The Atlantic Testing Platform for Maritime Robotics

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Project Coordinator	Approved the updated second version as the final version and sent to the European Commission.	INESC TEC	30.07.2020

Disclaimer

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List of acronyms

Acronym	Meaning
ACAS	Automatic collision avoidance system
ACFM	Alternating current field measurement
AET	Acoustic emission testing
AIS	Automatic identification system
ANACOM	Autoridade Nacional de Comunicações
APA	Agência Portuguesa do Ambiente
ASV	Autonomous surface vehicle
AUV	Autonomous underwater vehicle
CP	Cathodic protection
CPS	Cable protection system
CTV	Crew transport vessel
DGRM	Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos
DP	Dynamic positioning (vessel)
EC	European Commission
ECS	Electronic chart system
EU	European Union
GA	Grant Agreement
GES	Group on good environmental status
GNSS	Global navigation satellite system
GPS	Global positioning system
GWT	Guided wave testing
HD	High definition
HSE	Health, Safety and Environmental
HW	Hardware
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
I-AUV	Intervention autonomous underwater vehicle

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IMO	International Maritime Organization
IMR	Inspection, Maintenance and Repair
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IoT	Internet of Things
LE	Leading edge
LIDAR	Light detection and ranging
MVOW	MHI Vestas Offshore Wind
NDT	Non-destructive testing
O&M	Operations and maintenance
OSH	Occupational Safety and Health
PCB	Project Coordination Board
PM	Permanent magnet (machine)
PMC	Platform mooring connectors
PMT	Project Management Team
PPC	Power plant controller
PPE	Personal protective equipment
PS	Pressure side
RACON	Radar beacon
ROV	Remotely operated vehicle
SCADA	Supervisory control and data acquisition
SHM	Structure health monitoring
SOLAS	Safety of Life at Sea
SOV	Support offshore vessel
SS	Suction side
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
SW	Software
TE	Trailing edge
TRL	Technology readiness level
UAV	Unmanned aerial vehicle

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WFA	WindFloat Atlantic
WTG	Wind turbine generator

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1. Introduction

The purpose of this document is to formulate multiple possible inspection, maintenance and repair (IMR) scenarios, that can be applied to an offshore wind farm, focused on, but not limited to, the WindFloat Atlantic (WFA). This formulation is an important step to understand how the current solutions can be improved by new ideas based on robotisation and automatisation of IMR operations. The document is covering all scenarios identified in an offshore wind farm and thus it constitutes a survey of new concepts and technology which have to be developed to modernise, de-risk and significantly reduce costs of offshore operations, improving the efficiency and cost-effectiveness of renewable energy generation. It is important to understand that not all of the described solutions will be possible to demonstrate during the course of the ATLANTIS project and should be treated as a vision of what can be developed in the future. The reason for this is the complexity of some of the IMR scenarios, which require significant research and technology developments. These kind of ideas are introduced to give a choice to the technological partners as well as show how the ATLANTIS Test Centre can be utilised after the end of the ATLANTIS project. The document is also discussing the ethical issues regarding potential harm to environment due to the ATLANTIS Test Centre, and the health and safety of personnel enrolled in validation and demonstration activities.

The document is organised as follows. Section 2 describes the identified IMR scenarios, including the current methodology and the new ideas. Section 3 presents the role of the on-shore control centre. Section 4 discusses the cost reduction opportunities associated with the proposed ideas as well as other ways the developments can impact the industry and natural environment. Next, Section 5 discusses ethical issues that may arise due to the new technological and scientific developments. Finally, Section 6 concludes the document.

2. Scenarios

Multiple IMR scenarios were identified in the WFA farm as well as fixed-base wind farms. A detailed description of these scenarios is presented in the subsequent sections, with information about the current operations, the proposed innovative solutions and the foreseen advantages of the latter. Moreover, Table 1 presents an association between the scenarios and the project partners, to better understand the cooperative nature of the developments.

Table 1. Association of consortium partners with the proposed IMR scenarios: leaders (blue) and other contributors (yellow).

Code	Title	INESC TEC	UdG	ECA	Iqua Robotics	VTT	RINA-C	SpaceApps	ABB
S1	Inspection of blades and tower at WFA	blue				yellow	yellow	yellow	
S2	IMR of the transition piece or the floating structure	yellow	yellow	blue	yellow	yellow	yellow	yellow	
S3	Repair of underwater floating wind turbine cables protection systems	yellow	yellow	blue	yellow	yellow	yellow	yellow	
S4	Underwater monitoring over extended time periods	yellow	blue		yellow	yellow	yellow	yellow	
S5	Underwater close-range inspection of foundations	yellow	yellow	yellow	blue	yellow	yellow	yellow	

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S6	Underwater monitoring of scour protection interventions								
S7	O&M operations supported by crewless vessels								
S8	Optimization of robotic-based operations								

It should be remarked that not all of the scenarios listed in Table 1 are applicable to the WFA, due to its inherent characteristics, but may be of interest in case of other types of wind farms. Figure 1 presents the approximate location of the IMR operations that are applicable to the WFA, covering scenarios S1 to S5. In scenario S5 we are not only interested in inspection of fixed foundations but also anchoring systems present in floating wind turbines. Scenarios S7 and S8 are focused on logistic and support, therefore they are applicable to all kinds of offshore operations, not necessarily related to wind power generation.

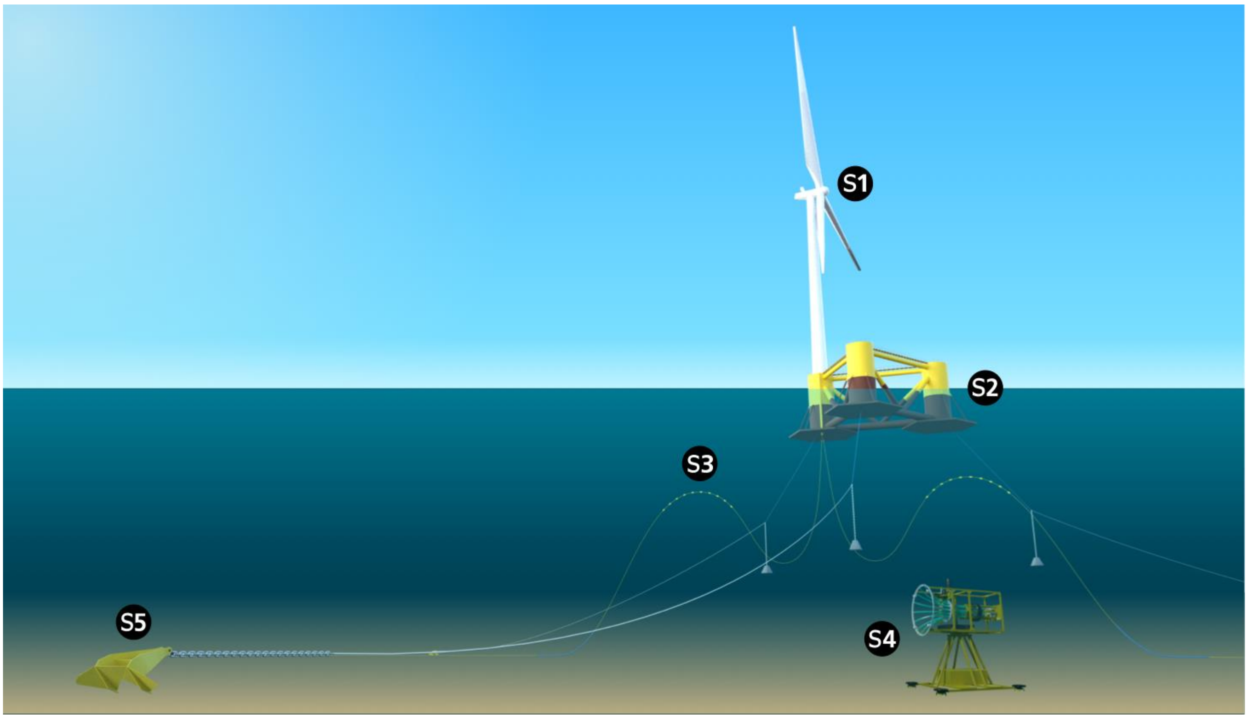

Figure 1. Approximate location of the IMR operations related to scenarios applicable to the WFA.

2.1. S1: Inspection of blades and tower at WFA

On offshore wind farms several wind turbines can be found, placed in relatively shallow water, close to the coastline, where the mean wind speed is beneficial for the electric power generation. A wind turbine consists of three main components: the tower, the nacelle or the generator house, and the rotor, as depicted in Figure 2 [Nicholas2020]. The rotor is composed of three blades connected to a central hub on the nacelle.

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Figure 2. Composition of a wind turbine.

In the specific case of the WindFloat Atlantic (WFA), the implemented wind turbines are developed by Vestas Wind Systems A/S, designated as model V164-8.0, with a rated power generation of 8.00 MW (Figure 3). This wind turbine begins to operate at the wind speed of 4.0 m/s and can continue its operation up to wind speed of 25 m/s, with a safety cut-off above. The rotor diameter of the Vestas V164-8.0 is 164,0 m and the tip height, including base, tower and rotor, is 190 m. The rotor area amounts to 21.124,0 m^2. The wind turbine is equipped with 3 rotor blades with the maximum rotor speed of 12,1 U/min. Vestas Wind Systems A/S uses a permanent magnet (PM) generator with an output voltage of 66 kV. The nominal frequency for this turbine is 50 Hz [WindTurbineModels2020].

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Figure 3. Vestas V164-8.0 - 8.00MW

The inspection of the blades and tower will be beneficial to ensure the safety, quality and cost-effectiveness of the wind farms. For instance, high-quality inspection images will be of benefit to owner/operators in the future, allowing for the creation of a timeline of the wind turbine condition with several visual information about the state and the defects evolution. This will allow to plan maintenance procedures early on, as well as to increase the capacity to evaluate the effects of the defects costs by comparing the repair costs and the production losses due to the damages. As so, inspection is required not only to identify the defects but also to evaluate the progression of damage over time and its influence on plans for repair.

The main concerns about **blades** are surely lightning strike, blades cracks (Figure 4b) and delamination. Less erosion (Figure 4a) could be expected compared to onshore wind, due to less or no dust.

Figure 4. Blades defects: (a) leading edge erosion; (b) blade crack.

Regarding the **tower,** major concerns are weld defects, re-torque of bolts on flanges connection (each section of the tower) and surface treatment defects. Corrosion is the most predictable and known effect,

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especially on the platform (e.g., on bolts). Cracks should also be a major concern, but model needs to be studied in more detail. Wind turbine generator (WTG) towers have been used standing on top of fixed structures (onshore and offshore wind) but they don't work as a monolith in floating offshore wind. Modal frequencies of the structures are different and may even have opposite directions for a few seconds. Torsional and opposing forces impact fatigue, on the tower and its bolts. Some alarms on WTGs resulting from the platform's behaviour have occurred during commissioning, but this is still under analysis. Moreover, pinholes often act as the starting point for erosion cracks, which can progress to compromise the structural integrity of a blade and damage to blade can lead to higher loads and reduced performance. The evolution of blade damage does not always progress linearly over time, thus providing on time high-quality inspection is a major concern for wind turbines owners.

2.1.1. Current methodology

Wind industry-specific inspection methods include:

- **Rope-access**: is the most conventional method of inspection, where a team of certified engineers accesses the turbine through the nacelle and rappels each blade to capture any turbine defects;
- **UAV**: a growing method on both onshore and offshore wind farms, where a qualified UAV pilot remotely operates the vehicle during the inspection with the aid of an inspection engineer. This allows for a “first glance” at the condition of turbines, highlighting areas of concern, to be further inspected and repaired with rope-access;
- **Elevated platform**: use of an elevated platform to inspect the length of blades in-situ, presenting risk similar to rope-access;
- **Ground camera**: use of static camera devices to perform visual inspection.

Nowadays, rope-access and UAV inspection are the two most widely-used methods in the wind industry [Cyberhawk]. Although possible, elevated platform and ground camera inspections are not typically utilised for large-scale inspection activities due to logistical, quality and cost limitations. Common to all this approaches are the usage a crew transport vessel (CTV) to transit and transfer operators and equipment. The share of different inspection methods for wind turbines are the following: manual **83**%, cameras from vessel/structure **10**% and Drones **7**%, see Figure 5.

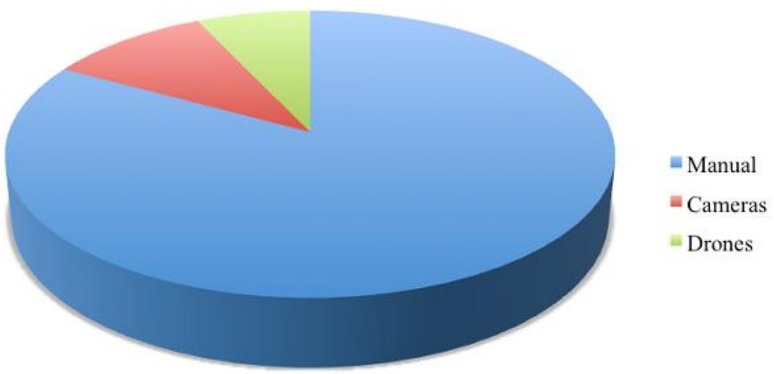

Figure 5. Frequency of the inspection methodologies that are deployed on-site. Source: Ariel Avitan, Percepto and obtained in: https://newenergyupdate.com/wind-energy-update/fully-automated-drones-could-double-wind-turbine-inspection-rates

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The current inspection intervals spawns on a period of **three years** between the inspection activities of the blades and **one year** between the inspection activities of the tower. Nevertheless, regarding the blades, some manufacturers perform **yearly** inspections using drones.

Visual material is expected as outcome of the wind turbine inspections. Thermography or gamma ray inspections could also be used from time to time. All measurements related to the WTGs are collected into MVOW (MHI Vestas Offshore Wind) SCADA and power plant controller (PPC). Apart from these measurements, Windplus has complementary equipment/measurements installed, namely navigation aid systems (1 RACON and 3 AIS), 1 bird radar, 1 bat detector and 1 LIDAR system.

The UAV technology is starting to be adopted for IMR activities. The UAV [Cyberhawk] can be remotely-operated by a qualified drone pilot and the inspection engineer highlights the areas of interest for inspecting. Offshore activities are normally performed from a CTV which removes the need for turbine transfers. During inspection the four sides of the blades, namely suction side (SS), pressure side (PS), leading edge (LE) and trailing edge (TE), can be observed, as well as the tower and the nacelle if needed. This method allows the inspection of up to 6 turbines/day with favorable weather [Cyberhawk]. All inspection data acquired on site (e.g. images) are analysed at the inspection centre, where inspection reports are created to detail relevant information relative to the defects such as location, size and severity according with the standard defined in stage 1. This process can take up to two weeks to generate the report from a full-scale campaign. The UAV presents high-quality images capable of depicting defects up to around 5mm, see Figure 6 and Figure 7.

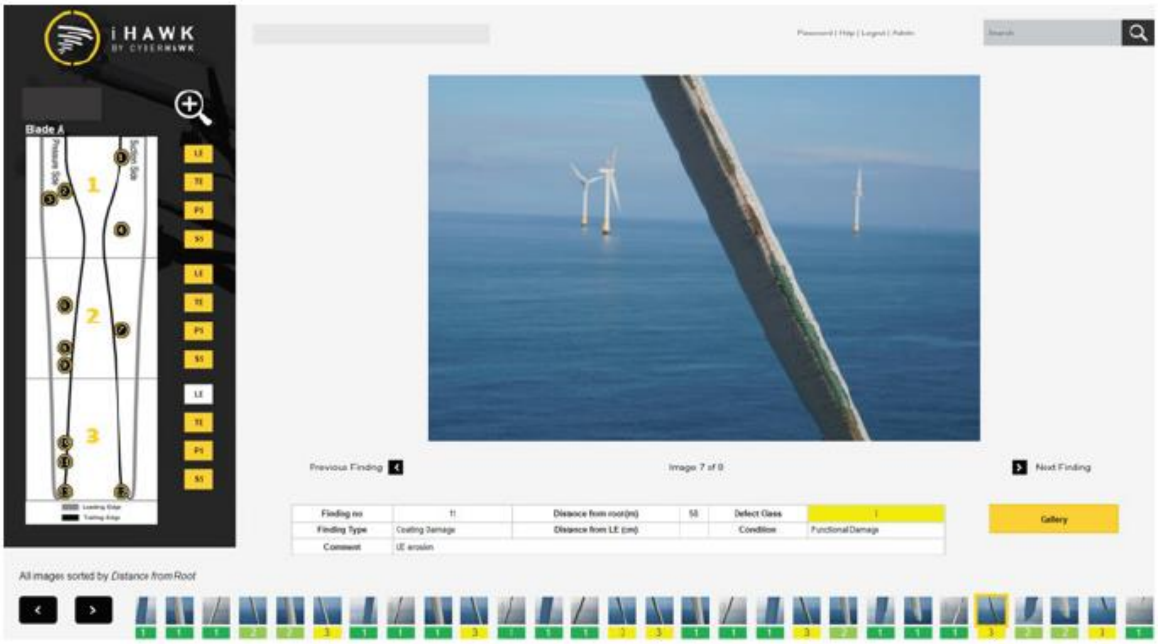

Figure 6. A view of the defects found during a blade inspection, source: [Cyberhawk].

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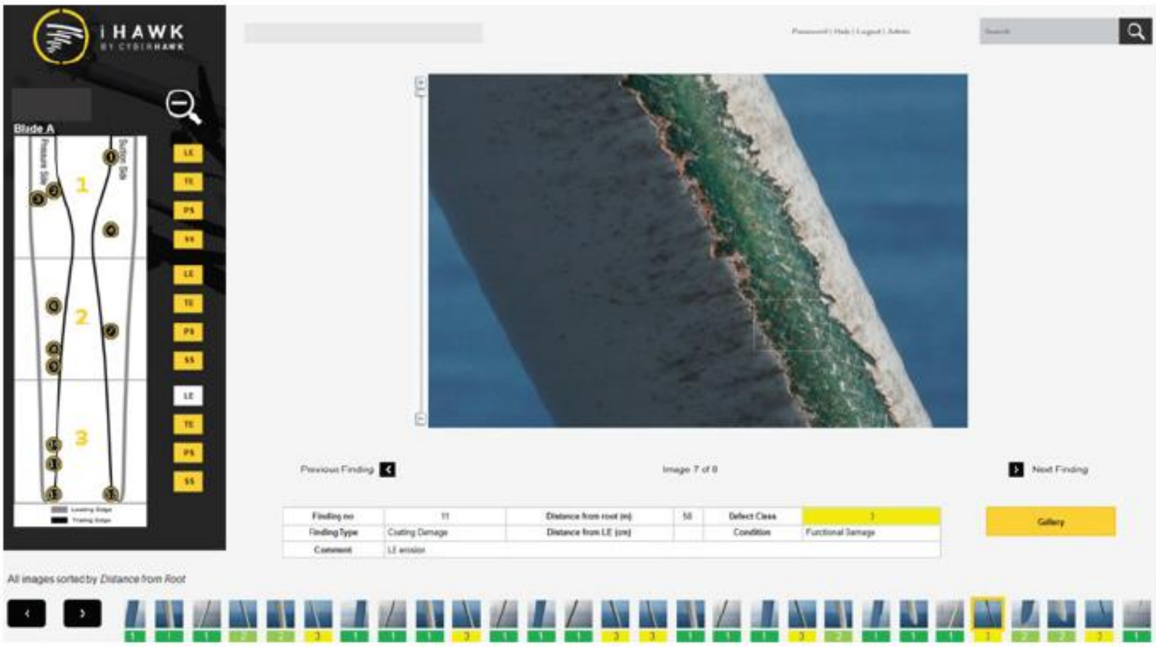

Figure 7. A magnified view of the damage, source: [Cyberhawk].

2.1.2. Proposed new solutions

A new methodology is proposed in the ATLANTIS. An UAV that is transported on a surface vehicle (SV) to the area located close to the inspected structure. The UAV autonomously takes-off and performs a pre-planned route to visually inspect the turbine structure. After the inspection is completed, the UAV will land autonomously on the SV. This methodology aims to create a more regular acquisition of data, with an equal distance between samples, and to easily cover areas out of the UAV operators line-of-sight. The following steps are proposed:

- The SV with an UAV on-board, situated on a pre-defined landing point, moves near to the turbine to be inspected.
- The UAV autonomously takes off and moves toward the blades.
- At medium range (+- 2m) the UAV starts the inspection from the higher placed blade and inspects clockwise each side of the blade, then moves towards the tower from the nacelle cover downwards, covering cylindrical areas.
- The UAV transmits visual data in real-time to an inspection engineer, and stores it on-board, after that, visible coarse flaws in each element can be labelled.
- At any time, with the inspection engineer's indication, the operation can be switched temporarily to a remotely operated mode, for a fine and close range manual inspection of specific flaws.
- At the end of the inspection process, the UAV autonomously lands on the surface vehicle.
- All data is provided and post-processed using the methodologies currently adapted in the industry, such as manual annotation by inspection engineers or automated annotation by computer software.
- Subset of the data critical for maintenance and repair planning is stored and represented in interfaces (e.g., IoT platforms).

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This will allow for a more standardized inspection of all turbines, with less ambiguity, since a more regular and equal framing and distance to the turbine is possible. This method will also avoid transfer of operators from the vessel to the structure for manual inspection routines that are dangerous to the workers. Moreover, with the flaws labelling, more relevant information is passed to the inspection engineers who can provide a quicker analysis of defects.

The operator will be able to use the control system to plan the autonomous or semi-autonomous inspection of multiple assets and to visualize and/or alter the route defined by the inspection planner. The algorithm will compute the best approach and global path of the UAV given the initial position, the wind turbine characteristics and environmental conditions.

Communication between the aerial vehicle and the surface vehicle fitted with the landing platform will be realised via a RF link and the communication between the vessel to the onshore control centre via either a satellite communication link or by connecting to the WindFloat communication infrastructure.

