & gas or naval industries. Nevertheless, the health & safety assessment's goal is "target zero", which means zero serious incidents throughout the entire project lifetime. The health & safety assessment covers the offshore safety of the full-scale PivotBuoy floater, which comprises on-platform working conditions, transfer operations of personnel and equipment, and emergency situations.

1.3.4 Environment Scope

One of the major catalysts for the increased interest in the development of (floating) offshore wind projects is the reduction of carbon emission, which is clearly an environmental driver. However, while reducing carbon emissions, it is important to minimize the impact on other environmental receptors such as flora, fauna, and contamination of soil & water on every level of the ecosystem (benthic, marine, terrestrial, etc.).

Since this document is not based on a specific project site, detailed environmental impact cannot be assessed. Therefore, the scope of this section is a high-level assessment of the (potential) environmental impacts of a commercial sized floating wind farm. Ultimately, each project requires an individual environmental impact assessment consulted by environmental specialists. These individual assessments may vary strongly per project site as a result of different stakeholders, ecosystems and site conditions.

In the environmental assessment, the environmental impact will be evaluated in 3 distinct phases listed below.

- Installation phase
- Operational phase
- Decommission phase

2 RELIABILITY

As stated, the main aim of the current work package (WP6) is to de-risk any possible threat to the integrity of a PivotBuoy® floater. An essential tool to achieve this goal was the frequently updated FMECA, which' progress is shown throughout Deliverables 6.1 to 6.3. This analysis aims at regular, systematic review of the floating wind turbine system to identify critical failure modes with the most up-to-date design data and to de-risk these threats through adequate mitigation measures. The current section highlights the lessons learned throughout the preceding analyses and applies them to the full-scale systems. The critical risks per main component are summarized and the proposed mitigation methods to diminish these risks are listed. As priorly stated, the main focus of this section will be on the reliability of a single unit rather than the full farm as few new or increased risks are identified between single or multiple units. More specifically, the extensive maintenance routines required for commercial-scale wind farms will result in an increased presence of operation vessels in the area. This potentially reduces the mean time to repair and herewith increases the reliability of the floaters.

For the FMECA, the system is divided into main components as listed below and labelled in Figure 1.

- Anchors (Foundation)
- Tendon System (Mooring system)
- Pivot Bottom
- Yaw System (includes bearings and elastic coupling
- Pivot Top
- Pontoons & Masts (including damping plates)
- Main Columns
- Electrical Power
- Utilities

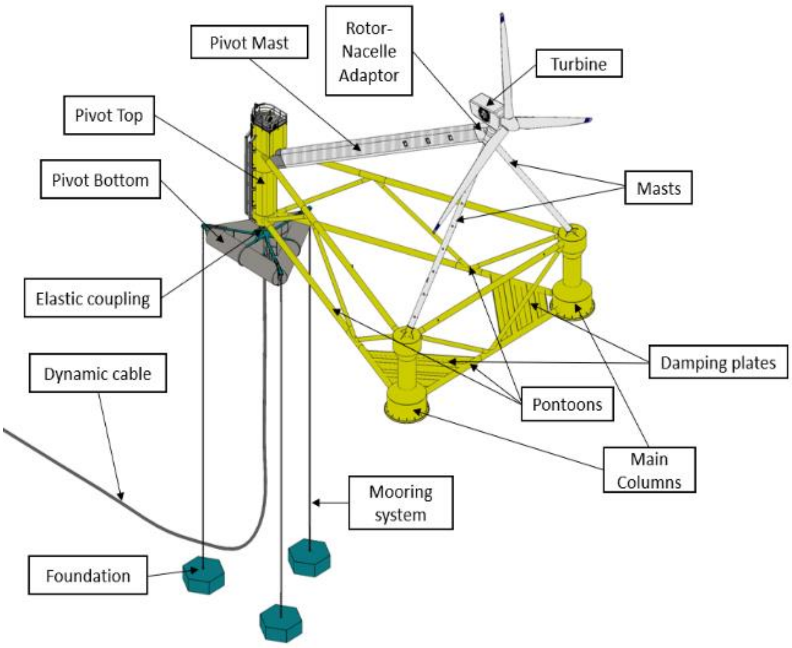

Figure 1 PivotBuoy X30 Design

2.1 Anchors

The X30 anchor system consists of a gravity-based structure attached to the tendon system. The prototype design includes three reinforced concrete blocks each connected to a single tendon. It must be noted that the selected anchoring technology may differ between seabed conditions and structure size of the full-scale systems.

Main failure modes identified for this component are related to either fatigue or structural strength failure, both of which can typically be mitigated by detailed design including adequate utilization factors, proper material selection and high fabrication quality control. The full-scale system's lifespan is significantly longer than the prototype's, resulting in longer exposure to dynamic loading and higher risk of wear and corrosion. Therefore, fatigue related issues and associated de-risk measures become increasingly important for full-scale designs. Note that this comment applies to all components.

To de-risk the possibility of failure through soil interaction, detailed geophysical and geotechnical survey is required for each project, resulting in a comprehensive understanding of the geotechnical conditions of the seabed below each individual floater. Depending on the soil type, scour protection may be required to prevent settlement or sliding of the concrete blocks.

2.2 Tendon System

The tendon system of the prototype consists of three vertically tensioned tendons, which connect the Pivot Bottom to the anchors and restrain the motions of the system (mainly heave and pitch). Each "line" comprises three main elements: the bottom connector, connecting the mooring line with the anchor, the top connector, connecting the mooring line with the Pivot Bottom, and the mooring line itself.