2.1.3. Equipment and personnel requirements

Current	Proposed
▪ **Rope-access**: Requires at least a two-persons team of qualified engineers to scale a turbine; ▪ **UAV**: Requires a qualified UAV pilot and inspection engineer for this type of inspection; ▪ **Elevated platform**: similar to rope-access inspection; ▪ **Ground camera**: is required a static visual device within a wind farm.	▪ UAV ▪ Surface vehicle (Autonomous or Crew Transport Vessel) with landing platform ▪ Control station ▪ Inspection manager ▪ Qualified UAV driver ▪ Vessel crew (if required)

2.1.4. Safety issues and weather limitations

Current	Proposed
The weather limitations related to the turbine inspection are mainly focused around the wind speed, which cannot be higher than 12m/s. In terms of safety issues, there are inherent risks associated with working at heights and in the confined and hazardous environments of turbine nacelles. Moreover, there are added risks of CTV transit and transfer. Accidents can happen mainly during the transfer operations.	Similarly to the current solutions the maximum admissible wind speed is 12 m/s. Since there is no transfer from the surface vehicle to the turbine structure and the UAV operation is autonomous, the safety issues are only associated to people transportation with a surface vehicle, if crewed, which does not pose major safety risks.

2.1.5. Necessary scientific and technical developments

- Autonomous deployment and recovery procedure on a mobile landing area (surface vehicle);
- Hybrid navigation system for path following and remote operation;
- Autonomous 3D navigation for inspection (improve quality and stability of data, recall);

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- Mission planning and obstacle avoidance techniques;
- Augmented reality interface to display visual data and operation status.

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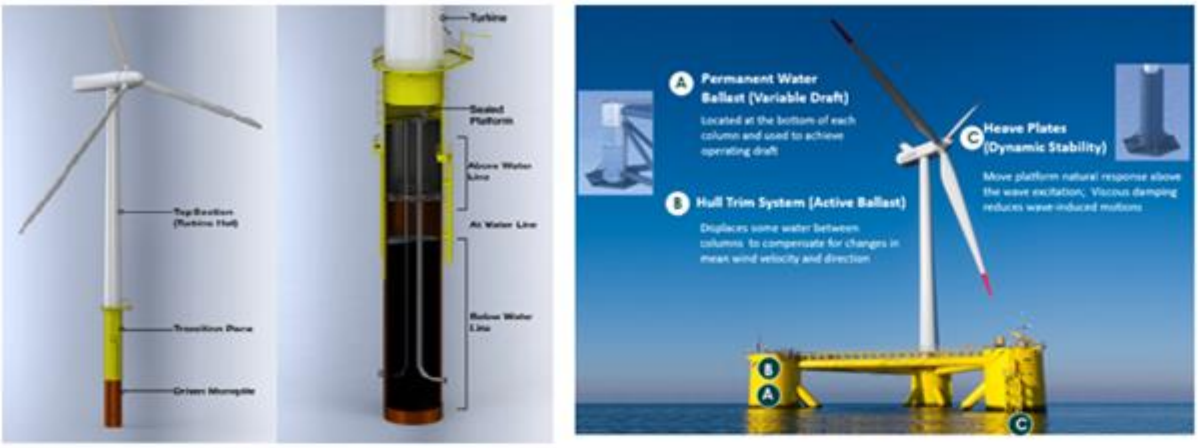
2.2. S2: IMR of the transition piece or the floating structure

The submerged structures of the fixed (Figure 8a) and floating (Figure 8b) wind turbines need to be inspected regularly. Regardless of differences between the specific kinds of offshore wind turbines, the requirements for the IMR operations are very similar in the majority of the aspects and the methodologies used. In all cases these underwater structures require regular inspection in order to check their technical condition.



(a) (b)

Figure 8. (a) Architecture of fixed offshore foundation (b) Semi-submersible floating structure

Floating wind turbine usually uses three floaters partially immersed in the sea. This technology allows coping with higher water depths, typically until 60m.

IMR of submerged structures comprises:

- 3D mapping of the submerged structure;
- TV inspection;
- NDT measurements of weld and anodes;
- Light maintenance work.

2.2.1. Current methodology

Nowadays, submerged structures are typically inspected and maintained by specialized divers and by ROVs. Light cleaning and maintenance operations are performed by divers. ROVs are deployed from the platform or from a support vessel used to transport them to the working place. The surface cleaning is an important facet of the IMR operations because without proper cleaning the little chance exists of obtaining valid results from the non-destructive tests (NDT) such as: visual inspection, ultrasonic testing or cathodic protection.

2.2.2. Proposed new solutions

Due to the complexity of this scenario, multiple new solutions can be proposed, each one solving some of the problems and allowing for better efficiency and less equipment and personnel requirements. Below, a few ideas are presented, with different technology readiness levels (TRL) [Trl20], summed up in Figure 9. The TRL estimation is based on complexity of the specific operation and the current level of technology and research based results.

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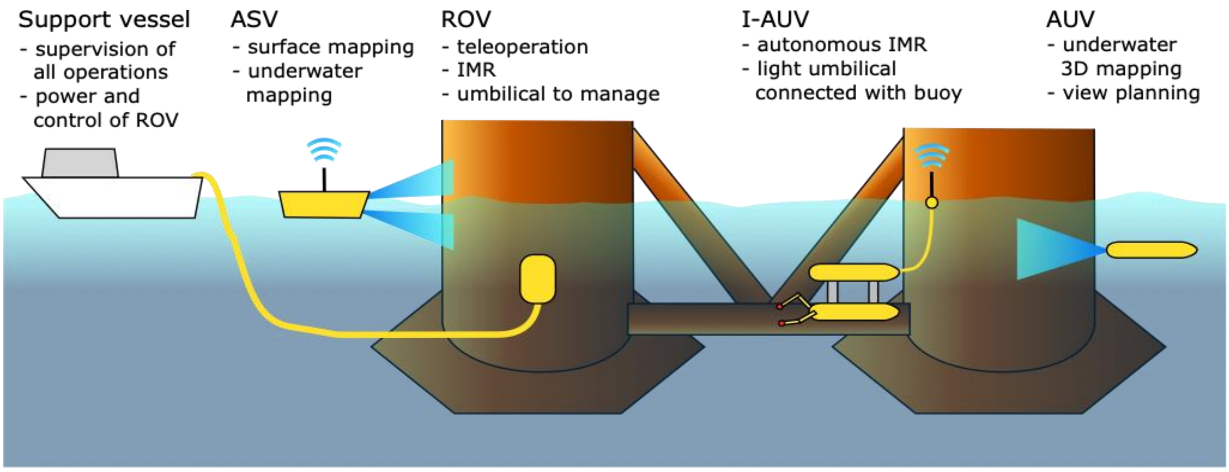

Figure 9. IMR solutions for the transition piece or the floating structure.

A. Cleaning and NDT using a hybrid ROV (TRL7)

Summary : a remote control hybrid ROV will perform IMR operation on the submerged structure.

This solution is based on using a dedicated, multi-purpose ROV, capable of freely navigating and able to land and crawl on the structure, to reach the areas of interest, while keeping contact with the surface at all times. The operations that will be performed by the vehicle include:

- visual inspection of the subsea structures using a video camera,
- cleaning of soft marine growth on subsea structures to be inspected or measured,
- inspection of welds and NDT measurements,
- light maintenance work.

For these operations the ROV will be equipped with a HD TV inspection camera, a navigation low light camera and/or with a multi-beam imaging sonar (MBIS) if the turbidity of the water makes it impossible to observe the structure.

B. Mapping and visual inspection using an AUV (TRL5)

Summary: an AUV will perform a UW mapping of the structure. The detailed mapping can be used by the Hybrid ROV or by another AUVs.

An autonomous robotic platform with hovering capabilities and equipped with optical and acoustic range sensors, can be deployed to perform a visual inspection of the submerged structure. The vehicle should be capable of reaching the starting position, for instance, a reference point in the structure whose position is known, or alternatively, using a GNSS measurements while in surface and close to the area to be inspected.

The vehicle should initiate a mission to map on-line the scenario using acoustic range sensors and, at the same time, compute obstacle-free trajectories to discover the non-mapped parts of the scenario. The view planning algorithms running on the vehicle, will be in charge of designing a survey trajectory around the structure which ensures the full coverage of the area to be inspected using the optical sensors carried by the vehicle. After finishing the mission, the vehicle is recovered and the acquired dataset extracted for post-processing. The outcome of the survey should include images from the inspected structure and its position according to the vehicle navigation, so any identified anomaly can be located with precision.

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C. Mapping and visual inspection using an ASV (TRL5)

Summary: an ASV equipped with aerial and underwater sensors performs a multi-domain full coverage 3D mapping of the structure.

An autonomous surface vehicle (ASV) equipped with 3D sensors for the aerial domain (e.g. stereo cameras, 3D LIDAR) and surveying sensors for the underwater domain (e.g. multi-beam sonar) is transported to the offshore site to perform visual inspection of the floating turbine structure, by carrying out a collision-free close-range navigation procedure to explore the transition piece/floating structures and increase the coverage in areas difficult to access using underwater equipment. With the available sensor payload, it will create a multi-domain 3D map of the structure, both above and under the water line. The output of the inspection will provide a textured 3D model of the floating turbine.

D. Cleaning and NDT using a cooperation between a hybrid ROV and an AUV (TRL4)

Summary: an AUV will perform a underwater mapping of the structure before the scenario A. This detailed map can be used by the Hybrid ROV for its own mission to automatize or, at least, assist the pilot for obstacle avoidance trajectories to reach the point of interest.

In this case, the hybrid ROV will use a map of the structure, generated by the AUV to plan for the best possible landing point and trajectory on the structure surface, to efficiently perform cleaning and NDT operations. In this way the vehicle navigation can be automatised, to simplify control by the operator, and the inspection can be focused on challenging areas by delivering a detailed assessment of the structure condition specially on crucial locations.

E. Cleaning and NDT using an Intervention-AUV (TRL3)

Summary: new methodology by using an I-AUV equipped with 2 manipulators. In this case an AUV will first perform a 3D mapping and the ASV can complete the inspection of the aerial domain: transition pieces / floating structures.

An intervention autonomous underwater vehicle (I-AUV) with hovering capabilities and equipped with one or two manipulators is deployed to perform cleaning of the structure/anode surface using a rotating brush system and later performs a cathode protection measurement with the manipulator and a specially designed tool. The same robot can also perform acoustic NDT inspection or close-range visual inspection with a sensor/camera mounted directly in the manipulator wrist. Cleaning and inspection operations will be performed during hovering manoeuvres or by using one of the manipulators for grabbing the structure. In case of the latter approach, it will probably be possible to remove strongly attached marine growth like molluscs. To facilitate vehicle navigation around the floating turbine it will be necessary to obtain 3D maps prior to the inspection, which can be done with the aforementioned AUV system. The robot should be able to autonomously reach the cleaning/inspection location, perform the cleaning, take measurements and come back to the starting position for recovery.

2.2.3. Equipment and personnel requirements

Current	Proposed
▪ Vessel ▪ ROV ▪ ROV operators ▪ Divers	**Solution A:** ▪ Crawling ROV ▪ Vessel equipped with a crane for launch and recovery operations ▪ Control station with power supply

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	▪ ROV operator **Solution B:** ▪ Hovering AUV equipped with adequate opto/acoustic sensor suite ▪ Small vessel for launch and recovery operations ▪ Control panel (laptop) ▪ AUV operator/supervisor (potentially in the on-shore control centre) **Solution C:** ▪ ASV equipped with cameras, LIDAR and multi-beam sonar ▪ Vessel equipped with a crane for launch and recovery operations ▪ Control panel (laptop) ▪ ASV operator/supervisor (potentially in the on-shore control centre) ▪ **Solution D = A + B** ▪ **Solution E:** ▪ Hovering I-AUV equipped with 1 or 2 manipulators ▪ Specially designed manipulator tools for cleaning and NDT ▪ Small vessel equipped with a crane for launch and recovery operations ▪ Control panel (laptop) ▪ I-AUV operator/supervisor (potentially in the on-shore control centre) ▪ Technician

2.2.4. Safety issues and weather limitations

Current	Proposed
Offshore wind farms are located in areas where severe environmental conditions can be present: winds, tides, swell, marine growth. Worst environmental conditions for IMR activities are: waves 1.5 m Hs and water current around 2 knts. The operating conditions are also limited by the poor accessibility to the underwater infrastructures. This is a big challenge for performing inspection and maintenance work by specialized divers and ROVs will also encounter difficulties to perform inspection and maintenance tasks in these kind of conditions because swell, strong currents will make it hard for ROVs to keep a stable position in front of the locations where tasks need to be done. In	All of the proposed solutions significantly reduce the operation risks by not requiring transfers to the inspected structure and not utilising divers. The only risks that remain are associated with deployment and recovery of the assets, i.e., crane operation, heavy load manipulation, as well as general risks related to the work on a vessel or the use of a small boats. Due to the reduced amount of necessary personnel, the risks are also reduced. Moreover, the operators will be working inside the vessel or in the on-shore control centre to de-risk the operations even further.

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addition, efficient underwater interventions often require additional operations related to the removal of marine growth and cleaning of surfaces from corrosion which should be performed before the NDT.	

2.2.5. Necessary scientific and technical developments

Solution A

The deployment of the ROV into open water like on a wind farm field introduces new constraints because of the severe environmental conditions taking place offshore.

Necessary technical developments include the modification of the current existing hybrid ROV, initially designed for inspection and maintenance of ships' hulls - most of the time performed in protected locations - in order to cope with the specificities of offshore wind farm subsea IMR operations.

To reach these objectives, the actions described below can be undertaken.

- Increase the navigation capabilities in order to cope with the sea stream encountered in wind farm environments (2 knts). This is especially important for the free flying modes to go from one inspection area to another.
- Increase the adhesion capabilities to maintain the vehicle stuck onto the structure when performing inspections close to the splash zone. Keep good locomotion capabilities by reviewing the crawling system's design.
- Modification of the vehicle frame, in terms of architecture, construction materials, and mechanical interfaces, to be adapted to the sea condition and also during launching / recovery operation in sea condition of waves 1.5 m Hs.
- Reduce the umbilical cable diameter to decrease the drag effect.
- Extend the umbilical length to give more range of operation.
- Redesign of the power supply unit to make it lighter and to be compatible with the new design.
- Evolution of the control unit (HW and SW) to fit with the communication requirement of ATLANTIS project.
- Redesign of the telemetry unit embedded on the vehicle for reducing its weight and dimensions.
- Optimization of the position and inclination of the cleaning system nozzles with respect to the vehicle and the structure to be cleaned.
- Design of a new 7-function full-electric Cartesian mode manipulator arm to increase its range of motions, to deploy a water jetting cleaning tool and other inspection tools.
- Implement a precise positioning system using an odometry by image processing, this to be able to correctly position the Roving Bat on the structure manufacturer 3D mapping or advanced 3D mapping delivered by the preliminary AUV operation.

Solution B

For the autonomous visual inspection of the submerged structures, it would be necessary to develop a new payload for the hovering AUV which combines acoustic sensors providing range measurements for real-time mapping of the scenario and optical sensors for the acquisition of the survey images. Other improvements are also expected on the vehicle regarding the power and navigation systems which should ensure its correct operation with a docking station and in front of magnetically relevant structures like

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that of the Wind Float. From the point of view of the software, it will be necessary to develop algorithms for the real time mapping of the scenario, the evaluation of the coverage, the planning of the trajectories and the control of the vehicle.

Solution C

Fostering the completion of data in the splash zone using the ASV. Multi-domain mapping technology can provide helpful and more general overview of any structure installed offshore (of fixed foundations of floating substructures) because there are sensor limitations that create lack of information in a relevant area that need to be properly inspected, the splashing zone. This zone is severely affected by tides, and the accumulation of bio-fouling which may jeopardize the stability of floating substructures and accelerate the degradation of coatings and the corrosion of metallic surfaces.

Solution D

The development of the MARESye technology. This is an underwater perception system for inspection tasks, that consists in a hybrid imaging system that provides dense and accurate 3D information from harsh underwater environments. This sensor is suited to close range inspections to provide high accuracy 3D reconstructions. This technology can be applied in ROV/AUV systems. For instance, the adaptation to perform together with a ROV for creating high quality 3D maps due to the proximity inspection capabilities of this ROV provided by its crawling feature.

Solution E

The development necessary for performing autonomous cleaning and inspection, using a hovering I-AUV, include design of specialised grippers, connection of sensors with the AUV system, development of 3D map based navigation and visual-servoing algorithms, development of manipulation algorithms (cleaning, NDT, CP).

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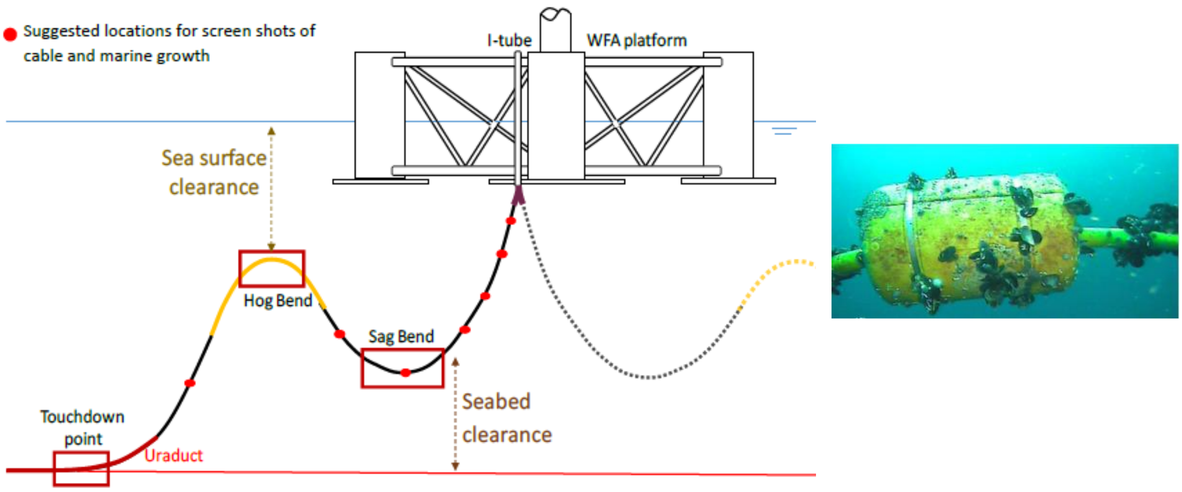
2.3. S3: Repair of underwater floating wind turbine cables protection systems

Subsea power cables failures account for 80% of insurance claims in the offshore wind industry and they are one of the main risks affecting offshore wind farm operations [WindBiz19]. Therefore, protecting subsea power and communications cables is of great importance for offshore industries. The underwater power cables of offshore wind farms are usually protected by burial. This is a well-proven method of cable protection used in other marine industries like O&G. However, at both ends, the cables pass from burial to water and to the wind turbine foundations.

Figure 10a shows, how starting from the floating structure, the cables are transiting down to the sea bed. This free cable section is susceptible to substantial wave and current loads that introduce movement and bending that can lead to deformation, over-stressing, fatigue and abrasion damage. At the outputs of the foundation interface there is also a risk of cable damage due to fatigue, abrasion and impacts from foreign bodies. Marine growth (see Figure 10b) is another important factor to keep under control to protect the cables. Several systems are used to protect the exposed part of these submarine cables. Platform I-tube and subsea buoyancy modules have been incorporated and designed to reduce stresses, wear and fatigue on the cables and riser protectors, bend restrictors, bend stiffeners and Uraduct are common cable protection systems (CPS) used in the offshore industry. These accessories are usually made of polyurethane and, in case of failure, are usually recovered and replaced.

To ensure the correct operation of power cables it is paramount to follow a rigorous policy of inspection and maintenance. With the help of ROVs and divers the condition of the power cables, as well as their CPS, is surveyed carrying out the necessary maintenance and reparation operations. The type of faults to be inspected on the cables are:

- Abrasion damage caused by contact with the seabed;
- Failure of fastening accessories (buoyancy modules, bend stiffener, Uraduct, etc);
- Stresses, wear, and fatigue need to be assessed;
- Cable deviation respect to their initial position;
- NDT measurements.



(a) (b)

Figure 10. (a) Lazy wave configuration with red circles indicating suggested location for video stills. (b) Buoyancy modules with marine growth.

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2.3.1. Current methodology

Nowadays, power cables and CPS are typically inspected and maintained by specialized divers and ROVs. While inspections are mostly performed by ROVs, light cleaning and maintenance operations are usually carried out by divers.

According to [DNVGL-RP-0360], after installing the power cable it is necessary to perform an initial inspection to determine its position and condition as well as the CPS state. After the initial inspection, regular inspections must be carried out to ensure that the design requirements are still satisfied and that no significant damage has occurred. The inspection programme should at least address the following points:

- Exposure and depth of burial of buried or covered cables, if required by design, regulations or other requirements;
- Clearances, including mapping of length, height and condition of end supports;
- The condition of the artificial supports installed to reduce the free space;
- Scour, settlement, sinking or instability of the local seabed affecting the integrity of the cable;
- Sand wave movements that affect the integrity of the cable;
- Cable settlement in case of exposed sections;
- The integrity of cable protection covers (e.g. pads, covers, sandbags, gravel slopes, etc.);
- Mechanical damage to cables;
- Significant residues on or near the cable that can cause cable damage.

Special attention must be paid to the following items, by underwater close inspection:

- The functionality of the supports and guides and their integrity (e.g., cracks in the welds);
- Damage or displacement (e.g., due to the impact of a ship or the laying of a foundation);
- Corrosion on the J- or I-tubes;
- Damage on the coating;
- The extent of marine growth.

After completing an inspection, the most common maintenance and repair operations to be performed are:

- Non-destructive testing;
- Remedial burial of cables;
- Cable replacement and repair joining;
- Cable protection systems replacement;
- Subsea cutting and clamping;
- Removal of foreign objects;
- Water Jet cleaning.

In the case of large cable segments, inspections can be done using AUVs however, in the case of CPSs, (such as riser protectors, bend restrictors, bend stiffeners and Uraduct) the use of ROV systems is more common. Maintenance and repair operations can also be performed by ROVs to some extent. However, when depth allows, many of these tasks are performed by divers, especially those requiring good dexterity.

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2.3.2. Proposed new solutions

In the ATLANTIS project, we propose the use of new tools to simplify, and in some cases even automatize, both the IMR operations. We propose a combination of an AUV and a hybrid ROV both equipped with state of the art mapping and navigation tools that together will be able to inspect both the cable and CPSs as well as perform some of the maintenance operations.

A. Mapping and visual inspection using an AUV (TRL4)

This task is similar to the task described in section 2.2.2-B. The AUV will be deployed by a support vessel close to the cable that must be inspected. The cable segment and the CPS to be inspected will be defined by the offshore wind farm owners. The AUV will navigate across the environment to collect visual and acoustic information from the underwater scenario. Instead of performing a predefined survey pattern, the AUV will be equipped with control algorithms that allow it to collect data not only from the seabed but also from the wind turbine foundations and CPSs, while preventing it from colliding with any of these elements. When the automatic inspection ends, the AUV will ascend in the water column and upload the information retrieved from this survey to the vessel. Once the data gathered by the AUV is post-processed, specific areas will be identified where more detailed inspection or maintenance operations will be required by the hybrid ROV.

B. Cleaning and close inspection with a hybrid ROV (TRL4)

The ROV will be deployed from the vessel and it will navigate to the spot zones in order to conduct some of the following activities:

- Video inspection of specific CPS:
  - I-Tube connection;
  - bend stiffeners and Uraduct;
  - touchdown protections;
  - buoyancy modules including straps, bolts and nuts.
- Cleaning of soft marine growth by water jetting or brushing.

The need for cable protection replacement or for cable repair will be estimated from the data gathered by both the AUV and the ROV. General policy is to replace the cable instead of repairing. In this case, the cable has to be lifted and repaired above sea level. The assistance of the hybrid ROV can be also required for this operation.

To improve the performance of the ROVs in both inspection and maintenance tasks, the use of new tools such as 3D vision from stereo cameras, structure from motion techniques or an underwater laser scanner can be proposed. To improve the ROV dexterity, new intervention algorithms will be tested to allow an automatic or semi-automatic cleaning of soft marine growth using a water jet or a brush, and NDT measurements. The exploitation of these new technologies will help to reduce the time for IMR and therefore reduce costs.

2.3.3. Equipment and personnel requirements

Current	Proposed
▪ Support Vessel with cranes and crew ▪ ROVs ▪ ROVs operators	▪ Support Vessel with cranes and crew ▪ ROV ▪ ROV operator

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▪ Divers For this kind of operation the ROV are typically equipped with HD video cameras and multi-beam sonar.	▪ AUV ▪ AUV control station ▪ AUV operator ▪ Divers (to a lesser degree) For this kind of operation both the AUV and the ROV can be equipped with stereo camera and/or a 3D laser system and a multi-beam sonar.

2.3.4. Safety issues and weather limitations

Current	Proposed
Safety issues concentrate on vessel operations, heavy load manipulation, deployment and recovery, as well as diving issues. Typical inspection operations can only be performed in certain weather conditions, which greatly complicates their planning. The state of the sea has to remain appropriate for the deployment and recovery of all assets and potentially divers. This means that there is a high risk of delays and interruptions during the inspection.	Safety issues include crane operations and load manipulation when deploying and recovering the vehicles. The weather limitations for these operations should follow the industry standards. The AUV operation is less impacted by weather conditions however, weather conditions affect their deployment and recovery because the workload of divers is reduced and the safety is improved.

2.3.5. Necessary scientific and technical developments

Inspecting the status of components such as I-Tube, J-TUBE, FLANGE or Buoyancy modules requires several scientific and technical developments. The most important ones can be summarized here.

A. Mapping and visual inspection using an AUV

For the autonomous inspection of the cables and protection systems, it will be necessary to equip a hovering AUV with a combination of acoustic and optic sensors. Using data provided by sensors, a control algorithm and a system for detecting the elements will be developed. The combination of these two systems allow to inspect the cables and its CPS without the need for a predefined trajectory that would be impossible to have due to its dynamic nature. Other improvements are needed for the vehicle in relation to navigation, as well as the development of algorithms for real-time mapping of the scenario.

B. Cleaning and close inspection with a ROV

To improve the pilot's perception, MARESye technology [Andry2020] can be used. This underwater perception system provides dense and accurate 3D information of complex underwater scenes. This sensor provides high-precision 3D reconstructions for short-distance inspections. It is expected that with it, high quality 3D maps will be created. These maps will enable a very accurate assessment of the state of the CPS.

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2.4. S4: Underwater monitoring over extended time periods

Subsea power cables failures account for 80% of insurance claims in the offshore wind industry and they are one of the main risks affecting offshore wind farm operations [WindBiz19]. Cable maintenance strategies are still fairly immature in this industry and robots are needed to inspect and repair connection of the offshore power plant to the onshore power transmission system. This connection is composed of two different types of underwater cables: the array cables - interconnecting the turbines and the offshore substation and the export cable - connecting the offshore substation with the onshore infrastructure (see Figure 11).

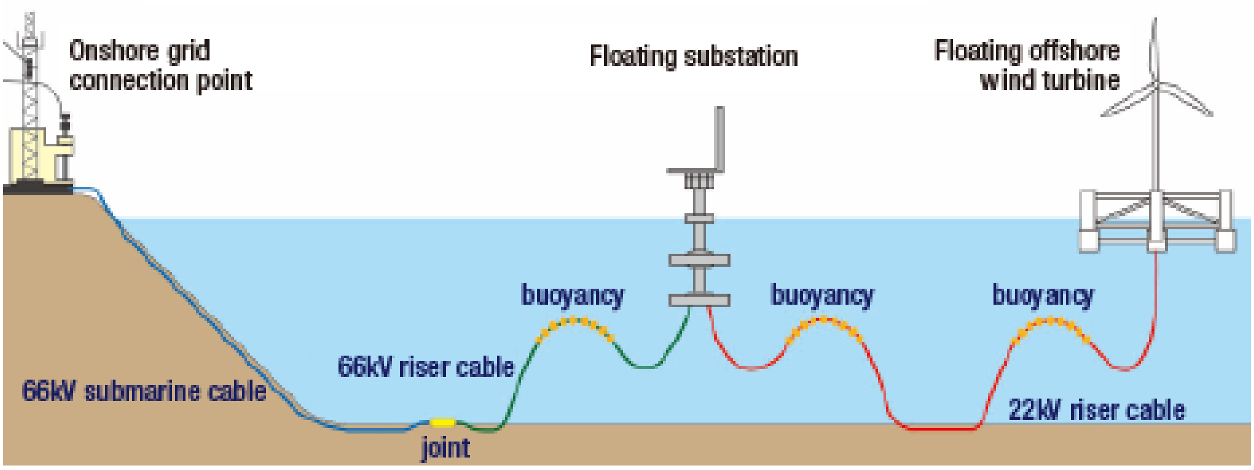

Figure 11. Floating offshore wind turbine network connection, source: [Fuk16].

“*Export cable or array cable faults have serious implications on the amount of energy that can be harnessed and utilised from an offshore wind farm, so proactive intervention before they happen as well as quick action when they do occur make all the difference to minimising any loss in revenue*” Director of Power Cable Maintenance at Global Offshore, Andrew Lloyd.

Cable failures can shutdown entire sections or even an entire wind farm. They can be caused by:

- A reduction of the thickness of the welds, leading to regions of high electrical stress and degradation of the insulation;
- A failure on the outer zone of the cable diameter, which is the cable core’s most susceptible surface to direct mechanical damage;
- A failure at the copper tubing surrounding the fibre optic cables;
- A failure of the outer plastic shield of the fibre optic cables not uniformly semiconducting due to a defect in the manufacturing process.

Moreover, physical processes within the water flows around the array cables should be monitored at spatial scales ranging from centimetres to kilometres, and over time scales from seconds to months. These physical processes impact the local scour development at array cables, and scour cable connections (array and export) which can jeopardize the structural integrity of the offshore platform. Although no problems with scour development were detected in the WFA, it is a common problem in the industry.

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There is a clear need for automated solutions that could acquire information in a frequent basis due to the cost of bathymetric surveys, mainly obtained using vessels. Deploying any survey vessel can be time-consuming and costly since the vessel may not be near the site and transporting it there may take some time. By de-risking the subsea cable failure, the offshore energy grid will be more reliable due to an additional control over the costs of the offshore cables throughout their lifetime. At the present, offshore farm operators combine on-site inspections with monitoring campaigns however, these inspections present significant challenges related to the cost, health and safety of personal and equipment involved.

Autonomous systems are capable of operating autonomously without the need for maintained visual line of sight of the operators. These are systems that can operate from being manually deployed and piloted remotely to fully autonomous systems that are permanently stationed offshore. However, autonomous underwater vehicles (AUV) are still very expensive to operate on multi-day missions away from shore due to the manned surface vessel required to support recharging. Persistent undersea operation is dependent on effective and accessible underwater docking, data transmission and charging mechanisms for AUV.

This scenario intends to extend the endurance capability of robotic platforms and systems aiming to save costs, efforts and time of launch and recovery. Continuous condition monitoring systems aim to reduce operational costs, reduce the requirement for offshore access and also, to increase reliability and safety, since fewer personnel are required, less time is required on site and less fuel is used (e.g., supporting vessels). A detailed understanding for the value of data acquired in a frequent basis can be crucial as an early warning system by identifying areas affected by corrosion or other unknown defects, to improve the predictions of morphological features such as, sand waves around subsea cables, and to develop a decision support tool for measuring design fatigue life, modelling of scour and their evolution over time, as well as, for validating design assumptions and thereby optimizing technical assumptions which lead to more cost efficient designs in future.

2.4.1. Current methodology

Measurement techniques have been used in intervals of between six months and five years:

- Sidescan sonar (vessel based);
- Multibeam sonar (vessel based);
- Equipped ROV;
- Visual inspection or video footage.

The AUV technology with varying degrees of autonomy is already being tested for the offshore wind sector and primary targeted applications include the subsea survey where AUV can be used to provide high-resolution bathymetric surveys for monitoring seabed conditions.

The AUV docking stations were mostly studied and developed in research projects or for specific systems, on demand. One of the solutions deployed in realistic conditions is the MBARI docking station designed to connect to the Monterey Accelerated Research System (MARS) cabled observatory (see Figure 12) [Mbari].

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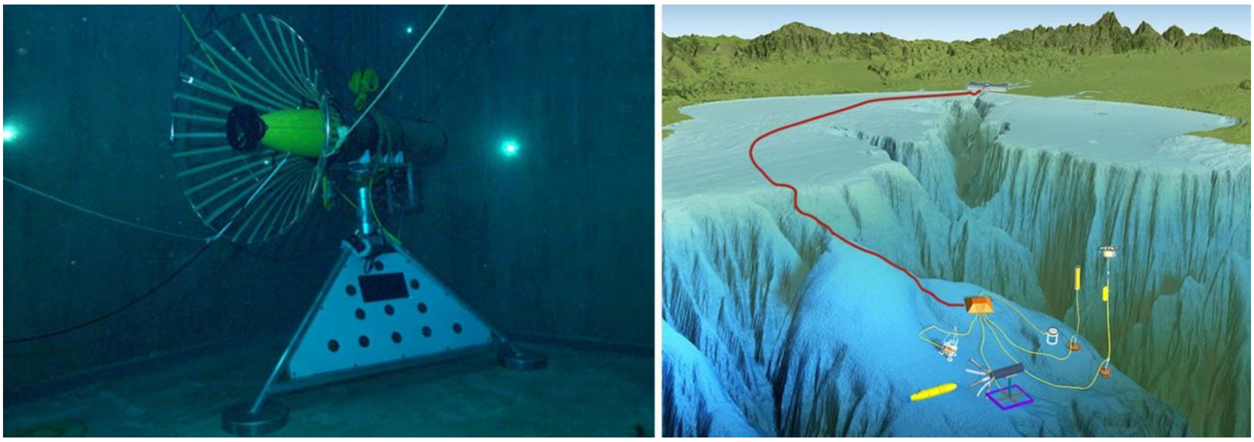

Figure 12. MBARI docking station for MARS cabled observatory, source: [Mbari].

Figure 13. Blue-Logic universal docking station (landing platform), source: [Blue].

Figure 14. MODUS docking station, source: [Modus].

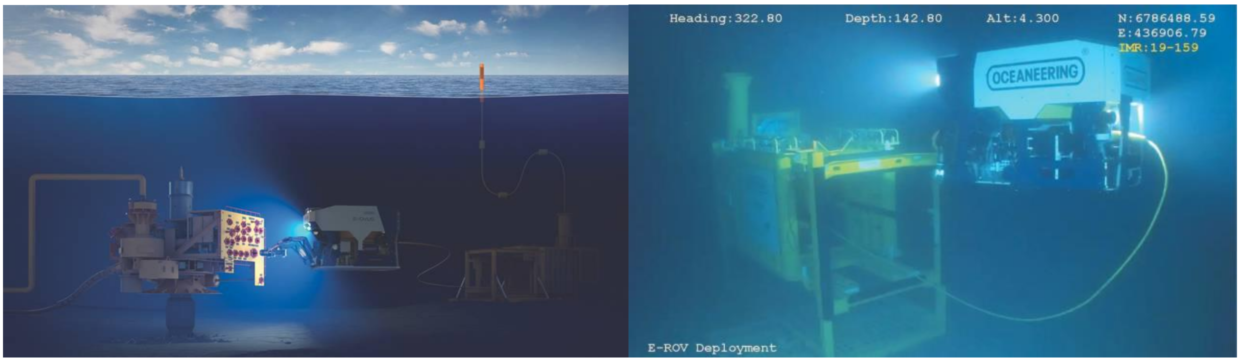

Figure 15. E-ROV concept by OCEANEERING, source: [Ocean].

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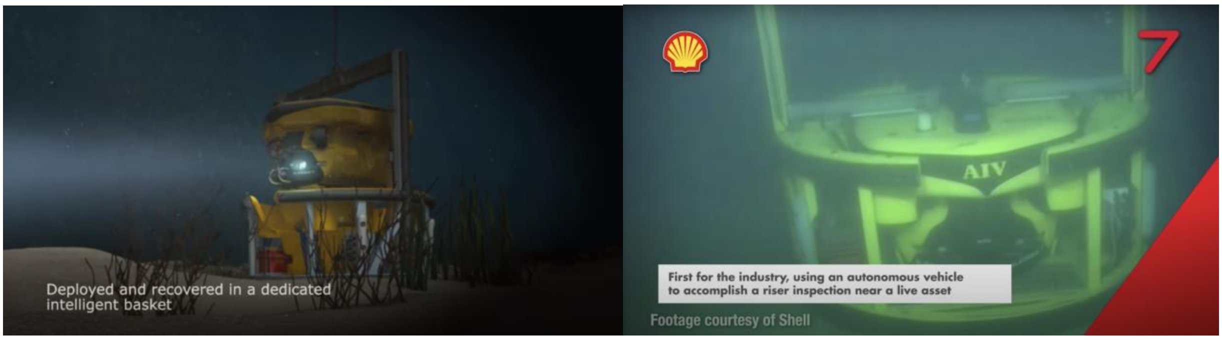

Figure 16. Subsea7 autonomous inspection vehicle (AIV) concept, source: [Subsea7].

Figure 17. Residential ROV (RROV) increasing operations efficiency, source: [Ikm].

Recently, there is an increasing trend in the industry to develop permanent deployment solutions based on semi-autonomous underwater vehicles. The interest in these systems is mostly driven by significant cost reduction due to minimal personnel and vessel time requirements. One of the examples is the Blue-Logic subsea docking station [Blue], presented in Figure 13. Another solution being actively developed is a docking station from Modus (see Figure 14), targeted at the offshore wind farm market [Modus]. A big player in this field is the Oceaneering company which is testing docking of AUV and ROV [Ocean] (see Figure 15). Another subsea leader industry, Subsea7, is cooperating with Shell to deliver an intelligent deployment and recovery platform for an AUV [Subsea7] (see Figure 16). Lastly, a residential ROV (RROV) solution is delivered by the IKM company [Ikm] (see Figure 17).

2.4.2. Proposed new solutions

In the ATLANTIS project, we propose a new solution, based on the AUV and a light-weight battery powered docking station, equipped with a satellite link. The docking station will be deployed from a vessel to be fixed on the bottom of the sea by gravity, close to one of the wind floats. The satellite link will be achieved by connecting the docking station with an antenna installed on a floating buoy. The docking station will stay on the seabed for the time of performing a survey and inspection of the whole wind farm. The AUV will be used to complete all required tasks (potentially related with the other scenarios), like bathymetry, sonar mosaicing, visual inspection, laser scanning etc. The data will be stored and integrated and will constitute representation of the cable array and export cable. The docking station will be used to charge the AUV, transfer collected data, monitor the state of the robot and command new missions, all from the onshore control centre. When the inspection is finished, the docking station and the AUV will be recovered together using the support vessel. The procedure is depicted in Figure 18.

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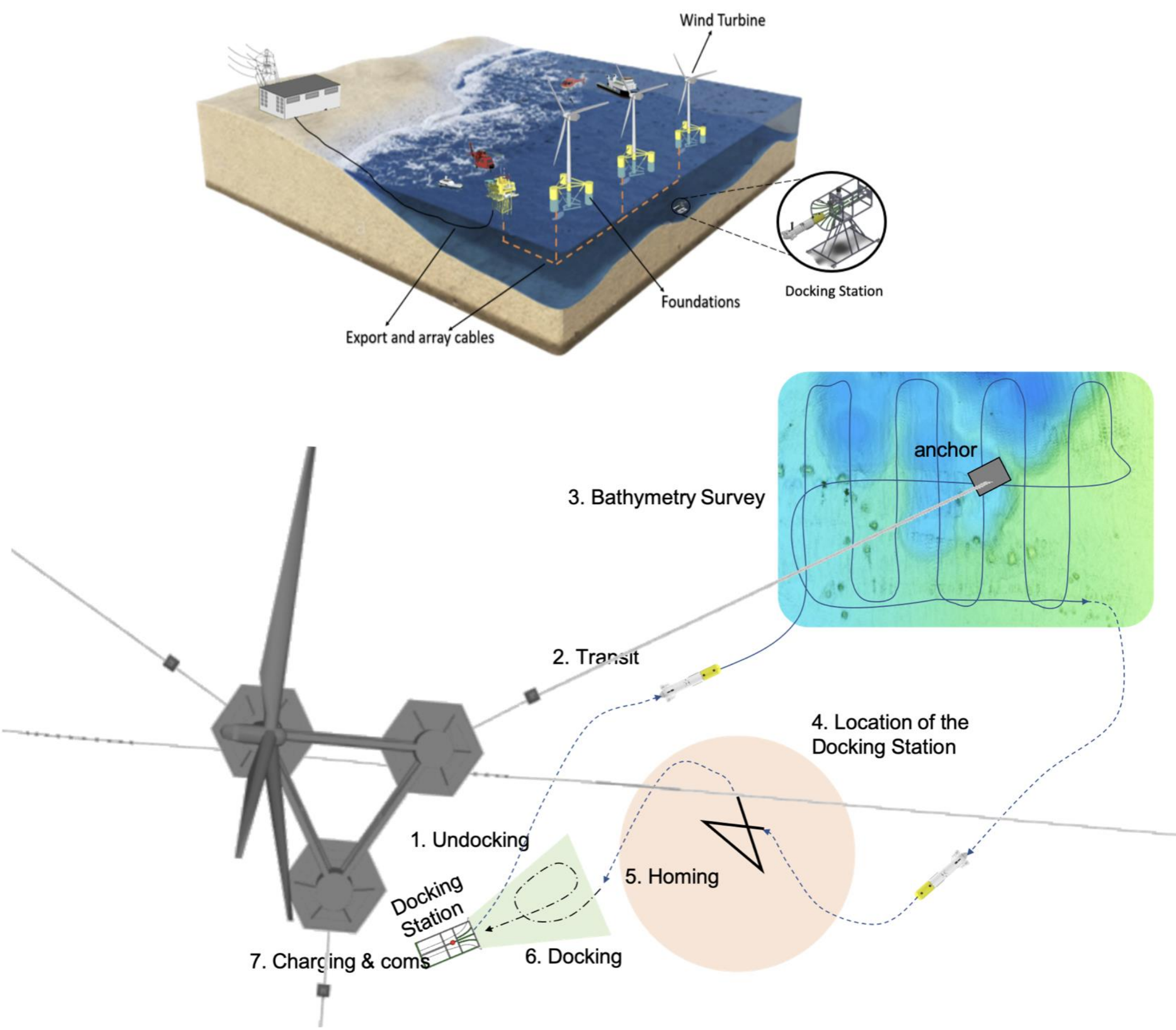

Figure 18. Semi-permanent AUV deployment concept.

The procedure will be controlled from an onshore centre where the operator can schedule surveys over the remote assets and monitor the progress of each survey. During the periods when the AUV is undocked, the control centre will receive limited information regarding the state of the AUV, connectivity and position. The communication done between the AUV and docking station in undocked state is done through available acoustic signals.

The results of the periodic inspection of the underwater assets will be downloaded from the AUV once it gets into docked state and then retransmitted to the control centre via the satellite link. The operators will be able to access the received data. Images and sensor output will be accessible using the control centre visualization tools and will be stored for reference in the RMCC database.

The control centre will assist the operator deploying different monitoring activities by providing a sample plan of actions undertaken by the AUV based on the high level goals set by the user. The plan can be visualized and reviewed by the user before deployment. The user can also amend the plan. The algorithm will compute the best approach and global path of the AUV given the initial position of the robot, the localization of the docking station, the characteristics of the area to be surveyed and environmental conditions.