As discussed, the prototype tendon system comprises three tendons (one for each anchor). However, the full-scale design might incorporate more than 3 mooring lines to create redundancy. It must be noted that this will increase the required number of operations and potentially adds risk such as contact between the lines during installation.

The main failure modes of the tendon system are again focused on the fatigue limit state, especially at the connections, e.g., locking and shackles. Incorporating experienced design partners in this field and including adequate safety factors (over-dimensioning of the components) can lower the risk of significant damage or loss of integrity. Additionally, the added heave plates that were added to the design during the prototype development will damp vertical motions and herewith reduce the magnitude of the frequent tendon loads.

2.3 Pivot Bottom

The Pivot Bottom is a buoyant element comprising three legs to which the tendons (one or more per leg) are connected. It connects the elastic coupling with the platform through the quick connector directly attached to the bottom of the Pivot Top (and thus the yaw system). Hence, it functions as the single point mooring for the platform but is also ensures transferability of electricity.

The component should provide sufficient buoyancy to avoid slack tendons under all conditions. The structural design is ultimately a trade-off between weight, complexity (in terms of construction and installation), and costs while remaining resistant against effective loads resulting from the elastic coupling and mooring lines.

Like the preceding components, fatigue related risks are diminished by detailed design and overall effective forces are reduced by the heave plates. Any potential risk of loss of buoyancy is mitigated by an adequate maintenance plan and compartmentalization of the buoyant compartments. Risk of potential unplanned disconnection or other disconnect issues are reduced by detailed design of the locking systems and post-installation inspection.

As this concerns a novel component, to ensure reliability, extra attention is paid to the structural strength assessment. Separate extreme environmental load cases are simulated using both the installed configuration where the floater is connected and the pre-installed configuration where the floater is yet to be connected.

2.4 Yaw System

The turret yaw system, located in the Pivot Top, permits the floater to passively weathervane with the prevailing environmental conditions. The system comprises a yaw bearing and elastic coupling system. The former's function is to connect the elastic coupling to the Pivot Top and the latter enables the structure to rotate in pitch and roll direction. The yaw system is coupled to the pre-installed mooring system via a submerged quick connector system.

As this main component has relatively high mechanical complexity through its moving sub-components, it has increased risk of wear and/or fatigue. Typically, higher safety factors are used for this type of components resulting in low utilization of material strength and a relatively conservative design. Additionally, most of the components are not completely new to the industry and experienced manufacturers can be selected to decrease risks. An example of such a component is the sealing of the bearing system lubrication. As this is an issue applicable to many other mechanical systems, high quality sealings which are tested to adequate standards are available. To ensure this high quality throughout the system's lifetime, checks will be incorporated in the maintenance plan.

As the quick connector is a novel technique, extensive testing and detailed design is conducted. A dummy solution of a 1:7 scale prototype system was tested at the university lab on both endurance and ultimate limit loads and the results of this testing campaign were satisfactory. Naturally, with the increased dimensions, change in effective loading, and longer lifetime, this system will need to be re-designed to fit large-scale floaters. This is why X1 Wind is currently preparing a new testing campaign to qualify this component at full-scale. Lessons learned throughout the prototype testing process will serve as highly valuable lessons and will speed up the overall development.

2.5 Pivot Top

The Pivot Top connects the bottom part of the system to the rest of the floater. Apart from housing the previously mentioned yaw system it also provides extra buoyancy. The column consists of several watertight compartments housing the machinery room of the platform, which will be fitted with the electric- & electronic systems, HVAC, and the top bearing of the yaw system. The compartmentalization through the watertight compartments reduces the loss of buoyancy risk.

Even though overall risks were considered low for this component, the Pivot Top will be subjected to several interesting load conditions that require extra attention. These conditions include extreme environmental load cases, but also extra load cases such as loads transferred through the boat landing (as discussed in Section 3.1). These exceptional load cases are included in the design to ensure integrity. Overall, the Pivot Top is considered a robust design capable of withstanding the entire spectrum of load cases.

2.6 Pontoon & Masts

The pontoons and masts form the structural frame between the different columns and the nacelle. The pontoons consist of tubular members that are sealed to provide additional buoyancy. Besides supporting the nacelle, the Pivot Mast also provides the transfer access to nacelle. A more elaborate discussion on this transfer is given in Section 3.2.3.

It was previously addressed in [6] that critical failure modes of the full-scale pontoons might arise during lifting operations for transportation/installation and extra bracing/sea fastening might be required for the full-scale systems during these operations.

Another typical cause of failure modes for offshore wind turbine are the so-called nacelle induced vibrations which can result in fatigue damage when one of the systems natural frequencies interferes with nacelle induced vibration such as the blade-passing frequency. As the support structure consists of three masts rather than a single tower, the PivotBuoy® system permits more flexibility in avoiding these frequency zones and increases vibrational energy dissipation. As a result, the risk of fatigue damage on the pontoons and/or mast is reduced.

2.7 Main Columns

The main columns are the remaining water piercing cylindrical elements providing buoyancy and structural integrity located underneath the nacelle. Previous designs included de-ballasting pumps, which were later removed to increase passivity of the system and herewith increase reliability. Due to the simplistic design and no moving subcomponents, the potential failure modes are significantly reduced, and no high-risk failure modes are identified for this component.