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The main topic of this demonstration is the docking procedure and the AUV residency features including charging, data transfer and on-shore command centre integration. The docking procedure will follow developments presented in the LOONDOCK project [Loondock]. The AUV and the docking station will be both equipped with acoustic modems, allowing for range based localisation, using a special, star-shaped AUV motion pattern. Moreover, the docking station will be equipped with light beacons used as guidance at the final stage of the docking. The docking station will be upgraded to include a battery system with an inductive charging solution, capable of recharging the AUV a couple of times, to be able to present a multi-day residency of the system. The battery will also constitute the source of power for the AUV locking mechanism, light beacons and satellite link.

2.4.3. Equipment and personnel requirements

Current	Proposed
Typical subsea inspection involves a vessel capable of deploying AUV and/or ROV. This vessel is occupied for the whole duration of the wind farm inspection, which is a multi-day task. The crew consists of sailors as well as technicians and highly trained inspection specialists, that have to stay on the vessel for the time of the operations. Moreover, it may be required to use specially trained commercial divers, depending on the operations performed.	The presented methodology requires the use of one AUV and one docking station, deployed and recovered by a support vessel. Thus, the vessel is only needed at the beginning and at the end of the multi-day inspection. The required personnel will be limited to the basic vessel crew, without the need for divers - the docking station is fixed to the seabed by its own weight. At the onshore control centre the operation of the robot requires one technician.

2.4.4. Safety issues and weather limitations

Current	Proposed
The safety issues of a typical inspection concentrate around the safety related to the vessel operations, heavy load manipulation, deployment and recovery, as well as diving issues. The typical inspection operations can only be performed in certain weather conditions, which greatly complicates their planning. The state of the sea has to remain appropriate for the deployment and recovery of all used assets and potentially divers. This means that there exists a high risk of delays and interruptions during the inspection.	No significant safety issues are foreseen, due to the lack of use of divers. The identified safety issues include crane operations and load manipulation when deploying and recovering the assets, as well as installation of the satellite antenna on the wind float and its connection to the docking station. The weather limitations for these operations should follow the industry standards. The AUV operation is not impacted by weather conditions, however the satellite link may be disrupted and autonomous emergency behaviours have to be implemented in the AUV for this possibility. Another important advantage of using a semi-permanent deployment system, as presented here, is the ease of planning the inspection in terms of weather conditions. These conditions only matter during the deployment and recovery of the system and in the event of poor conditions the AUV can stay docked, while the vessel is awaiting a recovery window.

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2.4.5. Necessary scientific and technical developments

In the ATLANTIS project, the described methodology will be demonstrated using the AUV with its docking station. Both assets will have to be equipped and updated according to the new requirements.

The necessary scientific and technical developments will include:

- Development of the inductive charging device for AUV;
- Development of a satellite communication link for the Docking Station;
- Upgrade of the AUV to support the inductive charging;
- Installation of the necessary sensor suite on AUV;
- Upgrade of the Docking Station to include sufficient battery capacity;
- Development of autonomous homing and docking algorithms;
- Development of autonomous emergency algorithms;
- Integration with the on-shore command centre.

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2.5. S5: Underwater close-range inspection of foundations

The four most commonly used offshore wind turbine foundations include monopile, tripod, gravity based, and jacket (see Figure 19):

Monopile: A monopile is a steel tube of a large diameter that is driven into the seabed by using a large hydraulic hammer;

Tripod: A tripod is a steel tube that protrudes out of the ocean surface where an anchor pile is driven into the seabed to hold the foundation in place. It provides enormous stability against bending moments and has the ability to resist very strong vertical forces, as well as bending moments induced by the turbine and the waves;

Gravity-based: A gravity-based foundation is a very heavy displacement structure usually made of concrete, which applies vertical pressure to the area below, and stands on the seabed. The size and weight of the foundations make their transport and installation cumbersome, and the seabed must be prepared by dredging and backfilling material to install the foundation;

Jacket: A jacket foundation is a lattice-type steel structure, usually square in footprint and constructed of thin tubes, which is exclusively used for large water depths.

Figure 19. Clockwise: monopile, tripod, gravity based and jacket foundations, source: Principle Power.

These structures are mostly used in shallow waters, however with the increase of water depth, the construction costs of fixed-bottoms offshore wind turbines significantly increase (especially when water depth exceeds 50 meters). As for the *Wind Float Atlantic*, semi-submersible floating structures have been adopted (Figure 20). The floating structure is anchored to the seabed through anchoring systems and serves as a base platform for installing wind turbines.

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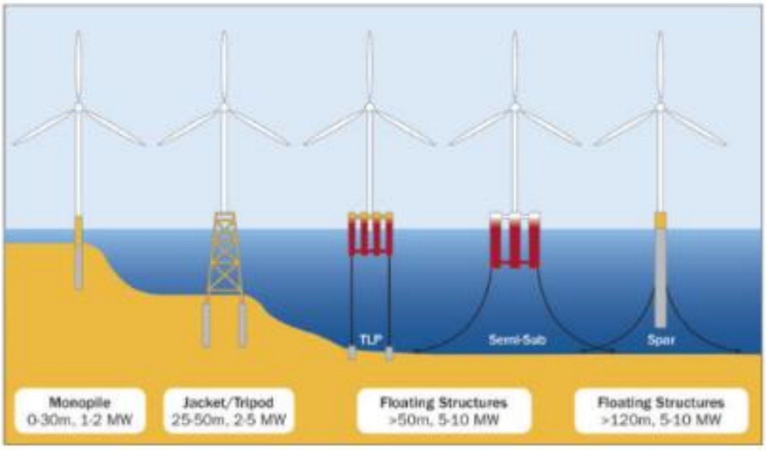

Figure 20. fixed and floating structures, source: Principle Power.

As described in [Roddier2011], sea anchors can be secured to the sea floor prior to towing the floating wind turbine platform to the installation site. When the floating wind turbine platform is moved into position, the mooring lines can be fastened to the columns and tightened to a predetermined tension.

In general, the tower is mounted over one of the columns and the mooring lines are arranged in an asymmetric manner, with more of the mooring lines coupled to the column supporting the turbine tower than to the other columns. For example, if four mooring lines are used, two of these lines are connected to the column supporting the tower at an approximately 90-degree angle interval and one line is connected to each of the remaining columns see (Figure 21).

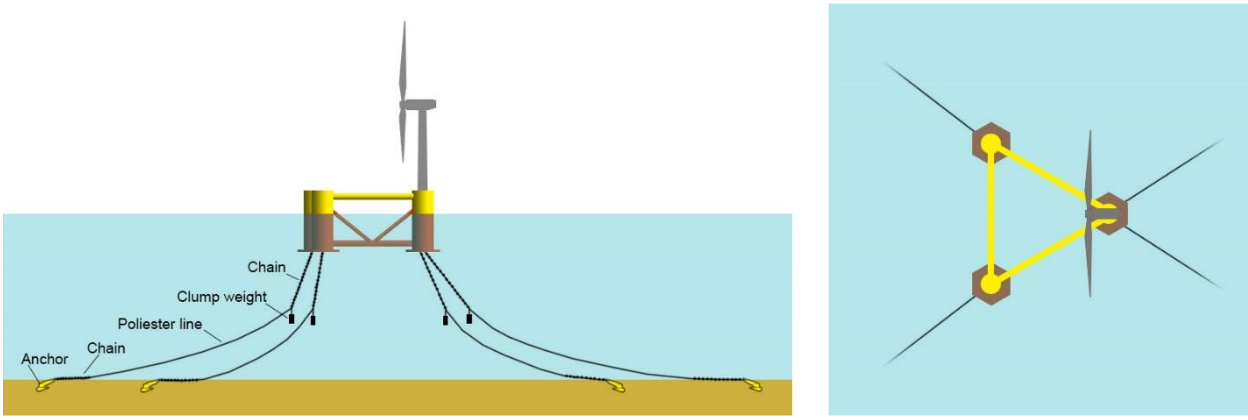

Figure 21. WindFloat mooring example, source: Principle Power.

The mooring lines can be conventional catenary shaped lines composed of a combination of chain, wire ropes and drag-embedment anchors (see Figures 22 and 23). Alternatively, the mooring lines can be composed of taut polyester sections, and also include clump weights, which are heavy masses suspended to sections of the mooring system. The anchors are embedded into the sea floor and a section of chain is coupled to the anchors. Polyester line can be attached to the chain to provide some elasticity to the mooring line. Where used, the opposite end of the polyester line can be coupled to an additional length of chain that is attached to one or more tensioning mechanisms on each of the columns. Heavy clump weights can be attached to the chains that are connected to each of the columns to lower the angle of

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the chains to the columns, and the mooring lines can be tensioned by mechanisms coupled to each of the columns.

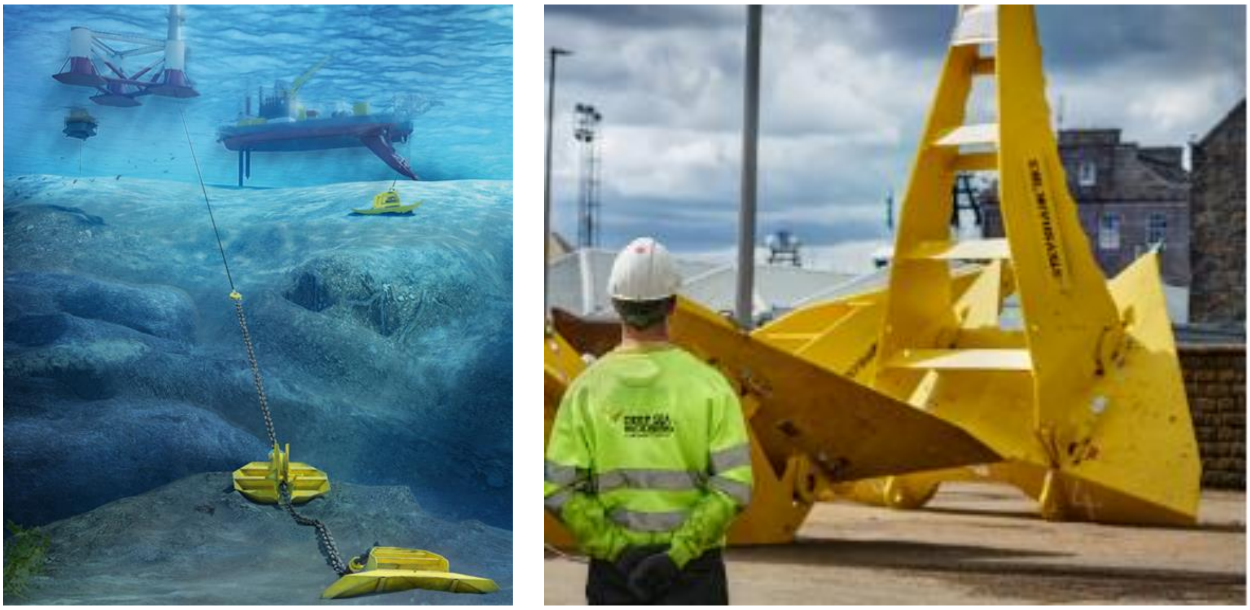

Figure 22. Depiction of a mooring line like the ones used on a Wind Float (Left) and its anchor (Right) (pictures from Vryhof).

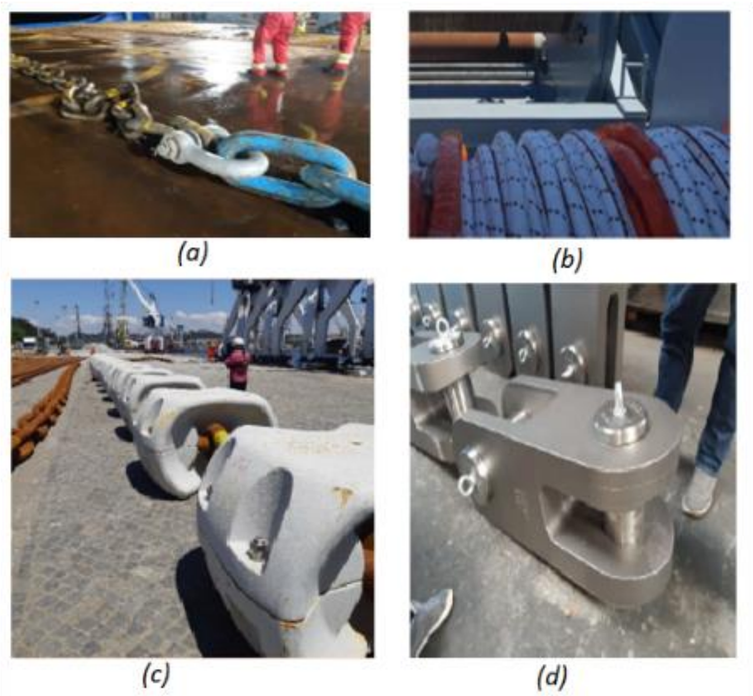

Figure 23. (a) Chain, shackles and safety pins; (b) ropes and splice covers; (c) clump weight and clump weight fasteners; (d) connectors and safety pins.

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The technical requirements from offshore IMR activities on wind turbine foundations include: motions of the platform and the loads experienced by the mooring lines when subjected to the distinct sea states (waves, wind, and currents) and the assessment of all marine growth, scale, rust and coatings. The surface cleaning will be also an important facet for IMR operations since that, without a proper cleaning, little chance exists of obtaining valid results from non-destructive tests (NDTs) such as, visual inspection, ultrasonic testing, and acoustic emission, electromagnetic or cathodic protection.

For example, in underwater tripod foundations, the examination of the welding seams for detecting cracks is an arduous and time-consuming work for divers since they need to remove crustaceans and algae from the welding seams and then, create an electromagnetic field around the spot and place iron filings on top. This task is hugely important as the offshore foundations are conventionally welded and exposed to strong loads by waves, wind and salt water.

2.5.1. Current methodology

Typically, fatigue and abrasion damage, cracks of loading bearing elements and abrasion damage at interface between elements are the most common foundation failures. They are mainly caused by sea conditions, storms and structural performance. The following equipment shall be inspected (Figures 22 and 23):

- PMCs - Platform Mooring Connectors;
- Chains;
- Clump weights and soil condition around them;
- Anchors.

Prior to the execution of the IMR task some documentation is prepared describing the operation. The documentation usually includes:

- The type of inspection to be executed;
- The objective to be accomplished;
- The preparation works which are required before performing the operation;
- Limiting factors to be considered such as weather, lightning conditions, visibility, equipment calibration, etc;
- Instructions detailing the type of measurements to be acquired, as well as the quantity, frequency and procedure to ensure an optimal outcome;
- Description of the asset and key points to be inspected, generally depicted on a schematic of the installation, together with details such as reference points to be used, landing points for the boat, etc;
- Details on the reporting such as the type of data, its codification and the format of submission and communication protocol in case of anomaly detection.

To perform the work, it is necessary to mobilize an appropriate vessel, equipment and personnel to the site. The method to perform the inspections is water-depth dependent. Down to 30 m ROVs and divers are used, although the use of divers has become obsolete due to HSE (Health Safety and Environment) concerns and weather limitations. For depths below 30 meters only ROVs are deployed.

The outcome of the inspection is a set of videos with display of date, time, position, bathymetry and name of the operation. Typically, operations include cleaning, NDT, visual inspection (both general and at close range) and marine growth thickness and twist measurement along the mooring lines and cables.

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2.5.2. Proposed new solutions

New developments focus on the achievement of two objectives: improving inspection methodologies and systems to reduce the duration, associated costs and number of technicians required on the field; and improving the quality of data and the efficiency on their acquisition.

The first objective should be tackled through the automation of current solutions based on robotic platforms that can execute the IMR tasks with less resources. There are different approaches that could be adopted with progressive level of complexity however, the final concept should be based on a docking station transported from shore with the help of a surface vessel, that navigate close to the elements to be inspected, starting from the anchoring points on the WindFloat and then moving along the mooring lines down to the anchor, while carrying the set of sensors and actuators required to perform the tasks.

The second objective affects the type of sensors which need to be used in the AUV, and the format in which their information will be delivered to ensure better decision making. The solution should include capabilities such as visual mapping for the inspection and posterior location of anomalies, the development of 3D laser scanning technologies for marine growth assessment and the development for the underwater domain of well-established NDT techniques such as: AET, ACFM, GWT, or even Computed Tomography using gamma rays or X-rays. Other developments with potential for the interpretation of inspection results are the application of mapping and localization techniques for the referencing of inspection data, and image processing and machine learning algorithms for the automated detection of failures and the tracking of changes over time.

A proposal for a new solution dealing with these objectives could be: a robotic platform with hovering capabilities is deployed on the wind farm. Once the mission is initiated, the vehicle should be capable of reaching the starting position, for instance, the connection between a mooring line and the WindFloat, and then, with the assistance of its perception systems, following the mooring line at a close distance (~1m) along all its length down to the sea floor where the anchor is placed. After surveying the anchor and its surroundings, the vehicle should return to the starting point following the mooring line again, but facing it from the opposite side to ensure a better coverage. During this operation, the sensor suite of the vehicle should be capable of acquiring images and range data (possibly from a laser scanner), as well as performing NDT at selected locations (cleaning of the locations may also be required). The operation should be repeated for all the mooring lines before completing the mission and uploading the acquired data to the control centre. The post processing of this data should merge the vehicle navigation with sensor data in a SLAM framework to produce a visual 3D reconstruction of the moorings, where faults can be detected and its location determined. Algorithms for automated detection of failures should indicate to the human operators the areas of concern. The acquired data annotated with failure information constitutes a representation of the mooring line.

In concordance with the described concept, a second one, this time dealing with more focused inspection of key elements, could consist on a vehicle that will locate and navigate into predetermined points of interest (e.g. anchors, clumps and safety pins) and will use a manipulator to grab and attach to the structure to perform a detailed 3D reconstruction of the structure using a 3D imaging system. It will create a coarse reconstruction in real-time to check the completeness of the structure exploration.

The procedure will be controlled from an onshore centre where the operator can schedule surveys over the remote assets and monitor the progress of each survey. During the periods when the AUV is undocked, the control centre will receive limited information regarding the state of the AUV, connectivity and

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position. The communication between the AUV and docking station in undocked state is done through a low speed acoustic signal.

In the case of using an ASV, the data will be retrieved continuously during the survey via a satellite link (best effort in the available throughput) or the WindFloat infrastructure. The control centre will assist the operator deploying different monitoring activities by providing the plan of actions undertaken by the AUV or the ASV based on the high level goals set by the user. The plan will be visualized and reviewed by the user before deployment. The user can also amend the plan. The algorithm will compute the best approach and global path of the AUV given the initial position of the robot, the localization of the docking station, foundation characteristics and environmental conditions.

2.5.3. Equipment and personnel requirements

Current	Proposed
To perform the IMR on the foundations, a boat with its crew is required to transfer the personnel to the offshore wind farm. The IMR operation will usually involve a small ROV with its operators and possibly a team of divers, although it is becoming less common. The required tooling depends on the task involved: brushes and jets for cleaning, rulers, callipers or others for measuring, knives and saws for cutting, handling tools for replacement of non-load bearing elements (fastening, anodes, messenger line, etc.) or grabbing tools for ROV positioning.	The proposed methodology requires the use of a robotic platform with hovering capabilities, a docking station which could be either installed on the wind farm or transported to site by an ASV or alternatively, a manned support vessel. Once the docking station and vehicle are deployed on site, only the personnel on an offshore control centre is required for the execution of the task, the monitoring and its data post-processing.

2.5.4. Safety issues and weather limitations

Current	Proposed
In terms of safety issues, there is always risk involved when personnel need to access the installations to perform the IMR tasks and, particularly if divers are involved on them. Maximum mean currents are 0.8 m/s, with a minimum visibility associated of 2 m and 1m Hs are typical weather conditions.	Safety issues should not be a concern since no personnel would be present on side during the execution of the task. Weather limitations should be the same, or even less, than the ones considered in current operations since the use of a submerged docking station does not require interaction with the waves and the weather occurring on the surface.

2.5.5. Necessary scientific and technical developments

Assuming that some aspects are already solved on other scenarios (such as the capacity of operating with a docking station), the required developments are the following:

- **Vehicle trajectory control:** a particularly challenging aspect of the problem of performing IMR on the WindFloat using autonomous technology is that of navigating along the mooring lines and at a close range. The small diameter of the chains and polyester lines makes difficult to be perceived, and their movement due to currents is challenging in terms of trajectory control;

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- **Image mosaicking:** for the visual inspection of the parts, a camera and a lighting system will be necessary. The system should be capable of building a mosaic with the acquired images and if possible, generate a 3D reconstruction to evaluate the dimensions on the scene. The resulting mosaic should be georeferenced as a consequence of merging the navigation data from the vehicle with the mosaic using SLAM techniques with the purpose of locating any anomaly.
- **3D reconstruction with dense data:** for tasks requiring higher dimensional accuracy, the development of new systems based on laser scanners may be required with the purpose of building a dense representation of the scenes with millimetre precision.
- **Better sensing for NDT**: new technologies should be developed for NDT. The use of contact-less systems like computed tomography will be particularly interesting for the application, particularly if cleaning is not required.
- **Development of inspection suite:** new algorithms and sensors will be necessary to guide the vehicle during the execution of the mission to acquire data.
- **Development of intervention suite:** tasks requiring contact with elements on the wind farm such as, cleaning of marine growth or some types of NDT will require a new set of specific algorithms and tools.
- **Offshore user interface and data post-processing:** everything related with the execution and monitoring of the missions from the offshore centre and the algorithms that will be in charge of post processing the acquired data until the generation of a results report.

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2.6. S6: Underwater monitoring of scour protection interventions

One of the most important inspection scenarios in the offshore wind farms is the inspection of the foundations and the sea bottom surrounding them since this may be important to ensure stability, longevity of foundations and can be crucial to avoid catastrophic failures. The four most commonly used offshore wind turbine foundations were described in S5. The presence of fixed foundations in a marine environment causes changes within the water current flow pattern, resulting in local sediment transport which causes a scour hole (Figure 24). This leads to scouring of the seabed around the structures which compromises the stability of foundations and may expose the cables on the seabed due to erosion. Hydrodynamic conditions related to tidal currents and waves have a strong effect on edge scour patterns, see Figure 25.

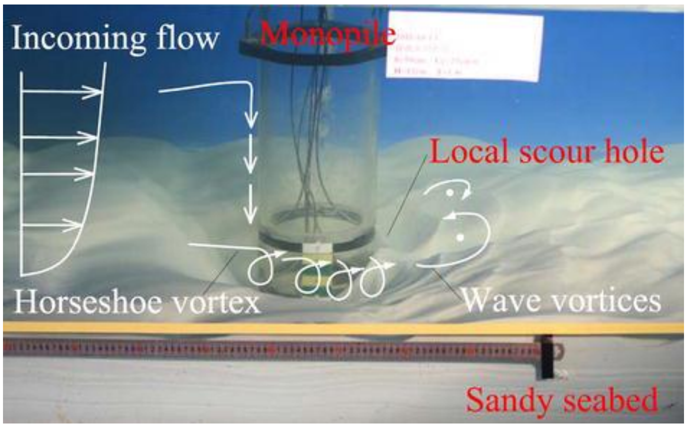

Figure 24. General flow patterns involving local scour around a monopole, source: [Qi2019].

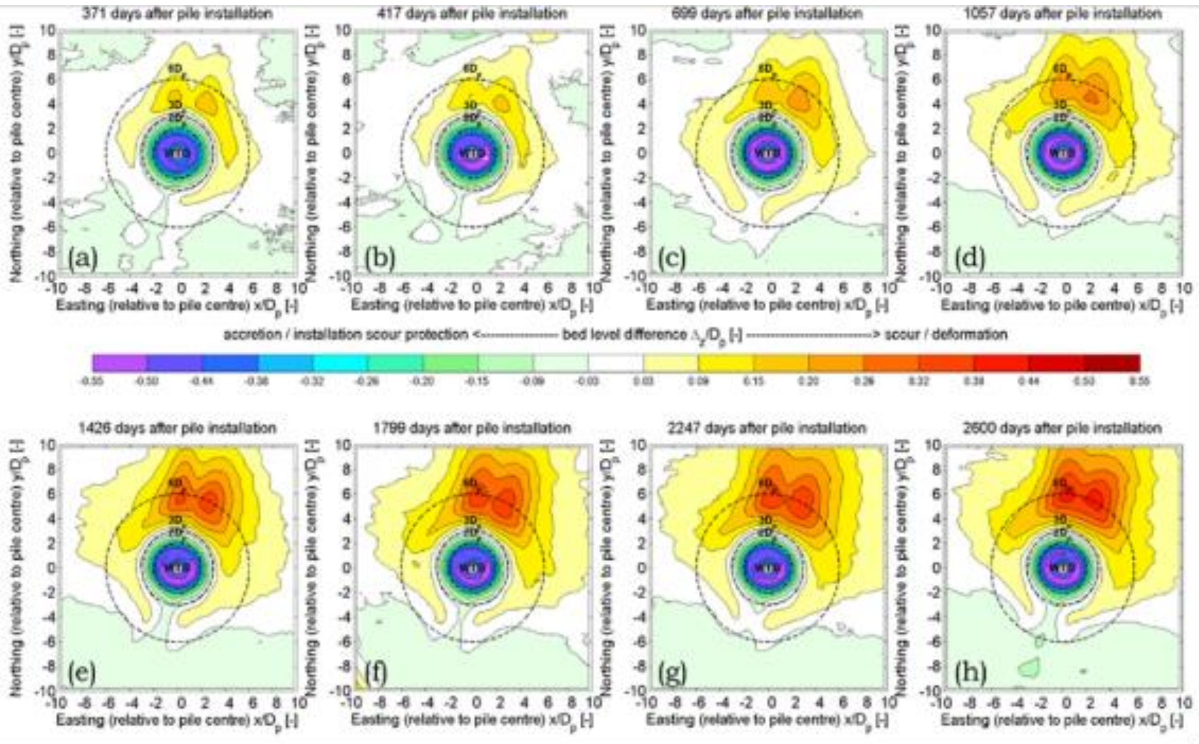

Figure 25. The development of scour in a monopile foundation. Courtesy of Nordzeewind, a 50/50 joint venture of Shell and NUON, source: [Petersen2014].

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Scour development can be divided into:

- Local scour (erosion in proximity to a monolithic foundation);
- Global scour (erosion of the seabed material around a structure formed by several foundations);
- Edge scour (erosion in proximity to scour protection);
- Far field scour (erosion at larger distances from the wind farm).

There are two possible strategies to this issue, namely trying to predict the scour hole size and dimensioning the foundation to reach an equilibrium when it appears, or trying to avoid their appearance through the addition of a scour protection system around the foundation. Both strategies require periodical monitoring campaigns of the scour around the structure to ensure the scour protection is fully functional or if the scour hole is within the estimated parameters. Array and export cables are also affected by scour. Protection systems include, riprap, geocontainers or concrete mattress, see Figure 26 [Esteban2019].

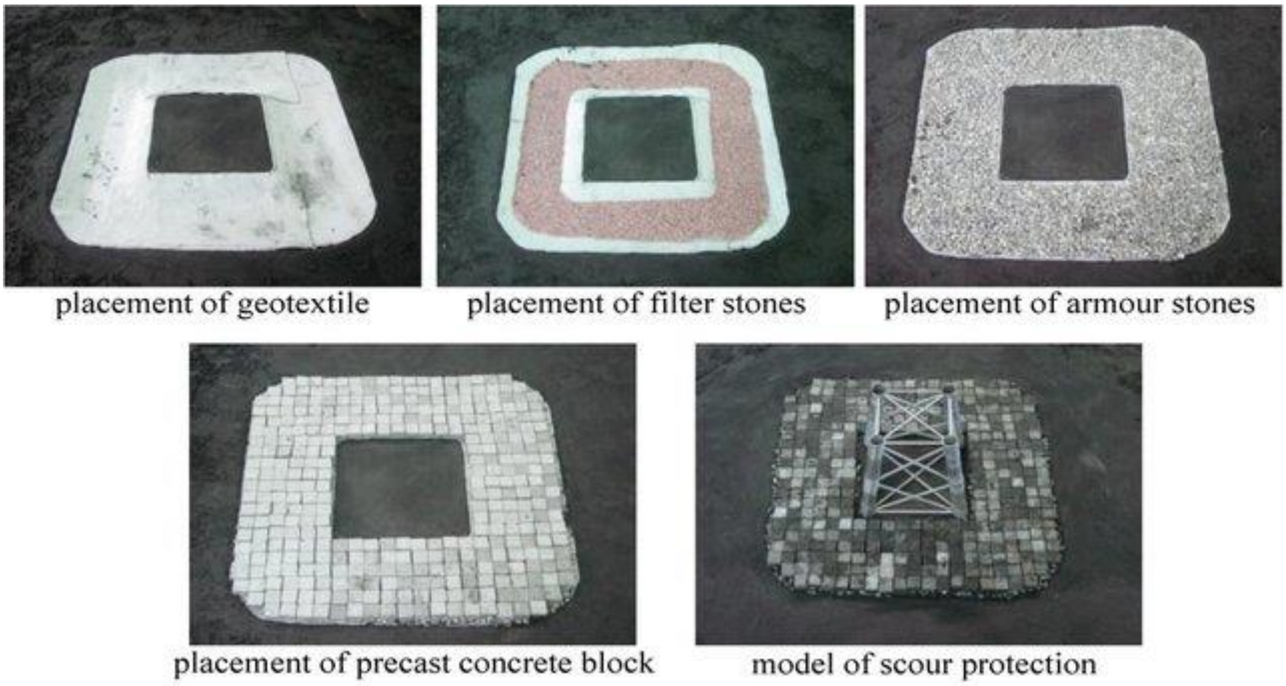

Figure 26. Different scour protection systems, source: [Esteban2019].

Figures 27 and 28 depict two examples of scour protection systems.

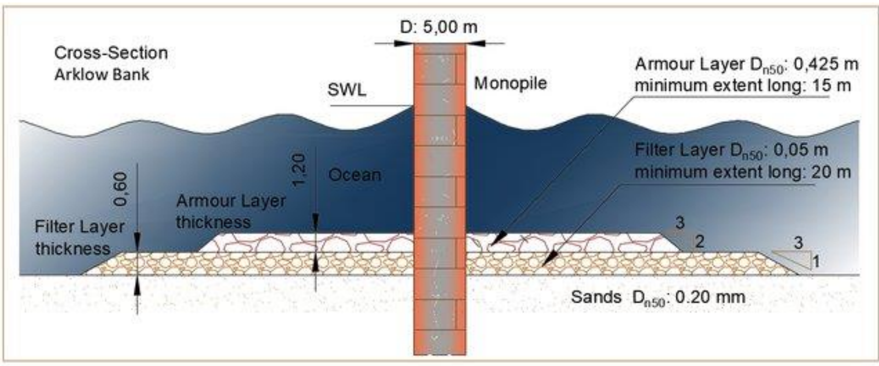

Figure 27. Main dimensions of monopile and scour protection of Arklow Bank phase 1, source: [Esteban2019].

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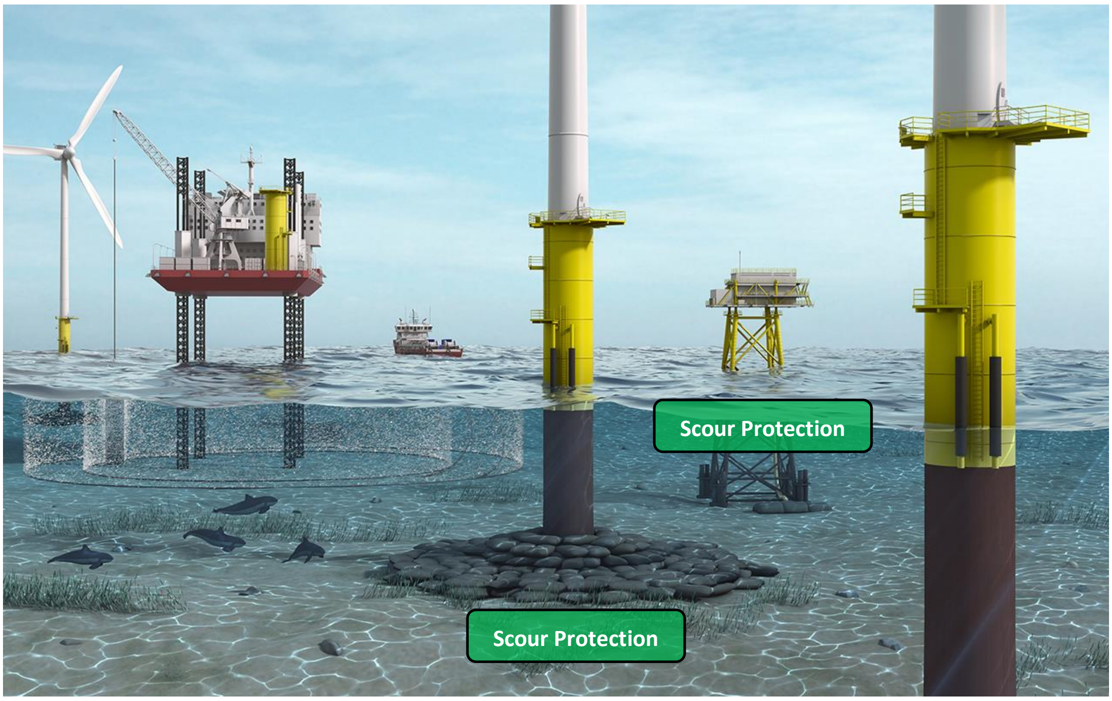

Figure 28. Scour protection example, source: [Jaeger2020].

Contrary to fixed foundations, scour related issues should not apply to the WindFloat Atlantic as it is a less or not common issue on mooring lines and electrical cables (although there are some examples where that happened in the North Sea with electrical cables).

Characterization of conditions

According to [DNVGL-ST-0126], the depth of the local scour holes is expected to be approximately 1.3 times the pile diameter:

- jacket pipes with diameters ranging from 1.5 m to 3.0m;
- monopiles with a diameter Dp = 4.6 m (to 10m).

Considering the Offshore Windpark Egmond aan Zee [Petersen2014]:

- Two layers of stone material for scour protection: a filter layer with a thickness of 0.4 m consisting of stones the size Df = 0.05 m; and an amour layer on top of the filter layer with a minimum thickness of 1.4 m comprising cover stones the size Dc = 0.4 m.
- The filter layer was installed in a circular shape with a berm width (expressed as diameter) wb ~ 5.2Dp,
- The maximum recorded amplitude of the depth-averaged velocity in the direction of the flood current is 1.31m/s against 0.91m/s in the direction of the ebb current.

Monitoring of the critical scour development at monopile foundations is commonly done with cost-intensive scour depth measurements. Scour pits require high costs of intervention such as refilling of the scour hole or reconstruction of the scour protection.

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2.6.1. Current methodology

Bathymetric surveys play an important role and they frequently resort to vessels equipped with multi-beams, single-beams, acoustic Doppler current profilers and sub-bottom profilers.

Usually, annual surveys were performed to evaluate the scour protection and to quantify the edge scour development. The use of autonomous underwater vehicles is also being considered for places that are difficult to reach by boat.

These surveys should be conducted along the offshore export cable corridors to supervise the morphology of the local seabed, see Figure 29. Scour developments are more prevalent in shallow water because of the increased tidal current which imposes an active reworking of the superficial sand layer or sediments. Natural scour will expose the export and array cables which may cause mechanical stress points and erosive forces in the cable against the hard sea bottom. Best practices are depicted in Table 2.

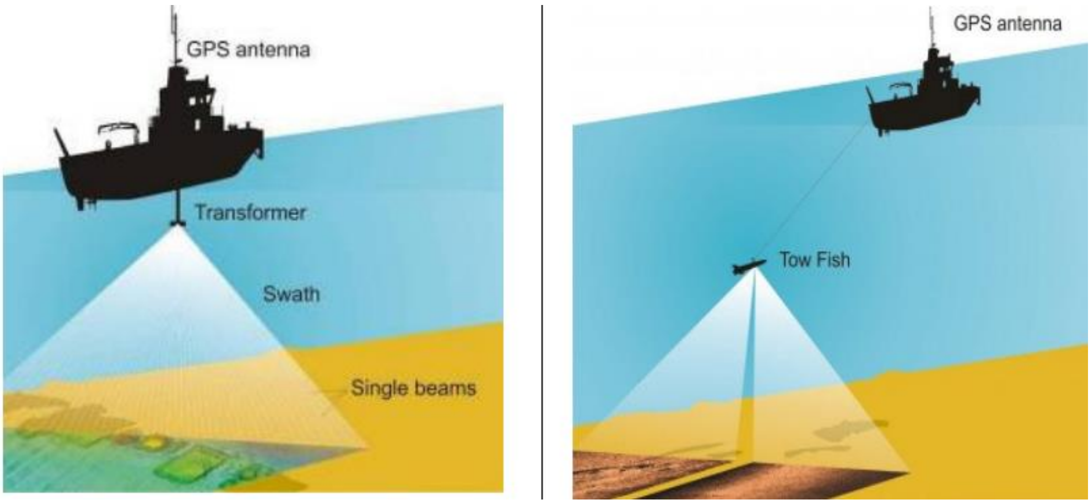

Figure 29. Survey vessel with multi-beam or side scan sonar, source: [GEO2005]

Table 2. Typical scope of geophysical survey, source: [GEO2005]

Survey purpose	Minimum survey area	Minimum depth	Means of survey
Seabed topography	Usually 1 km x 1 km in shallow water, 2 km x 2 km in deep water. Possible extension to 5 km x 5 km in areas with geohazards to incorporate possible platform location shifts etc.		Swath bathymetry, preferably multibeam
Seabed features			Sidescan sonar, line spacing 100-200 m depending on water depth, with sonar range set to provide 200 % coverage from line overlap.
Subsurface information		See geotechnical recommendations below	High-resolution / ultra high-resolution seismic survey for shallow geology and fault offset analysis. Line spacing: 100 m to 200 m depending on water depth. May be performed simultaneous with sidescan sonar. Also, 3D exploration seismic data (where available) to approximately 1.5 milliseconds for regional geohazard analysis and drilling hazard analysis to approximately 1000 m depth

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Bathymetry surveys (Figure 30) on the offshore wind farm are performed for the wind farm operators acknowledge the type of ground, if any unidentified objects are on the seabed and to access possible issues for the construction. Then the building phase will start. Licensing determines that bathymetry surveys should be carried out annually to validate the state of the foundations for the first three years.

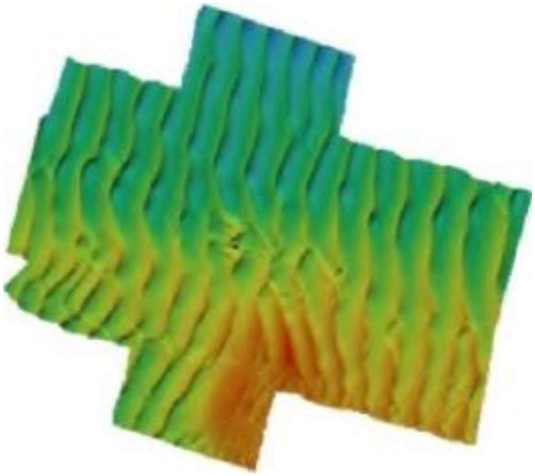

Figure 30. Bathymetry data, source: [DriX2019].

Bathymetry survey of the Gwynt y Môr Offshore Wind Farm was conducted by an ASV operating in a 400x400m box around a 20m exclusion zone on the base of each turbine (standard for surveys without dynamic positioning, DP) with a 25m corridor along each of the inter-array cables, as depicted in Figure 31.

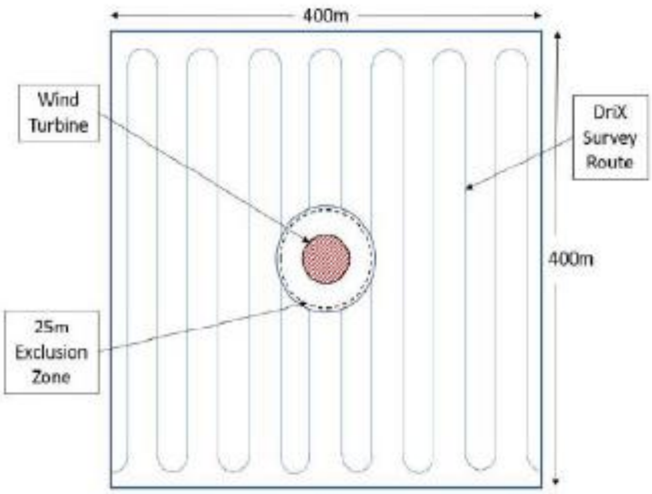

Figure 31. DriX turbine box survey route, source: [DriX2019].

According to [DriX2019], the path for the survey consisted of 13 North-South lines and two East-West lines, taking 29 minutes to acquire the 400x400m box when operating at an average speed of 8 knots. After performing the survey around two turbine boxes and three inter-array cables with 8km total, the ASV was remotely piloted back to the marina, where it was docked. All data acquired from this mission was analysed offline which resulted in a resolution of 0.25m. The quality data is presented in Figure 32 and 33.

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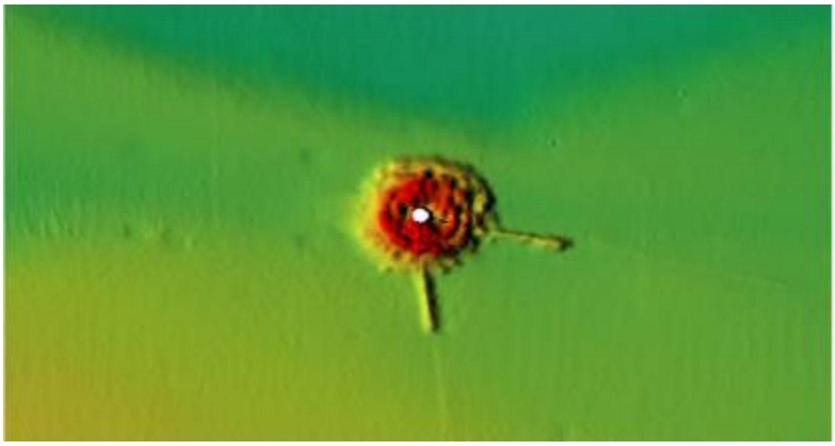

Figure 32. Data sample, source: [DriX2019].

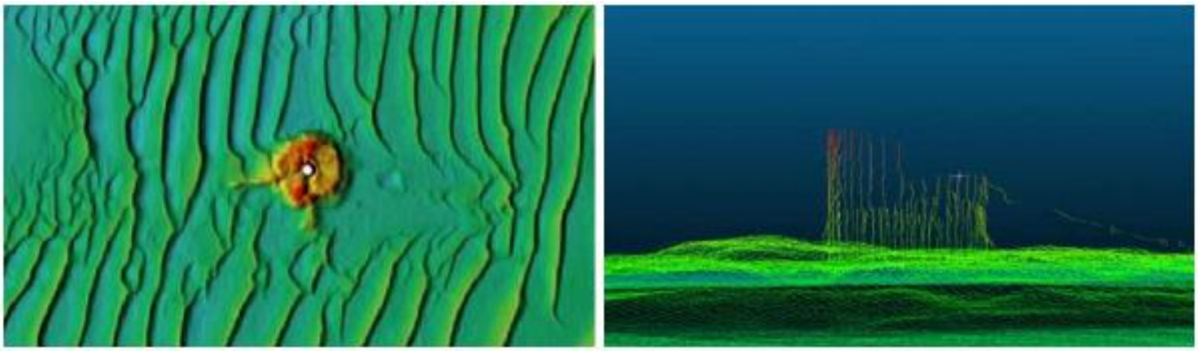

Figure 33. Examples of surveying data, source: [DriX2019].