Potential risk of severe damage due to vessel impact is mitigated by a proper logistic management and planning during installation or maintenance phases. A more elaborate discussion on potential transfer options is given in Section 3.1.

2.8 Electrical Power

The electrical power system comprises all the components relating to the transfer of electricity from the nacelle to the connection point. This includes the main electrical cable running from the nacelle to the control room in the Pivot Top, the slip ring assembly (which is a rotary joint, electrical swivel and collector ring that can transfer power, electricity, and data between a stationary and rotating component) and the dynamic cable.

Since the main electrical cable runs through the sheltered interior of the floater, damage is deemed unlikely. Additionally, visual inspection can be conducted to identify any possible damage to this cable.

Like the quick connector, the slip ring will be a continuously moving component. For the prototype sized floater this component is proven technology; however, similar systems for higher power rating (and increased voltage) are not available on the market yet. Fortunately, suppliers are already working on the next generation designs, which are expected to meet the demands of the full-scale designs. Note that this challenge exists for all weather-vaning floating concepts and not only the PivotBuoy floaters.

The industry's experience in the installation of cabling and risers is considered high enough to de-risk the potential failure modes of the dynamic cable and the cable on the seabed. Typically, the crucial phase is during installation and analysis shows that the load during this phase stays well below critical values.

It must be noted that, when scaling from a single prototype scale floater to multiple full-scale floaters, the number, size, and length of required (inter-array) cabling will increase, and the area covered by the cabling will enlarge. The ultimate cabling layout is a crucial design step and might differ strongly for different project dependent conditions such as soil conditions, marine traffic, and water depths.

2.9 Utilities

The 'utilities' comprise all remaining components such as the control room and onboard miscellaneous supporting systems such as navigation, signalling lights, and SCADA. Since these components are all proven technology in severe offshore conditions, their risk of failure is expected to be small.

3 HEALTH & SAFETY

Generally, floating wind platforms will be un-manned offshore structures with no anticipated activities that require any long-term stay on board. Therefore, the system will not be subjected to the same requirements as normally manned structures or vessels from, for example, the oil and gas or naval industry. Since un-manned structures provide less medical and emergency facilities, the personnel will be more self-reliant in emergency situations and require first-aid training. Emergency provisions such as first-aid, rescue, and fire-fighting equipment should either be easily accessible on board and inspected/maintained on a regular basis or brought onboard with the crew.

RenewableUK, a leading non-profit renewable energy trade association in the UK, has identified 24 different categories of risk relating to health and safety for offshore wind and marine energy [7]. The list includes topics like access and egress, fire, noise, vessel selection, and remote working. During the prototype design, a careful HSSE assessment was conducted through HAZID as described in Deliverable 6.1, 6.2, and 6.3 accounting for these topics. Lessons learned from this assessment will be incorporated in the full-scale design and extra considerations related to full-scale and commercial wind farms must be investigated. Especially the longer lifetime will call for some extra preventive maintenance strategies to ensure onboard safety.

In this section several health and safety considerations during offshore campaigns are assessed.

3.1 Transfer Methods

Throughout the project lifetime, transfers of both personnel & material are expected for maintenance, repairs, periodic inspection, etc. Actual number of transfer events is anticipated to be in the order of 5 to 10 per turbine, per year. In this section different transfer methods and scenarios are assessed while considering human factors (seasickness etc.) and HSSE requirements.

3.1.1 Vessel Access

The X30 prototype platform design features a boat landing at the Pivot Top designed to facilitate a Crew Transfer Vessel (CTV). This boat landing consists of two bumpers for the vessel to thrust against and a ladder for personnel to reach the platform. The boat landing of the prototype system is marked in green on Figure 2. Note that the full-scale platform will still undergo several design loops and access methods might be modified.

Figure 2 Boat Landing X30 Platform

The transfer of crew and equipment will only commence when all safety criteria are met. This means that the crew has the ability to embark, work onboard, and to disembark in a safe manner. As an example, when the vessel's transfer criteria for (dis)embarking (i.e., relative motion, visibility, etc.) are met, the working conditions on the platform (i.e., visibility, temperature, and motion criteria, especially in the nacelle) may still be critical and vice versa. It is stressed that transfer operations will only be carried out when the conditions are suitable for effective (dis)embarking, inspection, and maintenance activities.

In this assessment, two types of vessels and their transfer operations will be discussed:

1. Crew Transfer Vessel	(CTV)
2. Service Operation Vessel	(SOV)

As mentioned, the current design features a CTV compatible boat landing, but since the use of SOV is becoming increasingly popular in modern commercial wind farms, its assessment is considered relevant for the full-scale design.

3.1.2 CTV Transfer

A CTV is generally a relatively small vessel capable of transferring personnel and small equipment. Figure 3 shows a typical personnel transfer operation using a CTV for a jacket supported wind turbine.

Figure 3 CTV Personnel Transfer

The general process leading up to the personnel and equipment transfer to the platform is as follows:

1. The operation is organized onshore by planning the required activities and checking the weather forecast for a suitable weather window for departure. Typically, the limiting criteria for transfer follows from the relative motions between the vessel and the floating platform.
2. When arrived at the boat landing, the vessel approaches with reduced speed to minimise the impact loads on both the vessel and the floater.
3. After inspection of the condition of the boat landing bumpers, the CTV will dock.
4. After docking, the vessel will remain at the landing for a 'soak' period, typically in the order of 5 minutes, while observing the relative vertical motion between the ladder and the vessel. The limiting motions will ultimately depend on the selected vessel but are typically limited to less than 1 meter.