Thus, an autonomous surface vehicle can perform surveys at regular set intervals which can highlight changes in seabed conditions. Repeated surveys make possible to model the seabed and to assess the annual changes. This can help owner/operators to assess conditions around the wind farm.

2.6.2. Proposed new solutions

In Atlantis project, we proposed a methodology based on the Autonomous Surface Vehicle (ASV) and, if required, an Autonomous Underwater Vehicle (AUV). The ASV will perform a coarse bathymetry of the areas surrounding the foundation where the scour holes may form and provide a coarse map in near real-time. This map can be used to identify defects, areas-of-interest and zones of low visibility. The data can be post-processed to create an entire 3D reconstruction of scenario. When occlusions or low quality data is present, the AUV can be deployed for close-range observation.

The following steps are proposed:

- An ASV equipped with surveying sensors (such as multi-beams, single-beams, acoustic Doppler current profilers, sub-bottom profilers) is remotely operated up to the inspection site;
- Then the ASV performs a pre-planned route creating a survey of the underwater environment;
- The ASV provides a coarse representation in real-time and allows the identification of area-of-interest;
- At the end of the survey, the ASV will be driven back to shore;

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- 3D reconstruction and data fusion will be done offline to create an entire representation of scenario;
- When a defect or area-of-interest is characterized by low quality or occlusions, an AUV can be deployed to perform a close-range inspection required for a finer 3D representation of scenario.
- The reconstructions from the AUV will be used to augment the 3D obtained by the ASV.
- The 3D representation of scenario can be augmented with the new data. The final map can be used for predictive maintenance and planning operations.

This methodology enables more periodical monitoring campaigns around the structure to ensure that the scour protection system is fully functional. Also, it will create early warning systems for critical conditions at offshore wind turbines aimed to reduce maintenance costs and to avoid catastrophic failures.

The installation will be controlled from an onshore centre where the operator can schedule surveys for the remote assets as well as to monitor the progress of each survey. Data gathered by the ASV and/or AUV will be retrieved continuously during the survey via the satellite link or the WindFloat infrastructure.

2.6.3. Equipment and personnel requirements

Current	Proposed
Existing ASV prototypes require one operator and a support vessel and respective crew.	▪ ASV ▪ AUV (If required) ▪ Support vessel ▪ Control station ▪ Support vessel crew ▪ ASV qualified driver. ▪ Inspection engineer.

2.6.4. Safety issues and weather limitations

Current	Proposed
In terms of safety issues, the maximum mean currents are 0.8 m/s, with a minimum visibility associated of 2 m and 1m Hs are typical weather conditions.	Safety issues should not be a concern since personnel would be present on the support vessel that will deploy the ASV/UAV. Weather limitations should be the same, or even less, than the ones considered in current operations.

2.6.5. Necessary scientific and technical developments

- Develop close-range navigation techniques for ASV.
- Develop coarse 3D bathymetry techniques in real-time.
- Autonomous 3D navigation for inspection (improve quality and stability of data, S&H, recall).
- Mission planning and obstacle avoidance techniques.
- Data association for maps from different vehicles.

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2.7. S7: O&M operations supported by crewless vessels

Transfer of IMR technicians, equipment and spare part to the wind farm for O&M operations requires a transfer vessel with a large team, providing seafaring and support capabilities. Planning such transfer operations requires substantial expertise in vessel and crew selection, safety and logistics, and is subject to weather conditions. The complexity and cost of transfer operations motivate development of technologies to possibility to perform autonomous and unmanned operations, for example drone inspections or cargo transfer, improving assets' response time and the possibility to have fleets located globally.

Automated technologies and reduced crew on board for some manoeuvres, particularly short distances, and the desire to innovate will continue to appear. Operating wind farms on a vessel-less basis require new business strategies that should start emerging in a near future and that are fully supported with technology developments from the robotics industry.

This scenario will be used to demonstrate Autonomous Surface Vehicle (ASV) with capability to transport personnel and transport, deploy and recover robotic assets in real-environment.

2.7.1. Current methodology

Vessels typically used in the offshore activities are various supply vessels: crew transfer vessel (CTV), work boat and support off-shore vessel (SOV). The CTV being used is a Windcat MK3.

Typical transfer methods (for both people and equipment), when using CTV, imply personnel access from forecastle of vessel via embarkation ladders. Walk-to-work systems are also possible, although more expensive. All equipment is transferred using the davit crane on the platform. Access of people to the platform is also granted through the platform's landing and column stains. PPEs include: anti-fall equipment, life vest with GPS tracking device, safety boots, reflective pants and vest, gloves, glasses, helmet, flashlight, double harness, survival suit for less than 12ºC. Minimum training required: GWO and STCW level 1. Depending on the type of work, specific training is required e.g. work at height, confined spaces, and rope access.

When an SOV is involved a walk-to-work system equipped with hoist or SOV's crane can also be used.

Maximum weight on the CTV is 3.000 kg (also related to the platform's davit crane).

This scenario is not directly related to IMR activities but it is focused on the logistics support operations.

2.7.2. Proposed new solutions

This scenario will be used to demonstrate ASV with capability to transport, deploy and recover robotic assets in real/cyber environments. For personnel and cargo transfer purposes, the crewed SOV or CTV is replaced with an autonomous or semi-autonomous crewless vessel with no seafaring personnel or a minimal crew of one Watch Officer who can abort the mission in case of an unrecoverable exception in the transfer operation. The autonomous operation may be backed up by a Remote Pilot at a Remote Control Centre on-shore or a near-by vessel.

The introduction of autonomous systems capable of performing autonomous tasks will be studied. The major goals are to evaluate the requirements that will be needed to transport a diverse set of equipment

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to a wind farm as well as, to investigate the impact of automated vessels on logistics of IMR activities. Automated vessels are able to complement several scenarios depicted in ATLANTIS however, one example will be provided in scenario 1 for blades and tower inspection of the wind turbine, where an UAV will autonomously take-off and land on a mobile platform placed on a surface vehicle.

The vessel with a high degree of autonomy will be considered for transporting UAV technology (or other type of IMR equipment) from the shore to offshore wind turbines. Moreover, it plays an important role for reducing the crew that is needed which has a direct impact on cost structure: less personnel, less operation due to HSE restrictions and higher number of working days per year (operational window).

The use of autonomous ships is not possible due to legal and regulatory frameworks. However, a cyber-physical (or fully simulated) methodology will support this scenario by capturing the advantages of crewless vessels on the IMR activities conducted by robotic-based operations.

- A bridge ship handling simulation will be used to investigate de impact of several functionalities of the vessel with increased levels of automation to the IMR activities conducted offshore. This engine will simulate a vessel travelling to the offshore wind farm and reaching a pre-defined set of waypoints, where different IMR activities should be conducted using robotic-based platforms.
- As an example, the UAV can be deployed and recovered in these waypoints, which will be secured by real demonstration in the field or by using a simulated environment in order to capture different weather and sea state conditions.

This cyber-physical scenario supported by demonstrations simulated through engines are required due to regulatory constraints and low TRL of safety procedures, an ASV equipped with a landing area can be deployed from a dock near shore and safely navigate to a desired GPS location, while avoiding collision.

Each operation performed by the crewless vessel can have different objectives and destinations and it is performed in various conditions. In the scope of ATLANTIS, the deployment of O&M Crewless Vessels will be demonstrated by using simulated environment. The methodology of deployment of a specific mission will include:

- Simulated vehicle performing the operation through a link that can be active throughout the whole operation, which will most probably be a satellite link;
- Destination points of the vehicle;
- Operation status providers: for example, the system monitoring the loading of the vessel or the one monitoring the state of WindFloat;
- Environment status provider emulator like a weather service or AIS.

The communication status, the state of all simulated assets (vessel, payloads, destination), and the state of the environment will be visible and loaded at the RMCC by the operator in charge of defining the mission. The operator introduces the information about the destination of the vessel and the tasks to be performed once the assets arrive at destination. The mission planning algorithm will compute the following:

- If the mission can be executed given the present state of the system;
- A list of actions to be performed by the vehicles in order to achieve the goal;
- The optimal trajectory of the vessel.

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This specific type of operation will require a multi-agent type of planning. Once the autonomous task is deployed in the simulated environment, the operator will observe from the control centre the progress of the operation, being able at any point to send additional commands to the unmanned vehicle.

2.7.3. Equipment and personnel requirements

Current	Proposed
Manpower services (electricians, radio operators, drilling and production technicians, sailors, doctor, safety supervisors, etc.) are provided depending on the kind of vessel employed. If the access vessel is carried out with a Support Offshore Vessel (SOV), the crew will generally consist of a large team providing a range of competencies and skills on-board. The vessel crew supports the vessel operations and preserves living and working conditions, including on vessel HSE and medical, for all crew service personnel. The operational personnel can include, depending on the operation: ▪ offshore manager; ▪ shift supervisor; ▪ ROV supervisor; ▪ ROV pilots; ▪ project engineers; ▪ deck crew (riggers, deck foreman, banksman, crane operator); ▪ doctor; ▪ turbine IMR technicians (electrician and electrical engineer); ▪ foundation IMR crew (electrical technicians); ▪ walk to work operator; ▪ HSE supervisor.	This methodology requires: ▪ UAV ▪ Simulated Surface vehicle (Autonomous or Crew Transport Vessel) with a landing platform ▪ Control station

2.7.4. Safety issues and weather limitations

Current	Proposed
Weather requirements (sea conditions) to access the platform, for personnel transfer from CTV to platform, are: maximum Hs= 1.5-2 m; wind speed= between 10 and 16 m/s. If a 'walk to work' system is used to transfer people, maximum Hs could raise up to 3.5 m and wind speed could decrease up to 12 m/s.	ASV safety issues are an active research topic, especially, regarding the navigational topics the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS) provide challenges for autonomous vessels; that is, the vessel has to follow "good seamanship" in order to avoid collisions. For the time being, the COLREGS regulation does not recognize nor mention the ASVs. The autonomous collision avoidance systems are still under development, and there is

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	an ongoing discussion of how COLREGS should take into consideration the autonomous navigation systems. Furthermore, there are no established procedures nor guideline for classification and certification of these systems by the Recognised Classification Societies. In the context of the ATLANTIS project, the development of Autonomous Collision Avoidance System (ACAS) which takes into account COLREGS in all circumstances is beyond the scope of the project. In principle, the selected autonomous tasks of supple vessel can be demonstrated by taken into account the limitations related to COLREGS. Finally, the weather limitations depend on the selected vessel hull type and size. These will be specified as the scenarios are defined more detailed.

2.7.5. Necessary scientific and technical developments

Realization of the scenario requires development of an ASV capable of safely transferring personnel but specially cargo from shore to the wind farm under weather conditions of maximum Hs= 1.5-2 m and wind speed between 10 and 16 m/s. For WFA the distance to offshore test bed is 20 km.

Implementing this scenario for WFA would require a number of innovations beyond what is available on the market. Since the current regulation stipulates that the lookout at an ASV should be comparable to human vision and hearing, a development of electronic lookout system with sufficient sensory capability should be commenced. If the ship is controlled by a Remote Operator, the lookout must be communicated to the Remote Control Station giving the Remote Operator situational awareness equivalent to that of an operator on-board. This would place stringent requirements on the reliability, latency and bandwidth of the used communication channel which likely would be difficult to implement with readily available (satellite) communications. In the particular case of WFA the communication distance is relatively short and the WFA has a fixed fiber optic communication link to shore and it would thus be possible to provide wireless communications both from shore and WFA providing some redundancy of communications to the area the ASV would be sailing. However, the radio equipment and protocols for wireless communication should be carefully selected or developed since standard 3GPP 5G-NR Ultra-Reliable Low-Latency Communication which would be the likely candidate for commercial implementation is not yet readily available.

Regarding navigation, route finding and trajectory planning assisted by an auto-pilot integrated with Global Navigation Satellite Systems (GNSS) and the Electronic Chart System (ECS) is widely used in shipping. However, collision avoidance according to COLREGS is a complex subject that involves significant research challenges. As the current COLREGS stipulate the availability of a Master with ability to practice good seamanship they imply the development of an Artificial Intelligence Master that would provide the competence and experience comparable to that of a human captain. Given that such a system should be capable of ethical considerations comparable to those related to autonomous cars, development of such a system is unlikely in the near term. A more realistic approach to collision avoidance is through systemic

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change involving appending COLREGS to define rules for encounters of crewless ships and crewed and crewless ships and providing additional equipment and infrastructure for ship to ship communication for signalling and coordination. It's likely that crewless ships will be allowed only on designated routes in the near to medium term. It is also likely that port calls will remain manual or remotely controlled for the foreseeable future. This will likely apply also to access to offshore structures such as WFA unless additional docking structures and navigational aids will be developed and put in place.

Robust cybersecurity is critical for successful deployment of crewless vessels. Protecting against cyber threats such as remote hijackings requires technical hardening of the systems not only on-board the vessel and Remote Control Station but also infrastructure systems such as Global Navigation Satellite Systems. Due to fluid nature of cyber threats the provision of cybersecurity requires not only development of technical solutions but regulatory approach that would rather be a process rather than a static convention. Significant open issues remain in this area.

While crewed vessels have conventions and rules for the lay-out of manual workstations for human operators developed over centuries, the human factors of remote controlled and autonomous vessels are immature. The use of virtual reality and augmented reality and other advanced human-machine interface technologies hold great promise for developing, e.g., sufficient situational awareness for operators and ship owners but much research and development, both technical and regulatory, remain to be done before widely accepted solutions and conventions will be available.

In addition to the technical and regulatory aspect described above, crewless vessels also bring up new operational aspects. For starters, the lack of crew on the vessel will also remove the conventional IMR performed on the vessel itself by the crew requiring development of new practices relying on on-shore or offshore personnel and predictive maintenance technologies. With crewless vessels there will be the emergence of new business partners in the shipping industry such as, providers of the systems and services required for autonomous and remote controlled operations. This will lead to new business roles and models between the partners and will require also new models of risk distribution. These issues, however, are outside of the scope of ATLANTIS project.

For a recent review of current state-of-the-art in crewless vessels and lessons learned from crewless crossing of the English Channel, albeit at a very low level of autonomy see 0. Pre-commercial, TRL7 level technology exists at least at Rolls-Royce 0 and Kongsberg Gruppe 0. The technical verification and validation of the technology for wind farm logistics operations would be a non-insignificant task. Partially EU funded project AUTOSHIP is indicative of the effort required, see 0.

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2.8. S8: Optimization of robotic-based operations

This section provides a general description of the IMR scenario that will be tackled in this showcase. It should contain a description of the relevant part of the WFA/Pilot and the explanation of necessary IMR activities to be performed, expected outcome, etc.

Offshore wind farms are located in sea with the purpose of generating electricity by the ‘harvest’ of wind. The windmill farms are maintained with periodic inspections, scheduled maintenance and unscheduled repair due to unexpected failures. For the operation of a farm an extensive supply chain is required where goods and people are transferred on a regular basis between shore and farm location. With the wind energy market development, the trend is to develop farms further off-shore with bigger capacities (see Figure 34).

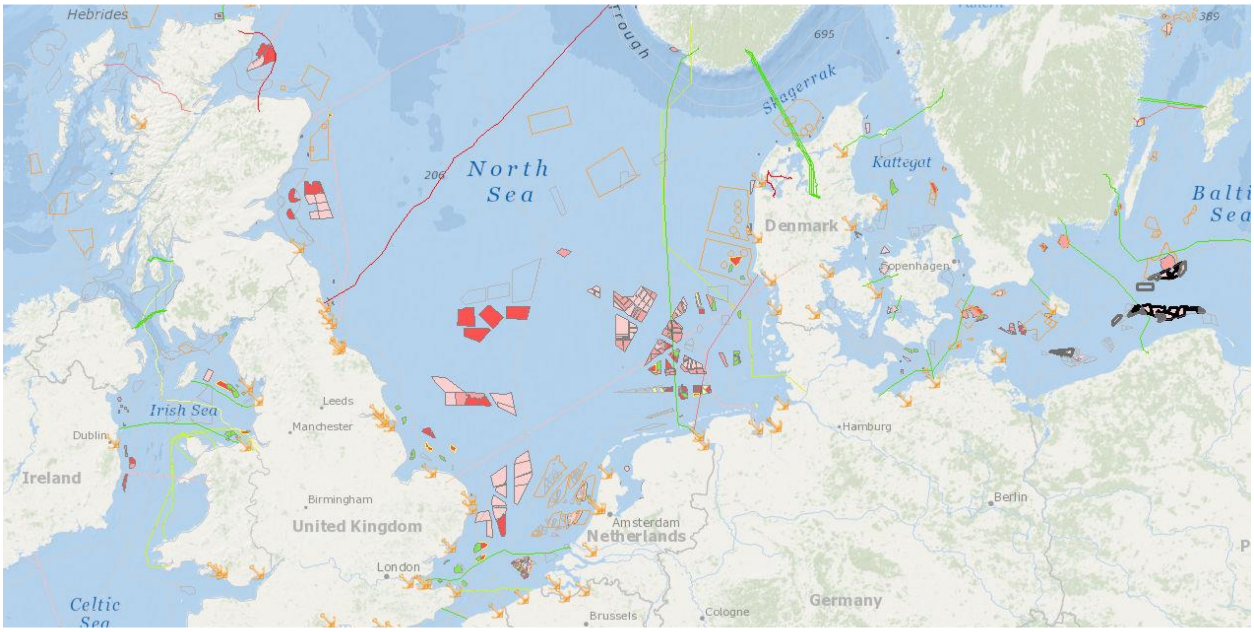

Figure 34. Scheduled wind farms in the north sea. Source: {4coffshore].

With the transfer of goods and people to offshore ‘wind harvest’ areas, the wind and sea conditions have a direct effect on the execution of the work. Delays and unforeseen schedule changes a part of day to day business due to weather effects. By adapting robotic solutions in the maintenance and inspection there are multiple possibilities for operational improvements. Reducing risk by limiting the work of people in hazardous conditions is a direct effect of this. A secondary effect of the use of robotics, is the improved definition of operational decisions. Robots have operational limitations based the hardware specifications, for example, the possibility to deploy a robot from a vessel to the water, is depending on the maximum impact on the water surface and its capability to compensate the sea current with it propulsion.

This scenario intends to improve the supply chain with the showcase of an operational planning tool for the deployment of robots in a windmill farm. By using response-based planning, taking into account the actual operational limits of robots and the support vessels which are used to deploy the robots. With the implementation of response-based planning, the supply chain from shore to assets can be improved significantly by reduction of waiting time.

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2.8.1. Current methodology

As the offshore wind farm industry is a relative young industry, different approaches are applied depending on the location and operator of the windmill park. In general, the inspection and maintenance is executed by personnel who are transferred between shore and windmill farm by ship (see Figure 35) or helicopter (see Figure 36). For the transfer with ships, small fast catamarans are used for short distance travelling. For assets further offshore, vessels are used with hotel capacity. These vessels stay for multiple days in the windmill park. For all types of transportation, the personnel is required to transfer between vessel and windmill. These transfers are made by direct connection between vessel and windmill or with assistance of an offshore motion compensated gangway (see Figure 37).

Figure 35. Transfer of staff by direct contact between vessel and windmill, source: [Ynf].

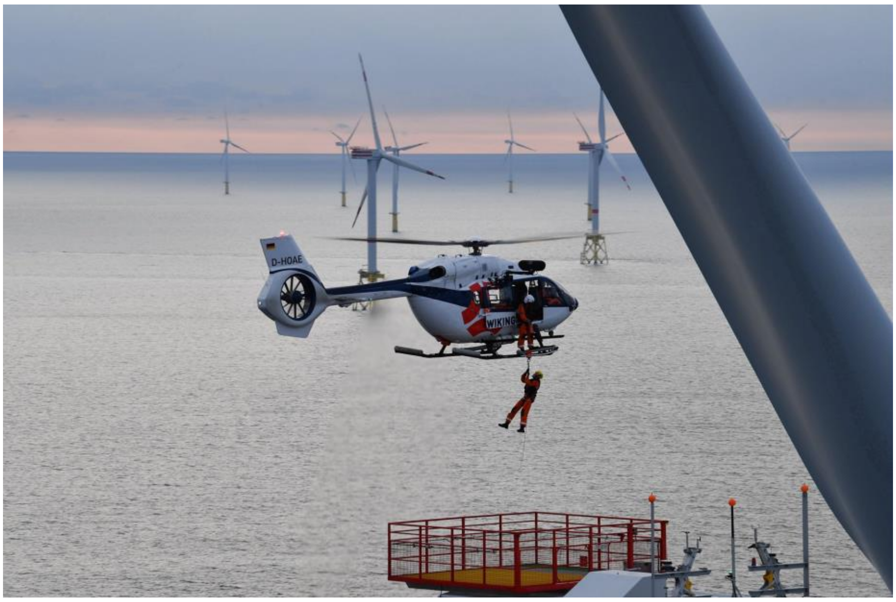

Figure 36. Transfer of staff by helicopter, source: [Airbus].

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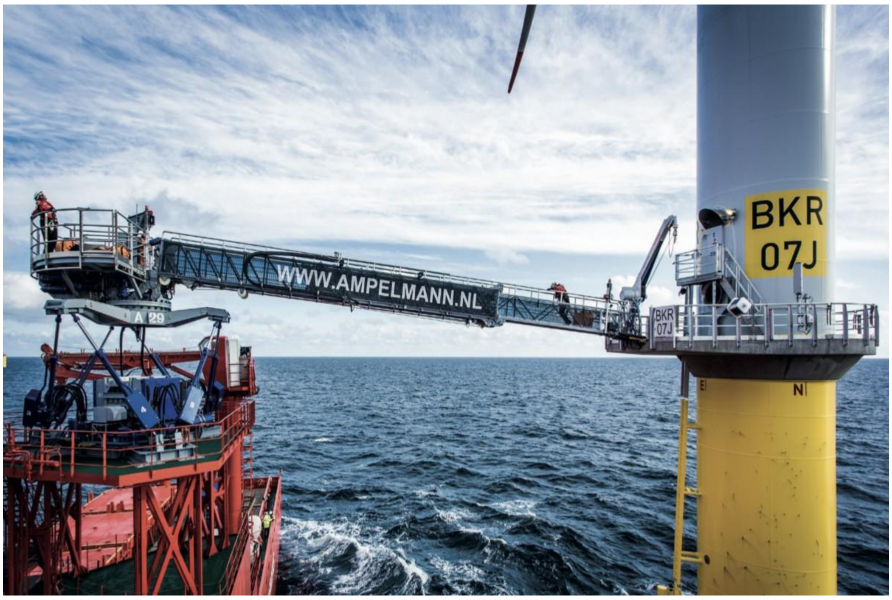

Figure 37. Transfer of staff by gangway, source: [Ampelmann].