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5. If the motion criteria are satisfied, the transfer can begin. If the conditions are deemed unsafe, CTV withdraws from the boat landing.

Since the design features a weather-vaning platform, the thrusting direction will be unidirectional with the prevailing sea conditions. As this will provide an extra 'push', it is important to investigate whether the transfer operation does not push the platform out of position.

The personnel transfer is performed as follows:

1. Personnel will connect to the fall arrest system (standard safety equipment), i.e., self-retracting lifeline (SRL)
2. When the vessel is at its maximum elevation with respect to the ladder, the personnel should step on to the ladder and climb to the platform. No extra equipment is carried by the crew during transit.
3. Personnel will gather at the waiting area for rest of the crew or equipment

The hull type of the selected CTV can have a significant impact on the motions; generally, multi-hull vessels outperform mono-hulled vessels in calmer waters due to their superior transverse stability. In rougher waters, mono-hulled vessels are generally preferred for their lower wave induced vertical accelerations.

As the X30 prototype platform had relatively small dimensions and short lifetime, no heavy lifting operations were expected. However, for commercial sized wind farms, these operations will be necessary, and the platform must be equipped with an adequate crane. Any lifting operation will only occur in safe working conditions and with secure logistical planning to assure safety of personnel and equipment.

3.1.3 SOV Transfer

SOVs equipped with motion compensated "walk-to-work systems" as shown in Figure 4 are becoming increasing prevalent in the offshore wind market. This transfer method works well for both personnel transfer and transfer of small equipment. For heavier loads, the SOV crane can be used to lift the materials to the platform.

Figure 4 SOV Transfer

Unlike CTVs that require constant thrust to maintain a correct position relative to the platform, SOVs feature dynamic positioning (DP) systems, allowing them to maintain a clear distance from the platform and thus decreasing the risk of damage to the platform. On the other hand, SOVs are significantly larger than CTVs and DP failure ('black ship' or DP drift-off) scenarios must be considered. Potential damage in such event could be larger than for relatively small CTVs.

The increased stability of SOVs makes crew and equipment transfer inherently safer than CTV transfer and may increase the number of viable weather windows. It is expected that the SOV transfer criteria will not be critical and hence the safety of the inspection and maintenance operations become governed by the on-platform working conditions.

Many potential deep-water sites for floating wind projects will be located further from shore than conventional sites. This typically means that vessels will need to operate in more onerous sea states and will have longer travel times between the port and the wind farm. Therefore, the SOV's benefits including increased stability, better accommodation and enhanced well-being of personnel will become more pronounced for commercial sized floating wind farms. As mentioned, the extensive maintenance programs will increase the presence of these vessels in the project area. Therefore, the SOV becomes well suited as an (additional) safe haven in the event of rapidly deteriorating weather conditions.

3.2 On-Platform Health & Safety

Due to the infancy of the floating wind industry, relatively little guidance in terms of health and safety requirements can be found in design codes when developing a novel concept like the PivotBuoy floater. A typical and indispensable issue concerning the safety of any WTG structure (both fixed and floating) is working in an enclosed space. For the X140 platform this issue also arises in components like the Pivot top, Pivot mast, Tower Top Adaptor (TTA) and the nacelle. The health and safety of these working environments are reviewed against available floating wind platform design codes and guidance, experience of conducting inspection and maintenance activities on fixed wind platforms and good practice from experience in oil and gas industry platforms and vessels. First, general working condition regulations are listed and hereafter specific considerations for the aforementioned components are summarized.

3.2.1 On-Platform Working Conditions

As mentioned, the floaters will have several confined working spaces. These confined working spaces typically come with items or substances that might produce hazardous fumes and electrical equipment that might produce heat. To prevent accumulation of these fumes or the fire hazard/overheating, suitable active ventilation is recommended for these spaces.

Generally, access to confined workspaces requires working with a 'buddy system'; i.e., two persons present to assists each other when required. Line of sight is thus an important feature to keep in mind to assure adequate reaction in case of emergency while developing the full-scale floaters.

Besides confined working spaces there are other typical safety focus areas such as (but not limited to):

- Working at height

- Working over open sea
- Working in the dark/during night
- General working environment including
    - Seasickness and/or dynamic motions
    - Temperature (sea can be cold, but enclosed spaces can also become very hot)
    - Moisture/humidity
    - General debris from for example birds
    - Slipping danger due to marine growth (marine fouling)

3.2.2 Pivot Top

The main access into the PivotBuoy platform will be via a hatch at the Pivot Top walkway level. Personnel can climb down using a ladder located at this access hatch and equipment can be lowered with adequate lifting systems through the same hatch. Required handrailing is provided inside the Pivot Top to prevent falling to lower levels.

Little information can be found on escape routes of these type of systems and most of the standards are based on manned vessels, such as DNVGL-OS-A101 [8] and BV NR445 [9]. However, DNVGL-OS-A101 states that, depending on the frequency of access, dimensions of space, and number of persons entering, a second escape route is potentially redundant. As small teams with permit to work are anticipated on the platform, it is expected that a single hatch/escape route will suffice for the Pivot Top. It is important that this hatch provides enough space, which typically means a width of approximately 1 meter, and that it opens towards the deck, i.e., in the direction of escape.

It must, however, be noted that a single point access means that any necessary equipment follows the same path as the personnel, increasing the risk of blocking escape routes. For the full-scale systems, a second hatch dedicated for material handling is required to ensure safety.

In the case of a MEDical EVACuation (MEDEVAC) it is likely that an individual is incapacitated and can therefore not use the conventional escape route. It is recommended to fit attachment points for temporary rescue lifting equipment in the design which would facilitate sufficient evacuation possibilities combined with the traditional route. The evacuation routes must be clearly defined from all locations onboard where activities might be required and it must be possible to evacuate personnel from any of these locations.

Finally, in the current design, the Pivot Top looks like the best location for a temporary safe haven. The personnel must be able to safely stay onboard in the event that the egress route is not available (e.g., SOV has a mechanical breakdown).

3.2.3 Pivot Mast

As the length to hub height ratio of the X140 platform is smaller than for the X30 platform, the pivot mast to TTA transfer will be steeper. Naturally, the increased dimensions will also make the distance larger, but it will on the other hand also increase the space within the pivot mast. As the transfer from the Pivot Top requires a climb of more than 150 m with potential equipment, a funicular-type elevator for lifting personnel and equipment is considered. As, again, the equipment follows the same route as the personnel, a thorough HAZID/HAZOP and FMECA analysis should be performed to ensure that the elevator and related operations remain safe for the personnel using it at all times. A secondary lifting system directly to the nacelle might be required for major equipment, for example from a laydown area under the nacelle. This extra laydown area can be accommodated at the center of the transverse pontoon and can simultaneously function as a second egress route in case the primary egress route (through the pivot mast and pivot top) cannot be accessed safely. Additional measures such as guide rails on the masts might be required to ensure controlled egress via this secondary route.

Throughout the full length of the Pivot Mast, sufficient ventilation, lighting, and safety secondary steel such as railings and handles are required. To reduce risk of injury during emergency, the crew should either bring emergency equipment or sufficient equipment should be available in the Pivot Mast.

3.2.4 Tower Top Adaptor and Nacelle

The Pivot mast is connected to the nacelle via the so-called tower top adaptor which forms the link between the two supporting masts, Pivot mast and nacelle. Since the evacuation route away from the nacelle in case of emergency becomes longer for full-scale systems, overall crew safety can significantly be increased by including a second egress in the full-scale design. Two proposed methods are an extra hatch in the tower top adaptor equipped with industrial rope access (as discussed in the previous sub-section) or helicopter access on top of the nacelle. In the case of using a 2 bladed turbine (such as 2-B Energy downwind turbine), current designs indicate that uncomplicated helicopter-based service access is enabled with the turbine in stationary mode and the rotor locked in horizontal position. Naturally, the possibility to lock the rotor is an important requirement for both evacuation methods. A visualization of helicopter access for the 2-B Energy 6MW turbine is shown in Figure 5. Higher power rating designs for 2-bladed turbines with similar access method are in development. It must, however, be noted that these operations are based on bottom-fixed concepts and that the relative motions of floating systems might severely increase the difficulty of these operations.

Figure 5 Helicopter Access 2 Bladed Turbine

4 ENVIRONMENT

As previously mentioned, there presently is no commercial scale wind farm development using the PivotBuoy® technology, although a EU-funded project to build a full-scale 6MW pilot using PivotBuoy technology has been recently launched (NextFloat Project). This section therefore addresses environmental aspects in a generic, non-site-specific sense. The environmental and ecological composition may strongly vary between potential project sites and hence also the possible environmental impact of a commercial floating wind farm will vary per project site. Each individual project will require a separate Environmental Impact Assessment (EIA) satisfying all relevant standards. Typically, the EIA should comprehensively assess the impact throughout three phases:

1. **Installation:** The offshore installation comprises the installation of the floaters, moorings, offshore electrical infrastructure including a potential offshore substation (depending on project size), inter-array cabling, and an export cable. The onshore part comprises the cable landfall, onshore cabling, and a substation.
2. **Operational:** The operational period of the wind farm with required maintenance and inspections. A typical lifetime of 25-30 year is adopted.
3. **Decommissioning:** The decommissioning of all the on- and offshore components at the end of the project lifetime. Note that typically the project decommissioning plan is firmed up near the end of the project lifetime to decide the best approach using up to date information. It may, for example, be that it will be environmentally beneficial to leave certain components at the site rather than removing them.

This section will first lay-out the general environmental impact assessment process and thereafter zoom in on several important topics with possible mitigations.

4.1 General Environmental Impact Assessment Process

Like the FMECA technique adopted in previous WP6 deliverables, the EIA will be an iterative process where all potential impactful operations in the different phases are logged and their significance is iteratively assessed. Highly impactful issues will be 'designed out' where possible, and issues with negligible impact are 'retired'. Below required steps are listed:

1. ***Collection of Stakeholder and Regulatory Information***

Different projects will be subjected to different obligations in terms of regulation and stakeholder requirements. It is of paramount importance to clearly discuss and confirm these requirements with the involved parties to identify any possible gaps.

2. ***Collection of (Existing) Data***

Available data on the current existing environment is gathered from available data sources, this is required to adequately assess any environmental effects of the wind farm realization. After assessing and reviewing all the existing data, gaps in data or evidence can be resolved by project-specific survey operations.