2.8.2. Proposed new solutions

The objective of ATLANTIS is to investigate and implement robotics into the windmill industry. This objective has a very positive impact on the planning and execution of windmill farm. The implementation of robotics will limit the requirement personnel transfers between shore and wind farm. This effect can be taken into account with a new planning tool for work based on criticality of the maintenance/repair, specific vessel behaviour and equipment limitations.

With the new proposed method of response based planning, an IoT representation for selected components and a hydrodynamic model for each service vessel in the windmill far will be developed. As the vessel response is dependent on more factors then only the wave height. These factors will be implemented.

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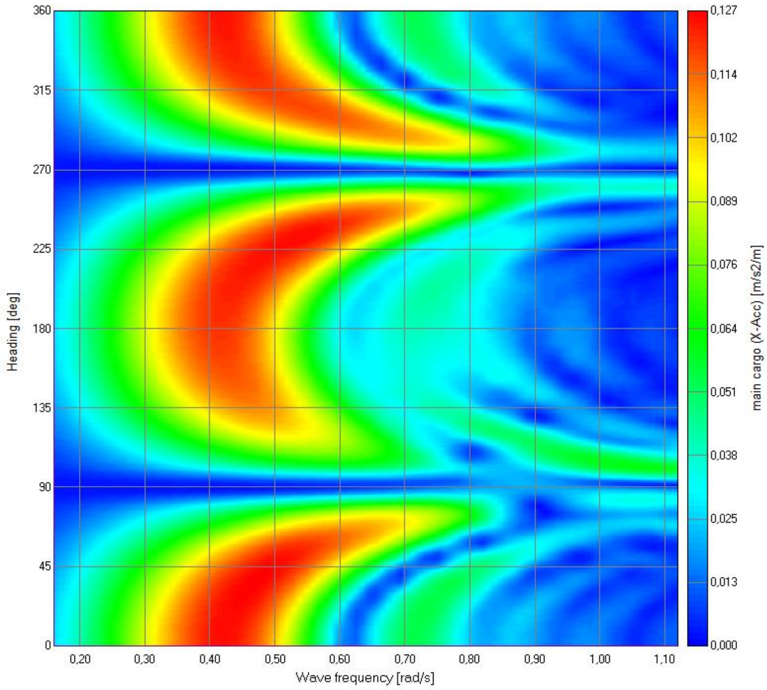

Figure 38. Exemplary vessel behaviour (lateral acceleration) for a constant wave height, with changing wave periods and heading.

Applying vessel response (see Figure 38) in combination with equipment limitations will enable the user to plan the work at a windmill with more realistic expectations of the actual execution and calibrate the tolerated risk level based on the criticality of the maintenance or repair (see Figure 39). Limiting the uncertainty in the planning with the delivery of the planning, simulations of service routed can be investigated with different types of operation. Investigation will be made for benchmarking robot based operation versus current operational profiles.

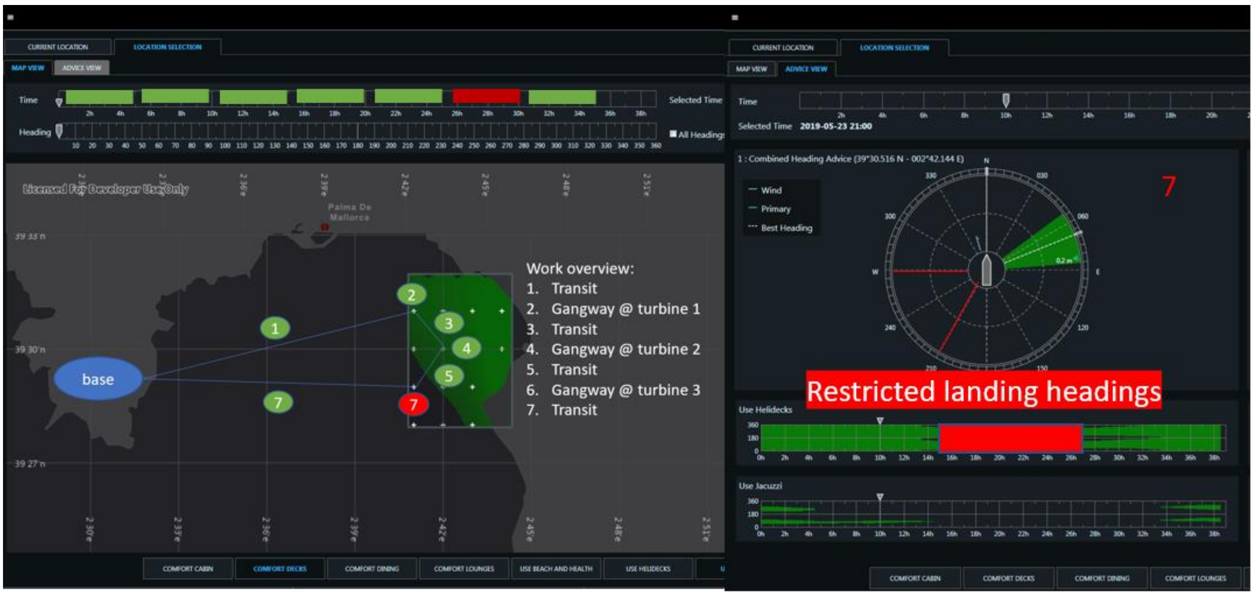

Figure 39. Example of a user interface for response based operation planning.

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The outcome of the operation planning performed in Scenario 8 could be used as an input for the other scenarios (1-7).

2.8.3. Equipment and personnel requirements

Current	Proposed
For planning transfer of staff and materials, planning tools are available tool fit the staff and equipment to the best fitting vessel. These tools are taking into account the maximum allowed sea state (Hs) where the vessel is allowed to operate. Currently the development and requirements in the wind farm industry are rapidly evolving due to the upscaling of the industry and the increasing distance between shore and wind farm. Therefore, the personnel requirements for planning offshore operations differ between offshore operators. The trend is to focus on digital twins for planning and maintenance, but the current status is that planning of maintenance is still performed with basic planning tools.	The development requirements for the planning and operation assessment tool require work from software developers, naval architects and software testers. For the use of the system in the operational centre/remote environment. A combination of naval architects, data scientist and operational planners are required for benchmarking and scenario simulation.

2.8.4. Safety issues and weather limitations

Current	Proposed
Safety is a key feature in the offshore windmill industry. With the growth of the offshore windmill industry, the required transfers between transportation (vessel) and windmill is increasing exponential. The weather limitation is and will be the most important factor when planning work offshore. Currently the limitations are set with limited thresholds on wind, visibility and wave height. The wave height is connected in a limited way to the vessel responses. A vessel is reacting different, depending on the wave periods and direction. The motions of the vessel in combination with the condition of the staff determine if the operation can be executed.	With the new solution implemented, weather limitations can be followed with more accuracy. Creating more potential while improving the safety. With the knowledge of the actual operation limits, robots and personnel can be retrieved from the windmill with greater confidence and less risk. For the use of the planning tool itself are no safety issues or weather limitations for usage.

2.8.5. Necessary scientific and technical developments

Development of the scenario requires adoption, development and integration of software and data. To reach the objective the following actions need to be taken:

- Development of route planning for offshore wind park usage. For the planning of an inspection/maintenance voyage. A dedicate trip-planner need to be developed for dividing transit and landing in a windmill park;

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- Development of high resolution weather forecast adapted for the dedicates location of the offshore assets;
- Research for robot specific limitations for deployment and recovery with a vessel;
- Calculation of the hydrodynamic profiles of the vessels used in the windmill park for transfer of equipment and personnel;
- Data analyses and benchmark for the simulation of different scenarios with a combination of robots and personnel;
- Development of training course for the use of hydrodynamic assessment tools by non-naval engineers;
- Benchmarking and verification of simulated missions versus real-life operation. Including data study for overall improvement with the implementation of robotic operation in windmill farms from the other scenario's in the ATLANTIS project.

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3. Role of the on-shore control centre

All the proposed IMR operations will be supervised by operators in the on-shore control centre to reduce the personnel needed offshore. This will also reduce the costs and risks of the operations and will centralise planning and access to data. The visual data and device parameters recorded by every ROV, AUV, UAV or ASV, will be sent to the on-shore control centre. At the control centre, the data will be stored in a database, from which it can be accessed at any time for reference or retrieved for further processing. The operator will have specialized, integrated visualization tools to see both the live or historic data related to the outcome of the inspection operation. During the inspection operation the gathered data will be stored on-board of each vehicle and then shared to the control centre via a satellite link, the on-site communication infrastructure or the support vessel.

The specific visualization tools available for the inspection will depend on the scenario and the assets used, and may include:

- 2D Map containing the position of the wind turbine, trajectory and current position of the assets and other points of interest on the WFA. Using the map, an user will be access the data for a specific position during the inspection process;
- 3D View of a WFA asset and the trajectory of vehicles during the inspection procedure;
- Images and videos recorded by vehicles;
- Representation of 3D data;
- The status of the vehicles (e.g. communication link quality, battery levels, speed, altitude, orientation or status);
- Display of NDT outcomes.

The data from the IMR activity will be linked to the offshore asset. The operator will be able to use the control centre for planning the operation using of multiple assets and to visualize the entire mission.

4. Cost effectiveness and impact of new solutions

The proposed solutions can lead to significant cost savings in both the inspection costs and the maintenance costs of the offshore wind farms. The inspection costs can be lowered mainly due to a reduction of personnel, no need for large nor dynamic-positioning (DP) vessels, and a shortening of the operations time in general. On the other hand, the reduction of the wind farm maintenance costs can come from the fact of more frequent and regular inspections, focused on continuous state monitoring and prediction of failures before they occur. Removing the human operator from the procedures can not only lead to cheaper inspections but also to a better consistency of data acquired which can be stored in a unified database to be statistically analysed. This approach can also be used for inspections of other type of offshore structures like, oil and gas platforms where manual operations when utilising heavy work-class ROVs still dominate. Moreover, statistical analysis of the acquired data can also lead to better understanding of underwater processes and formulation of new models, that can be used to improve designs and to help choosing proper location for the installation of new structures.

Scenarios of ATLANTIS will make possible to validate robotic-based technologies that allow a substantial reduction of the inspection costs by enabling the possibility of structure health monitoring (SHM), through permanent and semi-permanent systems.

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On a short time-scale, the semi-permanent deployments will have a significant impact on the cost of multi-day inspection operations, like performing an acoustic or visual survey of the whole wind farm, composed of many floating wind turbines. Moreover, it is not required that the weather conditions remain good during the whole inspection. In case of bad weather conditions, the AUV can wait for recovery as long as necessary. Using auxiliary systems connected to the electrical grid (e.g., at one of the wind floats), a fully permanent approach could be realised and validated. Although challenging in terms of prevention of bio-fouling and sediment deposition, it seems reachable with current technology. This would allow for a long-term observation of multiple aspects of the offshore wind farm structures as well as, sea bottom and water column conditions, giving a rich insight into the geological and environmental processes as well as corrosion and fatigue of human made structures. This opens possibilities for further cost reduction by better design and better location of plants as well as better protection of the natural environment.

Overall, the presented ideas, covering a wide spectrum of IMR operations, will lead to significant cost reductions, lowering of operation risks, improvement of efficiency, and prevention of costly downtimes, during which inspection costs add up to the losses caused by lack of energy generation.

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5. Health, safety and environmental (HSE) guidelines

ATLANTIS aims at establishing a pilot infrastructure for demonstrating key enabling robotic technologies for inspection and maintenance of offshore wind farms, contributing to reduce their levelized cost of energy by eliminating or marginalizing the use of supporting vessels in such operations. The pilot infrastructure will be established in Viana do Castelo, Portugal, by taking advantage of the location of the WindFloat Atlantic project and the weather and sea state condition of the Atlantic Ocean.

The Ethics Summary Report of ATLANTIS denotes that fact by describing:

> *"The project focuses on large scale demonstrations of various autonomous robotic platforms (air, water and ground) in a coastal environment of the Atlantic Ocean around the offshore wind farm. A risk assessment including the impact for environment is embedded in the project activities (T7.1) however, no specified deliverable is dedicated to it."*

The project is undoubtedly ambitious since it proposes significant advances in robotic platform development. Scientific and technical objectives of this action include: the enhancement of heterogeneous robots for IMR activities with varied levels of automation; the development of a new methodology for demonstrating robotic platforms for the inspection and maintenance of offshore wind farms; and, the promotion of robotics in supply chains by demonstrating unmanned platforms in a real offshore wind farm.

5.1. Environmental protection

The scope of this section is to provide information about the potential harm to the environment, biodiversity and animals caused by:

1. the use of technologies developed or used within the ATLANTIS project;
2. the deployment of the infrastructure that composes the ATLANTIS test beds;
3. the experiments, validations and demonstrations that are expected to take place in the marine environment.

The environment must be protected by any means necessary, particularly at the construction stage of a marine infrastructure. Activities planned within ATLANTIS were assessed and a set of mitigating measures were carefully designed to reduce the negative effects on natural surroundings, biodiversity and marine life. The deployment of the ATLANTIS Test Center has the following assumptions:

- the Coastal Testbed cannot be deployed in protected areas to safeguard the biological diversity and to minimize the negative impacts to bird, mammal and marine life in general. This Coastal Testbed will fulfil with all the legal and regulatory framework for this type of constructions in Portugal. This infrastructure will be preferably implemented inside of an existing segregated area (e.g., a harbour or a shipyard) and, in this way, the experimental work conducted in the Coastal Testbed is expected to have a minimum impact to the environment since robots will operate inside a safe zone and they will not introduce chemicals into the water during the IMR activities;
- the Offshore Testbed will use a commercial offshore wind farm (WindFloat Atlantic) which is already operating in a segregated marine area. The demonstration activities planned for this Offshore Testbed have the same (or lower) risk to the environment when compared the offshore IMR activities or maritime operations that are being performed nowadays. All legal and regulatory issues were

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already addressed by the owner of the WindFloat Atlantic Park, the WindPlus S.A., including the assessment of the environmental impact.

- Manned vessels will be used in this project to provide support to validation and demonstration activities. All vessels and marine operations conducted in ATLANTIS will be approved by the Portuguese maritime authorities such as, DGRM and APA, and follow the Portuguese law, IMO regulations.

Existing environmental impact data and studies of marine infrastructures deployed in the past, offshore or inshore, should be consulted as they may represent a form of validation for future developments. Moreover, the ATLANTIS project will generally follow the EU Recommendation on Integrated Coastal Zone Management and the 2008 Marine Strategy Framework Directive, focused on the protection of all European coasts and marine waters.

The effect of acoustic and electromagnetic noise emissions on those habitats should be evaluated and mitigation measures incorporated in the marine infrastructure design, see document [NATO06].

Environmental protection can also be enhanced by identifying possible conflicts with the shipping or fishing industry, as the area to be occupied by the marine infrastructure may be attractive to them in the context of their operations. A brief discussion with representatives of these industries may provide an understanding of their operational requirements and how they may be affected by the installation of a marine infrastructure nearby. Also, a clearer definition and standardisation of marking requirements may further help negating any conflict.

Although with less priority since there is no expected impact to this topic, there is also a need for an assessment of the visual impacts on landscape and on the built environment regarding national and European regulations. In this regard, improved public relations to counter the often ill-informed views of the local population is desirable. This task may be facilitated by a willingness to share information through dissemination events for example, and involve local populations throughout the development process.

5.2. Environmental Legislation

Table 2 provides an overview of the environmental legislation that will be considered in ATLANTIS.

Table 2Legislation related to environmental protection

Topic	Legislation
Ship-source pollution	Directive 2005/35/EC on ship-source pollution and on the introduction of penalties for infringements: Creates rules that are applicable EU-wide on the imposition of penalties in the event of discharges of oil or other polluting substances from ships sailing in its waters. International Convention for the Prevention of Pollution from Ships (MARPOL) An international conventional focused on the prevention of pollution of the marine environment by ships from operational/accidental causes.

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Assessment of the effects of projects on the environment (EIA)	Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment: aims to ensure: (1) a high level of environmental protection and (2) that environmental considerations are integrated into the preparation and authorisation of projects.
Strategy for the marine environment	Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive): • Establishes a common approach and objectives for the prevention, protection and conservation of the marine environment against damaging human activities. Two subgroups were created under the Working Group on good environmental status (GES) for further development of Descriptor 10 (Marine Litter) and Descriptor 11 (Noise/Energy).
General principles of environmental policy in Portugal	Lei n.º 19/2014 (*Portuguese law*) • Early measures to be taken in order to prevent or reduce, prioritizing at the source, adverse impacts on the environment. • Liability for persons or institutions responsible for pollution to assume the costs of both polluting activity and the introduction of internal preventive and control measures necessary to combat threats and aggressions to the environment. • Policy for the marine environment, covering the water column, the soil and the seabed, must protect its integrated management, in conjunction with coastal zone management, protect the protection of marine resources and ecosystems.
Administrative offenses within the scope of pollution of the marine environment in maritime spaces under national jurisdiction	Decreto-Lei n.º 235/2000 (*Portuguese law*) • Establishes the polluting agents in maritime spaces under national jurisdiction regardless of their nationality. • Defines offenses caused by pollution of the marine environment any discharge or spillage of a polluting product likely to cause changes to the natural characteristics of the marine environment, as well as any unauthorized immersion operation.

5.3. Risk assessment for environment protection

Table 4. below presents the identified risks and mitigation measures that were identified. The risk level is colour coded where orange, yellow and green are high, medium and low risk, respectively.

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Table 4. Potential risks and corresponding mitigation measures.

No.	Risk description	WP	Proposed risk-mitigation measures
1	Acoustic pollution and marine mammals.	WP5	A side effect of the ATLANTIS activities is the reduction of negative environmental impact associated to the operation of vessels. In fact, the use of robotic tools reduces and, in some cases, completely eliminates the use of supporting vessels. Nonetheless, the replacement of divers or remotely operated vehicles by more autonomous systems also brings additional environmental impacts. In this initial phase of the project, the major foreseen environmental impact is associated with the use of underwater acoustic networks for communications and navigation of autonomous underwater vehicles. Furthermore, during the testbed installation phase, a monopile is expected to be rammed into the ground which could cause noise levels up to 150 dB and potentially disturb fish and bird populations. Nevertheless, the installation phase is limited in time and hence, of low concern.
2	Jeopardizing the biodiversity during the demonstrations. The ATLANTIS testbed will be located in shallow coastal waters. There is a small possibility that animals such as fish or birds may be injured during construction and testing phases of the project.	WP5, WP6	In the case of the ATLANTIS project, the benefits to the ecosystem outweigh the negatives. Birds prefer shallow to deep water, due to better feeding possibilities. The foundations of the ATLANTIS testbed are expected to be a good living environment for small fish, mussels etc. Since fishery is to be forbidden within the site, the farm area may serve as feeding ground for birds, thereby improving feeding conditions. The impact is considered to be low because (1) construction will be limited in time and (2) testing is reserved to authorized teams only and those are subjected to an adequate scheduling to ensure safe operation within the test site. Nevertheless, since the main operations are performed with small-size robots (the bigger supporting vessels should remain mostly stationary during the tests) the risk to animal life is minimal. Relevant legislation and guidelines should be followed by the staff involved. All activities of ATLANTIS project will comply with best conduct guidelines, national regulations and other legislation that might be applied.
3	Air emissions. Emissions of Carbon dioxide (CO_2), Methane (CH_4), Carbon Monoxide (CO), Oxides of nitrogen (NO_X) and Sulphur	WP5	One of the goals of the ATLANTIS project is to minimize the need for such vessels during the latter activities by using electric vehicles that operate autonomously. Thus, in this context, the project itself is a mitigation measure that, if successful, will lead to a generalised reduction in

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	dioxide (SO_2) will result from the operation of the supporting vessels during the deployment of the ATLANTIS Testbed and during the execution of the planned testing activities.		emissions associated to offshore activities where robotic assets can be adopted.
4	Landscape and visual impact. Concerns on the visual impacts have played a major role in the public hearings. Also the visual impact is a determining factor for public acceptance at locations renowned for their scenery or close to recreational areas.	WP3, WP5	The ATLANTIS testbed will be installed in an area selected by the local authorities, somewhere on the coast of Viana do Castelo or inside a harbour. Hence, being a remote location, the visual impact can be discounted. The structures that compose the testbed are mostly underwater, thus with minimal impact. In the case of the Wind Turbine generator, the impact will be small since there are already others installed in the vicinity.
5	Influence from magnetic fields in cables. The array and export cables produce magnetic fields can produce high magnetic fields.	WP5	Calculations of magnetic fields from submarine cables dug down one metre under the seabed show that the magnetic field on the seabed above the cable will be smaller than the geomagnetic field. Therefore, no impacts are expected if the cables are properly buried [EIA00]. The Coastal Testbed will not use an underwater cable connected to the electric grid. The Offshore Testbed will use a commercial offshore wind farm which already have addressed all environmental issues needed by EU and national regulations.
6	Risk of collision. Accidental impacts on the environment may origin from collision between ship (e.g., maintenance vessel) or aircraft (e.g., helicopter) and turbine/foundation or substation, or from damage to submarine cable caused by anchoring or colliding ship, by trawling equipment or during construction. The effect of such accidents may be a pollution of the environment caused by substances from the offshore farm (turbine/	WP3, WP5, WP6	Mitigation measures such as protection of the cable (by trenching if possible) and prohibition against navigation within the area of the test site and around the cables are therefore highly recommendable. Other measures include marking lights and painting. Nevertheless, this is not expected to be a relevant problem as the area where the test site will be built will has restricted access. Furthermore, collision frequency is relatively low and a collision would not necessarily result in severe environmental damage.