The gathered data is used to evaluate all potential receptors and their relative importance based on factors like sensitivity and recoverability. This serves as important input to assess the potential impact of the wind farm on the different potential receptors.

Some typical sources of information used for collecting data are listed below [10]:

- National/regional databases of previous EIAs,
- Data collected under the EU legislation (especially the SEA Directive and the INSPIRE Directive),
- EU level and other international databases,
- Local level/community experts, and
- Primary research carried out by content

3. ***Impact Assessment***

Any potential negative or positive effects of the proposed operations to the receptors and their significance is evaluated. This includes all interactions between the 'new' project components and the baseline environment also including cumulative (joint effects with other potential users in the proximity of the proposed site) and inter-related effects (joint effects of proposed operations that might lead to increased effects when combined). To account for possible changes in the baseline environment throughout the project lifetime or unforeseen effects during operations, adequate monitoring systems might be required to signal the need of any active measures.

4. ***Mitigation***

Issues with a predicted significant negative effect resulting from the impact assessment will be mitigated by careful redesign of the associated topic. This might either remove the issue as a whole or lower it to acceptable levels. After the redesign, the issue is reassessed, and any residual effects are evaluated. If these residual effects are still significant, another design cycle will be required.

4.2 Identifying Significance of Impact

Even though the concept of 'significance' is challenging to define, certain common characteristics can be identified. Generally, the assessment of significance depends on experts' judgements on what is important, desirable, or acceptable with regards to certain operations. At present, there is no international consensus on a single best approach to assess significance of impact, which makes sense as the concept of significance may strongly vary for different contexts.

A common approach used to assess environmental impact is the multi-criteria analysis. Typically, significance is evaluated looking at the magnitude of the effect and the sensitivity of the environmental receptor.

- **Magnitude** considers the characteristics of the impact (timing, scale, size, and duration) on the environmental receptor as result of the project.
- **Sensitivity** considers the sensitivity of the environmental receptor to change, including its capacity to adapt or recover.

Practical examples of the above are shown in Table 2. Describing possible impact with these criteria results in a systematic basis for the comparison of expert judgement.

Criteria	Components of Criteria	Description and Examples
Sensitivity of the receptor	Regulations and guidance (law, programmes, guidelines, and zoning)	There are specific receptors in the impact area which have some level of protection, either by law or other regulations or whose conservation value is increased by programmes or recommendations. A list of possible receptors include: population and human health, biodiversity, land, soil, water, air and climate, material assets, cultural heritage, and the landscape.
	The value of the receptor to the society (recreational values, natural values, number of affected people)	Depending on the type of impact, it may be related to economic values (e.g. water supply), social values (e.g. landscape or recreation) or environmental values (e.g. natural habitat).
	Vulnerability to the changes (ability to tolerate changes, number of sensitive targets)	Vulnerability to the change describes how liable the receptor is to be influenced or harmed by pollution or other changes to its environment. For instance, an area that is quiet is more vulnerable to increasing noise than an area with industrial background noise.
Magnitude of the impact	Intensity and direction	Intensity describes the physical dimension of a development and direction specifies whether the impact is negative or positive. Depending on the type of impact, intensity can often be measured with various physical units and compared to reference values, such as the decibel (dB) for sound.
	Spatial extent (geographical area)	Spatial extent describes the geographical reach of an impact area or the range within which an effect is observable.
	Duration (reversibility, timing, periodicity, and regulatory)	Duration describes the length of time during which an impact is observable and it also takes other related issues, such as timing and periodicity, into account.

Table 2 Criteria for Assessing Significance [10]

After the sensitivity and magnitude of a certain effect is described, they can be inputted in the multi-criteria matrix to predict their significance. Prior to this it is important to scale the weight of both criteria, for which examples are given in Table 3 and Table 4.

High	Receptor has very limited capacity to avoid, adopt to, accommodate, or recover from the anticipated impact
Medium	Receptor has limited capacity to avoid, adapt to, accommodate, or recover from the anticipated impact.
Low	Receptor has some tolerance to avoid, adapt to, accommodate, or recover from the anticipated impact.
Negligible	Receptor is generally tolerant to and can accommodate, or recover from the anticipated impact.

Table 3 Sensitivity Levels Environmental Receptors

Major	Loss of resource, partial loss of or damage to key characteristics, features, or elements; Permanent impact, which is likely to occur.
Moderate	Minor loss of, or alteration to, one (or maybe more) key characteristics, features, or elements; Long-term impact, though reversible change, which is likely to occur.
Minor	Very minor loss of, or alteration to, one (or maybe more) key characteristics, features, or elements; Short- to medium-term impact though reversible change, which could possibly occur.
Negligible	Temporary or intermittent very minor loss of, or alteration to, one (or maybe more) characteristic, feature, or element; Short-term impact, intermittent and reversible change, which is unlikely to occur.

Table 4 Magnitude of Impact

Combining the two definitions, a traditional impact assessment matrix can be constructed as shown in Table 5, where the red gradient indicates increasing impact. Note that the magnitude can also be beneficial in which case the upper left combination would indicate major beneficiary impact.

		Magnitude			
		Major	Moderate	Minor	Negligible
Sensitivity	High	High	High	Moderate	Minor
	Medium	High	Moderate	Minor	Minor
	Low	Moderate	Minor	Minor	Negligible
	Negligible	Minor	Minor	Negligible	Negligible

Table 5 Environmental Impact Assessment Matrix

Naturally, these definitions will not fit all situations. Hence, modified versions of this setup can be used with more bespoke definitions of the receptors, sensitivity and magnitude.

4.3 Typical Environmental Considerations and Relation to PivotBuoy

Typically, EIA are highly site specific and provide a detailed view on possible environmental impacts and their mitigation. As this is a generic report key impacts will be summarized for different environmental fields and their relationship with PivotBuoy will be described where appropriate.

4.3.1 Flora, Fauna and Nature Conservation

Prior to the impact assessment, it is important to identify any Special Protection Areas (SPAs), Special Areas of Conservations (SACs) and Sites of Community Importance (SCIs) in proximity of the proposed wind farm location as extra caution may be required in these zones. The flora, fauna and nature environmental considerations can be sub-divided into several typical ecologies. A short description and important considerations for each ecology type are listed below.

4.3.1.1 Benthic Ecology

The benthic study area concerns the lowest level of the body of water, which in the case of floating wind farms include the seabed but also reefs/estuaries. Due to the small footprint and because there is no need to drive piles or support structures into the seabed due to the TLP mooring system with GBS anchor, the PivotBuoy floaters are expected to have smaller impact on the benthic ecology than, for example, concepts with catenary mooring systems with larger footprints. However, the required cabling and vessel anchoring could affect the different benthic habitats. Through surveying, highly sensitive habitats can be avoided in the project design.

4.3.1.2 Fish and Shellfish Ecology

With sea bordering countries often having an active fishing industry and the overall importance of fish and shellfish in the marine ecology, this topic is generally an important aspect of the EIA of commercial wind farms. This also means that, typically, there is a lot of information on the species and their spawning grounds, nursery period etc. Risk of damage to habitat can be mitigated by:

- Spatial design: Avoid spawning grounds and avoid interaction with cables
- Timing: Avoid impactful operations during spawning and migration periods

The realization of commercial wind farms also has a potential beneficiary side effect by serving as a Fish Aggregating Device (FAD).

4.3.1.3 Marine Mammal Ecology

It is likely that a range of marine mammals will be present around the project area, these might include whales, dolphins, seals, turtles and more. Marine mammals are often protected with conservations such as SACs, which are to be avoided in the design phase. Since no drilling activities are required, the underwater noise throughout the three considered phases is expected to be well below critical levels for commercial PivotBuoy farms.

4.3.1.4 Ornithology

Ornithology is the branch of zoology that deals with the study of birds. Information on this topic is typically found both from existing data and surveying. Typical potential impacts to the bird environment include loss of habitat and foraging success and increased risk of mortality due to collision with the WTGs. As floating wind farms are typically located relatively far offshore, the overlap of the foraging area and project site are expected to be lower compared to conventional wind farms. However, depending on the site conditions, seabirds might still reach the area. Therefore, survey data can be used to develop surface density plots/models and Collision Risk Modelling (CRM). Additionally, the effect of the wind farm on migratory species must be assessed.

4.3.1.5 Terrestrial Ecology

The terrestrial ecology is typically a smaller, yet relevant, topic in the EIA. It mostly concerns the area that is potentially affected by the export cable landfall and onshore cabling/substation. Especially the excavation for the cables can disturb the ecology and surveys/desktop studies are required to minimize the impact on sensitive species and habitats.

4.3.2 Physical Environment

Apart from potential impact on flora and fauna, the realization of a commercial sized wind farm can also have an impact on the physical environment. As shifts in this environment can have a lot of small- and large-scale consequences, potential impacts should be assessed and mitigated if deemed too large. Typically, most information on the physical environment (e.g., metocean data, bathymetry, soil data) will also be required for the overall design process and will thus be readily available. Typical topics that should be assessed include:

- Effects on sediment transport and coastal erosion
- Effects on water quality (both onshore and offshore)
- Effect on soil quality and composition (e.g., compaction and degradation of soil)

4.3.3 Human Environment

The final environmental considerations concern the human environment. Various important topics for a variety of human interactions with their considerations will be considered below.

4.3.3.1 Shipping Industry

The considered shipping industry comprises both the commercial fishery and other marine traffic. It is important to consider both the offshore area and the inshore waters as they typically will have different users.

The effect on the fishing industry is typically assessed by looking at the landed weight (i.e., the mass of resource landed from a certain area). Since the shipping vessels may be restricted from their typical grounds due to statutory exclusions and/or safety zones, their landed weight might be impacted. As the PivotBuoy systems have a significantly smaller footprint in terms of mooring lines compared to conventional catenary mooring, this impact might be reduced. It is noted that dynamic (inter-array) cabling will still require great caution. Additionally, it must be assessed whether the export cable landing activities don’t impact inland fisheries, where both shellfish and fishes are fished, in unacceptable levels. This issue arises for all types of windfarms, both floating and fixed.

Regarding other marine traffic, it is desirable to minimize the interaction with existing transit routes. Typically, the wind farm lots are readily checked by governmental institutions and their interaction is minimized. However, during the installation and decommissioning phase, some routes might be temporarily closed. It is advised to incorporate marine traffic control for project vessels during these phases in order to avoid incidents. Additionally, inter-array cabling and export cables are protected by burying them to an appropriate depth or rock placement without reducing the navigable water depths by too much.