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	substation/cable) or substances from the colliding ship or aircraft.		
7	Seabed sedimentation. The construction activities, i.e. piling foundations, may cause sedimentation covering communities of organisms that live in the area, causing possible loss of habitat and individuals. Furthermore, changes in sediment structure may rise from changed water flow around foundations.	WP3	Seabed vegetation and fauna will suffer mostly during the construction phase, but this is not permanent. Monopile drilling may originate some sedimentation over the seabed around the monopiles but it will eventually disappear due to natural sediment movement as a consequence of currents.

5.4. Safety and health protection

This document may be considered an internal guide to assist researchers involved in the project, offering an overview of the issues surrounding the safe execution of IMR operations and defining guidelines for preventive action. This may be of particular value to assist in ensuring compliance with the Occupational Safety and Health (OSH) legislation, among others identified, at EU and national level.

In recent years, the European Union (EU) and its Member States have been at the forefront of improving maritime safety legislation and promoting high-quality standards. The aim is to eliminate substandard shipping, increase the protection of passengers and personnel and reduce the risk of environmental pollution. The EU is constantly developing and intensifying its maritime safety policy essentially through a convergent application of internationally agreed rules. This said, the ATLANTIS project intends to fully comply with such regulations, aiming to enforce safety throughout the project lifespan.

The human component is a critical factor in maritime safety. Not only that, but it is a complex multi-dimensional component that also affects maritime security and marine environmental protection involving the entire spectrum of activities executed by the ships crews and shore-based supervision systems. Near of 80% of maritime accidents[1] can be attributed in some way to human element failures.

Occupational health and safety standards and procedures will be considered during the ATLANTIS project. While there is no need for constraining the research community to the same levels of safety required for offshore oil and gas exploitation, as the working practices applicable to offshore are far more life threatening than the equivalent onshore practices, some conclusions may still be drawn from this sector. For example, to allow working on a wider weather window, installation methodologies, operational procedures and the marine infrastructure itself should be made less sensitive to wind/wave conditions.

[1] EMSA, Human Element in maritime safety, available on: http://emsa.europa.eu/safemed-iv-project/component-5-human-element-in-maritime-safety.html

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The development of alternative erection techniques should be considered, where assembly operations are mostly conducted onshore prior to transportation to the final deployment site.

The highest priority for operation and maintenance activities within the project is the safety of personnel who are required to visit the test site or the wind farm throughout the year. Safe access through adequate procedures and equipment should be provided. Another high priority task is to facilitate the remote access through digital communications technologies to the monitoring system infrastructure to investigate, rectify and plan operations with maximum knowledge and efficiency.

The robotic platforms and communication systems that will be deployed and used in ATLANTIS must follow the telecommunications national regulatory authorities specially, the ANACOM from Portugal.

The adoption of mooring systems which provide safe access to personnel disembarking on the platform from supporting vessels for performing installation or maintenance operations is also advised. The development of operation and maintenance procedures will continue throughout the ATLANTIS project, particularly taking advantage of the acquired operational knowledge and experience.

The development of purpose-built vessels can also be taken under consideration. Under the TEC4SEA infrastructure project, INESC TEC ordered a ship optimized to perform the type of robotic-based O&M operations that are being considered within the ATLANTIS project, respecting current maritime safety regulations and good practices.

Furthermore, given the goals of the ATLANTIS project, condition monitoring of critical components of the maritime infrastructure which are susceptible to wear and failure will be extensively studied and explored to improve methodologies and technologies to be used in future I&M operations. Innovative maintenance strategies may also be developed as a product of the project.

The effect of traffic near the ATLANTIS Testbed or experimentation area will also need to be considered on safety grounds. Certain areas will be prohibited for use as testing sites, as a safeguard measure to protect traffic on established shipping lanes. As offshore structures are a potential hazard to existing traffic, it is imperative that they be marked properly and effectively, in accordance with international guidelines. There are some concerns regarding the need to alter existing traffic routes and the increased collision risk which may be mitigated by avoiding construction of marine infrastructures near major navigation routes. Not only must they avoid traffic lanes, but related cable routes must also avoid locations where ships may lay anchor while waiting to enter harbours. For this reason, discussions with the local marine port authority are of utmost importance.

5.5. Safety and health legislation

Table 3 provides an overview of the safety and health legislation that will be considered in ATLANTIS.

Table 3 Legislation and guidelines related to safety.

Topic	Legislation
Health and safety at work: general rules	Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work:

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	Introduces measures to improve the health and safety of people at work. It sets out obligations for both employers* and employees* to reduce accidents and occupational disease in the workplace.
Maritime safety: marine equipment	Council Directive 96/98/EC of 20 December 1996 on marine equipment: • It lays down rules to ensure the safety and quality of marine equipment carried on board ships flying the flags of EU countries. These rules increase safety on board, contribute to tackling marine pollution and seek to ensure the free movement of marine equipment within the EU's internal market.
Maritime safety: minimum level of training of seafarers	Directive 2008/106/EC of the European Parliament and of the Council of 19 November 2008 on the minimum level of training of seafarers: Incorporates, into EU law, minimum standards of training, certification and watchkeeping for seafarers serving on board EU vessels which are fixed by the convention on standards of training, certification and watchkeeping for seafarers (STCW convention) of the International Maritime Organisation.
Security for ships and port facilities	Regulation (EC) No 725/2004 of the European Parliament and of the Council of 31 March 2004 on enhancing ship and port facility security: It ensures the uniform implementation throughout the EU of the security measures that the International Maritime Organization (IMO) agreed in December 2002 when it amended the 1974 International Convention for the Safety of Life at Sea (SOLAS). Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) It provides the recognition to traffic separation schemes by determining the best practices in terms of, safe speed and direction to avoid collisions.
Medical treatment on board vessels	Council Directive 92/29/EEC of 31 March 1992 on the minimum safety and health requirements for improved medical treatment on board vessels: Aims to ensure minimum safety and health systems are in place to improve medical treatment on board vessels.
EU maritime information and exchange system	Directive 2002/59/EC of the European Parliament and of the Council of 27 June 2002 establishing a Community vessel traffic monitoring and information system and repealing Council Directive 93/75/EEC: Aims to enhance maritime safety, port and maritime security, environmental protection and pollution preparedness. It also permits the exchange and sharing of additional information facilitating efficient maritime traffic and transport.

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Robots safety legislation	Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC: • Essential health and safety requirements relating to the design and construction of machinery; • Safety and reliability of control systems; • Protection against mechanical hazards.
Safety and health requirements for workers	Directive 2009/104/EC of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work: Lays down minimum health and safety requirements for the use of work equipment in the workplace.
National Marine Aids regulation	Portuguese Decree law n.º 284/92 adapted from the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Maritime Buoyage System: Markings and navigation rules.
(Recommendation) Marking of Man-Made Offshore Structures	IALA Recommendation O-139 on the Marking of Man-Made Offshore Structures (2008) - Guidance and information of stakeholders such as National Authorities, Lighthouse Authorities, Aviation Authorities and other competent Authorities, Aids to Navigation providers, and the Contractors, Developers and Operators involved in each type of the structures mentioned: • offshore structures/platforms in general; • oil and gas platforms; • offshore windfarms; • offshore wave and tidal energy devices; • offshore aquaculture farms.
Legal regime for the professional activity of seafarers in Portugal	Decree law n.º 166/2019 Establishes a new legal regime for the professional maritime transport activity, namely the rules applicable to maritime enrollment, medical fitness, training, certification, recruitment and vessel capacity, applying, in particular, the international regulations relative to the minimum amount of training to which they are subject to onboard seagoing ships.

5.6. Risk assessment for safety and health protection

Table 6. provides the risk assessment for the safety and health of personnel involved in ATLANTIS. The risk level is colour coded where orange, yellow and green are high, medium and low risk, respectively.

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Table 6. Potential risks associated to health and safety of personnel involved in ATLANTIS and corresponding mitigation measures.

No.	Risk description	WP	Proposed risk-mitigation measures
8	Misappropriation of robotic platforms in the ATLANTIS Test Center.	WP3, WP5	The physical access to Coastal Testbed facilities will be limited to authorized personnel/institution only. The physical access to the Offshore Testbed (during validation trials) will be granted after a background check and/or a declared authorization from the Windplus consortium (owner of the Windfloat Atlantic Park).
9	Injured personnel or animal during testing activities.	WP5, WP6	Most of ATLANTIS activities will take place on the premises of the project partners, where usual health and safety procedures are already implemented. Nonetheless, project activities also include field trials and demonstrations. Such operations require the participation of personnel for operating the robotic platforms on board of the supporting vessels working on temporary facilities acting as control centres. Relevant legislation and guidelines should be followed by the staff involved. When applicable, the ATLANTIS project mitigates this risk through insurance and by a training program (that is already contemplated in the work program).
10	Loss of structural integrity of marine (onshore or offshore) installations, including fixed and mobile platforms due to: • System malfunction or loss of stability, arising from collision or uncontrolled flooding; • Overloading and/or inherent weakness; • Deterioration due to ageing or from fabrication defects; • Damage due to accidental or rare events; • Inappropriate operator actions.	WP3, WP5, WP6	Structural integrity is fundamental to the safety of the personnel. It is assured by an inherently safe design based on good practices and must be maintained throughout the installation lifecycle by an appropriate procedure of inspection, analysis and repair. Mitigation measures may include: • assurance of the integrity of the mooring systems; • suitable structure/vessel inspection and repair programs to ensure continued integrity; • arrangements to ensure the provision of competent, experienced personnel, both offshore and onshore. The ATLANTIS Testbeds are located in restricted areas, the impact of such failures is minimal. In addition, as the project itself is focussed in performing I&M operations, the integrity of the structures and assets involved will be extensively assessed.

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11	Loss of communication or control of the robotic platforms	WP3, WP5, WP6	The increasing use of robots in performing tasks in the sea alongside human coworkers and other life forms raises novel occupational safety issues. Their autonomous and mobile behaviour may result in dangerous situations for personnel working in supporting vessels or to other vessels in the vicinity. Considering such implications, several mitigation measures can be implemented: • operate the robots in restricted areas where access is controlled by authorities; • development of monitoring mechanisms that allow robot operators/handlers to understand the current state of the system and act if needed; • operate the robots within communications range. • In case the vehicle is autonomous, implement safeguard mechanisms to detect and tolerate failures, automatically returning to a safe state (e. g., return to surface and notify the control station). Furthermore, under ATLANTIS, the technological partners will adhere to the established robotic safety regulations and guidelines, considering essential health and safety requirements relating to the design and construction of machinery, maximizing the safety and reliability of control systems and enhancing the protection against mechanical hazards.

5.7. Ethics assurance procedures

The ATLANTIS project aims at establishing a pilot infrastructure for demonstrating key enabling robotic technologies for inspection and maintenance of offshore wind farms. Hence, it involves the assessment of the feasibility, safety, robustness, reliability, and performance of the deployed robotic platforms and infrastructure, considering the relevant legal and ethical issues. Indeed, the installation of the ATLANTIS infrastructure, either near shore or inside a harbour, as well as the operation of robotic assets, may raise some environmental and safety concerns given the proximity to traffic lines and to the community in general, as well as the lack of maturity of the developed technology that will evaluated within the project. Globally, the ATLANTIS project will observe current EU Directives and national regulations, described in previous sections, placing an emphasis on:

- the assessment of the effects of projects on the environment;
- the general principles for the environmental policy;
- health and safety requirements at work, considering the working conditions, the equipment and training level of the seafarers;
- the robotics safety legislation;
- the installation of man-made structures in a marine environment.

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A detailed risk assessment was performed to identify possible risks and corresponding mitigation measures that would allow, if applied, ethical clearance to be obtained from the concerned authorities. In order to handle and monitor any ethical issues that may arise, the Project Management Team (PMT) will be responsible for creating adequate procedures to ensure that ethics requirements are implemented. Each work package leader will employ such procedures and report to the PMT the progress of their implementation. The PMT collaborating with the WP leaders shall monitor and deal with ethical issues.

All ethics requirements relevant to ATLANTIS should be adequately addressed in the project deliverables but relevant information should be disseminated within the consortium. It is the responsibility of PMT in the figure of the Ethics Monitor (Pere Ridao from UdG) to make such dissemination effort to avoid any kind of research misconduct due to lack of knowledge.

Furthermore, each participant is responsible for implementing the identified risk mitigation measures across its activities within the ATLANTIS project, ensuring the ethics requirements are met.

While the PMT will provide solutions and proper mitigation measures regarding the discussed ethics issues, if required, it may decide to appoint an external expert on ethics to assess the project and to define measures to specific unhandled issues. The PMT will be informed about internal documents that shall be provided as evidences and the procedures undertaken.

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6. Conclusions

This document has presented robotic-based solutions for performing IMR activities in offshore wind farms. These robotic solutions cover a wide spectrum of IMR operations categorized by eight industry-oriented scenarios. It should be noticed that these solutions will be conducted at different TRLs based on the industry available technology and research.

The document has shown that the consortium is capable of delivering a set of technical developments and innovations, that will surely impact the offshore industry Scenarios aim to accelerate the R&D of robotic-based platforms for de-risking the offshore operations by make them more efficient and much more cost effective. All these improvements can be achieved mainly by robotisation and automatisation to remove the human presence from the highly dangerous sea environment, particularly the underwater domain.

Moreover, the vision of the consortium is to create an ecosystem of assets with a common on-shore control centre, to be able to efficiently plan, command, supervise and analyse IMR campaigns. This will also lead to better, more coherent, possibly more frequent and easier way to analyse IMR relatable data. This data will be stored in a secure location and in cloud based services to enable a better understanding of the deterioration of the offshore structure with time, prediction of failures, as well as for helping to understand the impact of man-made offshore structures on natural environment.

We believe that ensuring consistency of the new developments with the industry needs, but at the same time introducing bold new ideas, will help the industry see the opportunities in this new technology, which is often hard to achieve by a single company or research group. Moreover, the demonstrations that will be formulated based on this document will help other interested parties - companies and universities - to see their chance of accelerating their developments utilising the ATLANTIS infrastructure.

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7. References

[Cyberhawk] Cyberhawk, https://www.arpas.uk/wp-content/uploads/2019/04/Cyberhawks-Approach-to-UAV-Inspection-Craig-Stout-ORE-Catapult.pdf, accessed in July 2020.

[Nicholas2020] Ocean Energy, *OFFSHORE WIND AND POTENTIAL WILDLIFE IMPACTS IN THE ATLANTIC*, https://sites.nicholas.duke.edu/oceanenergy/, accessed in July 2020.

[WindTurbineModels2020] Wind turbine models, https://en.wind-turbine-models.com/turbines/318-vestas-v164-8.0, accessed in July 2020.

[Trl20] TRL Scale in Horizon 2020 and ERC – explained, https://enspire.science/trl-scale-horizon-2020-erc-explained/

[Fuk16] https://www.gov-online.go.jp/eng/publicity/book/hlj/html/201609/201609_03_en.html

[WindBiz19] https://www.offshorewind.biz/2019/07/16/keep-calm-and-reduce-cable-failures/

[OffExport17] Export Cable Reliability – description of concerns, Offshore Wind Programme Board, July 2017.

[Mbari] https://www.mbari.org/autonomous-underwater-vehicle-docking/

[Blue] https://www.bluelogic.no/news-and-media/subsea-docking-station-sds-

[Modus] https://www.modus-ltd.com/2018/01/22/world-first-autonomous-subsea-survey-and

inspection-system-could-save-european-wind-farms-1-1bn/

[Ocean] https://www.oedigital.com/news/472302-steps-toward-freedom

[Subsea7] https://www.youtube.com/watch?v=1XMWmRkGD1Y

[Ikm] https://www.ikm.com/ikm-subsea/products/services/rrov

[Loondock] N. Palomeras, G. Vallicrosa, A. Mallios, J. Bosch, E. Vidal, N. Hurtos, M. Carreras, P. Ridao, AUV homing and docking for remote operations, Ocean Engineering, Volume 154, 2018, Pages 106-120, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2018.01.114.

[Roddier2011] D. Roddier and C. Cermelli. Column-stabilized offshore platform with water-entrapment plates and asymmetric mooring system for support of offshore windturbines. US Patent 2011/0037264 A1. February 17, 2011.

[Andry2020] A. M. Pinto, A. C. Matos. MARESye: A hybrid imaging system for underwater robotic applications. Information Fusion,Volume 55, 2020, Pages 16-29, ISSN 1566-2535, https://doi.org/10.1016/j.inffus.2019.07.014.

[Qi2019] Wen-Gang Qi and Fu-Ping Gao, "Local Scour around a Monopile Foundation for Offshore Wind Turbines and Scour Effects on Structural Responses", Geotechnical Engineering - Advances in Soil Mechanics and Foundation Engineering, 2019. doi : 10.5772/intechopen.88591

This project has received funding from the European Union's Horizon 2020 research and innovation programme, under the Grant Agreement no. 871571.

[Petersen2014] Petersen, T. U. (2014). Scour around Offshore Wind Turbine Foundations. Technical University of Denmark. Department of Mechanical Engineering

[Esteban2019] M.D. Esteban, José-Santos López-Gutiérrez, Vicente Negro and Luciano Sanz, "Riprap Scour Protection for Monopiles in Offshore Wind Farms ", Journal of Marine Science and Engineering, 2019. doi:10.3390/jmse7120440

[Jaegar2020] Jäeger Mare Solutions, https://www.jaeger-maresolutions.com/en/, accessed in May 2020.

[GEO2005] Geotechnical and geophysical investigations for offshore and nearshore developments, Technical Committee 1, International Society for Soil Mechanics and Geotechnical Engineering, September 2005.

[DriX2019] Autonomous Systems for Bathymetry Surveys Bibby HydroMap's DriX trials at Gwynt y Môr, https://ore.catapult.org.uk/app/uploads/2019/03/Autonomous-Systems-for-Bathymetry-Surveys-Alistair-Lee-CS0022.pdf, accessed in July 2020.

[IRI28] Irish-Scottish Links on Energy Study (ISLES), Construction and Deployment Report, MDR0707Rp0028

[Felski2020] Andrzej Felski and Karolina Zwolak, The Ocean-Going Autonomous Ship—Challenges and Threats, Journal of Marine Science and Engineering, 8(1), 2020, https://doi.org/10.3390/jmse8010041

[RollsRoyce2020] Rolls-Royce and Finferries, SVAN - Safer Vessel with Autonomous Navigation, Word's first fully autonomous, ferry demonstration, https://breakingwaves.fi/wp-content/uploads/2019/06/SVAN-presentation.pdf, accessed 17.6.2020.

[Kongsberg2020] KONGSBERG, Autonomous Shipping, https://www.kongsberg.com/maritime/support/themes/autonomous-shipping/, accessed 17.6.2020.

[Autoship2020] AUTOSHIP, https://www.autoship-project.eu/ acessed 1.7.2020.

[DNVGL-RP-0360] Recomended Practice. Subsea power cables in shallow water. http://www.dnvgl.com . March 2016.

[DNVGL-ST-0126] Standard. Support structures for wind turbines. http://rules.dnvgl.com. April 2016

[Ynf] CTruk launches first Volvo Penta IPS workboat. https://www.ynfpublishers.com/2014/03/ctruk-launches-first-volvo-penta-ips-workboat.

[4coffshore] Global Offshore Renewable Map. http://www.4coffshore.com/offshorewind/.

[Airbus] Airbus Helicopters focuses on the wind turbine growth market. https://www.airbus.com/newsroom/press-releases/en/2018/09/airbus-helicopters-focuses-on-the-wind-turbine-growth-market.html, September 2018.

[Ampelmann] Walk to Work solutions take flight for the offshore wind market. http://cdn.pes.eu.com/v/20180916/wp-content/uploads/2018/06/PES-W-2-18-Ampelmann-Corporate-Focus-1.pdf, September 2018.

[H2020Ethics] "Horizon 2020 Programme: Guidance How to complete your ethics self-assessment ", European Commission, Directorate-General for Research & Innovation, Version 6.1, 4 February 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme, under the Grant Agreement no. 871571.

[Dual09] Dual-use trade controls, Council Regulation (EC) No 428/2009 of 5 May 2009, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1527179601283&uri=CELEX:02009R0428-20171216

[EUFinancial] Consolidated list of persons, groups and entities subject to EU financial sanctions, https://eeas.europa.eu/headquarters/headquarters-homepage/8442/consolidated-list-sanctions_en

[EUCharter] EU Charter of Fundamental Rights, https://ec.europa.eu/info/aid-development-cooperation-fundamental-rights/your-rights-eu/eu-charter-fundamental-rights_pt

[UN2325] UN Security Council Resolution 2325 that reaffirmed the obligations in resolution 1540 (2004), https://undocs.org/S/RES/2325%20(2016)

[ECC2913] Community Customs Code (Council Regulation (EEC) No 2913/92) and the Code's implementing provisions (Commission Regulation (EEC) No 2454/93) and recasting the Modernised Customs Code (Regulation (EC) No 450/2008), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:01992R2913-20140101

[EIA00] Rødsand Offshore Wind Farm. Environmental Impact Assessment. EIA Summary Report, 2000, http://www.seas.dk/gruppe_artikel.php3?textno=444&groupname=Rødsand&headline=Rødsand

[NATO06] NATO Undersea Research Centre Human Diver and Marine Mammal Risk Mitigation Rules and Procedures, NURC Special Publication, 2006. Available on: https://www.cmre.nato.int/research/publications/latest-techreports/86-nato-undersea-research-centre-human-diver-and-marine-mammal-risk-mitigation-rules-and-procedures/file

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