4.3.3.2 Other Coastal and Marine Users

Many coastal and offshore areas are heavily crowded by other users. The density and nature of these users will strongly differ per project site, but all users will be important stakeholders to consider and consult at an early stage in the project. A list of possible users is listed below:

- Ports and Harbours
- Military training grounds
- Oil and gas industry
- Subsea cables
- Other renewable energy extraction sites

4.3.3.3 Aviation Industry

With floating wind farms typically located in deeper waters further from shore, the risk of collision with any aircraft is typically low. However, it is important to assess the interference with radar and communication systems between the WTGs and any airport and aviation. Mitigation measures might include warning lighting on top of the WTG and the inclusion of Non-Auto Initiation Zones (NAIZ) from radar signal.

4.3.3.4 Socioeconomics

In terms of socioeconomics the realization of a wind farm can have a significant beneficiary impact on the local population. Additionally, with the farms typically being far offshore, their negative impact on the population such as visual impact are heavily reduced. Some positive impacts might include:

- Increased employment and earnings
- Increased energy security
- Reduced carbon emissions

5 CONCLUSIONS

This document presents an analysis on the reliability, health & safety, and environment of commercial scale wind farms with full-scale PivotBuoy® floaters. The assessment is divided into three sections: reliability (1), health & safety (2), and environment (3).

The reliability analysis showed that the critical issues were readily resolved through the mitigation measures resulting from preceding iterations of the FMECA. Since the PivotBuoy® floating system is designed to be highly passive with few dynamic components, most identified risks were associated with structural and/or fatigue damage issues. These risks can typically be mitigated by detailed design with adequate (higher) safety factors, proper material selection and quality inspection during fabrication, installation and operation. Since the full-scale floaters will have a longer design life than the prototype platform, fatigue considerations become increasingly important. Finally, commercial scale wind farms will require an increased number, size, and length of (inter-array) cabling. The ultimate cabling layout is a crucial design step and might differ strongly for different project dependent conditions such as soil conditions, marine traffic, and water depths.

The health & safety assessment showed that, since the floaters will generally be novel un-manned offshore structures, official requirements will be less demanding and design codes will be less exact. It was concluded that, when designing the full-scale systems, it might be beneficial to switch from a CTV transfer to a SOV transfer with motion compensated gangways as the latter vessels are capable of withstanding more onerous sea states. This will increase workability and overall well-being of the crew, which becomes even more pronounced for commercial sized floating wind farms, which are typically further from shore than conventional sites. The increased dimensions of the full-scale system also elongate the current evacuation routes and herewith increases the complexity of MEDEVAC. Several considerations regarding this topic are proposed which are to be included in the full-scale design. The considerations include but are not limited to potential requirement of secondary egress, adequate availability of emergency equipment, extra lifting equipment and/or material transfer routes which reduces the chance of blocking the evacuation routes.

The environmental analysis indicates a reduced environmental impact compared to both conventional (bottom fixed) wind farms and other floating concepts (catenary moorings). Because of the redundancy of drilling operations, the impact on marine flora and fauna is heavily reduced. Additionally, the small footprint of the TLB-GBS foundation will cause reduced disturbance of all marine ecology compared to catenary moored systems. Finally, since the floating wind farms can be located further offshore, the social impact like visual disturbances and interference with recreational/industrial marine traffic is also reduced.

Overall, the reliability, health & safety, and environmental assessment for commercial scale wind farms identified no crucial showstoppers for the utilization of full-scale PivotBuoy® floaters for commercial wind farms. Both the extra considerations mentioned throughout this document and lessons learned from the prototype period can serve as valuable input for the full-scale designs, giving them redundancy to potential threats to the systems, health & safety and/or the environment.

6 BIBLIOGRAPHY

[1] PivotBuoy, "D6.1: Identification of Failure Modes and Initial Reliability, Health & Safety and Environmental Assessment of the PivotBuoy System," 2019.

[2] PivotBuoy, "D6.2: Update of Reliability, Health & Safety and Environmental Assessment of the PivotBuoy System," 2020.

[3] PivotBuoy, "D6.3: Final Reliability, Health & Safety and Environmental Assessment of the PivotBuoy System," 2022.

[4] PivotBuoy, "D6.4: Optimal Maintenance Strategy for Single Point Mooring Systems," 2019.

[5] PivotBuoy, "D2.5: Preliminary Design for 10-20MW Systems," 2022.

[6] PivotBuoy, "D3.5: Industrialization Plan for Serial Production of Large Farms," 2022.

[7] R. Proskovics, G. Hutton, R. Torr and M. N. Scheu, "Methodology for Risk Assessment of Substructures for Floating Wind Turbines," *Energy Procedia,* vol. 94, 2016.

[8] DNVGL, "Safety principles and arrangements," 2019.

[9] Bureau Veritas, "NR445 Rules for Classification of Offshore Units," 2019.

[10] European Commission, Directorate-General for Environment, McGuinn, J., Lukacova, Z., McNeill, A., et al., "Environmental Impact Assessment of Project: Guidance on Scoping," Publication Office, 2017.

[11] PivotBuoy, "D2.3: Detailed Design Review (Confidential)," 2020.

[12] European Commission, Directorate-General for Environment, McGuinn, J., Lukacova, Z., McNeill, A., et al., "2017," Publication Office, Environmental Impact Assessment of Projects : Guidance on the Preparation of the Environmental Impact Assessment Report.

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