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D7.1 - Social and economic impact analysis report

INESC TEC, EDP, PPF, RINA-C

atlantis The Atlantic Testing Platform for Maritime Robotics

Actions

	Action	Organisation	Date
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Acronym	Meaning
LCOE	Levelized Cost of Energy
WFA	WindFloat Atlantic
O&M	Operations and Maintenance
SME	Small and Medium Enterprises
IMR	Inspection Maintenance and Repair
AUV	Autonomous Underwater Vehicle
ASV	Autonomous Surface Vehicle
UAV	Unmanned Aerial Vehicle
ROV	Remotely Operated Vehicle
I-AUV	Intervention Autonomous Underwater Vehicle
KPI	Key Performance Indicators
SCC	Shore Control Center
DS	Docking Station

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1. Introduction

This document is entitled "Social and economic impact analysis report", and it is developed as part of the ATLANTIS project that received funding from the European Union's Horizon 2020 Research and Innovation program under the Grant Agreement number 871571.

The operation and maintenance (O&M) activities represent a crucial and critical aspect of offshore wind farm management, ensuring the resilience of the plant, by improving performance, safety, and reliability of the infrastructure over its operational lifespan, which can be extended for several decades. Effective O&M practices are essential for maximizing energy production, minimizing downtime, and ensuring the safety of personnel and the environment.

This sector is facing several technical and economic challenges in the recent years due to the complexity of such actions and level of innovation reached in the meanwhile, which aims to automatize it as much as possible, reducing as much as possible the human direct involvement. The application of robotics in support of O&M activities for offshore energy production by wind farms presents unique features with respect of onshore counterparts, increasing the difficulties in deploy completely the sector. In the context of the project, it was demonstrated the suitability of Inspection and Maintenance Repair (IMR) activities for aerial, surface and subsea operations, in two well defined showcases with multiple scenarios.

Major issues to be assessed to further develop wind offshore in EU are:

- Costs, which must be reduced by means of increased performance and reliability;
- Developing of floating substructures or integrated floating wind energy systems for deeper waters;
- Synergies with the dismissing Oil & Gas sector.

The vision depicted by ATLANTIS project is that robotics will actively contribute for the sustainability of the offshore wind energy in terms of social, economic and environmental aspects.

1.1. Overview of the projects and its four years

The ATLANTIS project faced and surpassed several technical challenges during its four years of deployment. Four different IMR scenarios, focused on the WindFloat Atlantic (WFA) have been built considering major aspects of operation (turbines, cables, foundations, and logistics), providing the most important challenges of activities. In addition, the ATLANTIS coastal testbed represented a demo pilot where robotic assets could demonstrate their capabilities in a highly realistic operating environment, with the installation and refurbishment of the offshore platform "DURIUS".
The coastal testbed is also composed of a Shore Control Centre (SCC) and IT systems to support and monitor the operation of the technological assets in the area. The combination of these two aspects enabled to create one of the first demo site in Europe where robotic technologies are deployed for IMR activities for offshore wind farms, in a safely way and in different phases of their development and upscaling.

Not only technical aspects were assessed during the project but also main non-technical complexities, in particular legal and regulatory ones. Surveys and studies on the topic showed how offshore O&M activities for OWF are not yet standardized, with a regulatory gap in the field

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of technical norms for the use of robots, whose own regulatory framework is still under construction and strongly dependant from the field of application. The O&G sector was taken as reference to look for standards or guidelines already in place, but none proposes a consistent approach starting from the design phase.

ATLANTIS also covered the topic of data integrity and system resilience against possible threats in connected systems, enhancing cybersecurity measures. It ensured interoperability among diverse devices and platforms, supported by ROS2 (Robot Operating System 2) and DDS (Data Distribution Service). The project established a consistent framework for data-driven decision-making, including predictive maintenance, real-time monitoring and informed operational strategies. The aim was to enable the transition of IMR executions into proactive, developing tools for predictive maintenance. In particular, it was possible to target IMR activity schedule according to the weather forecast and specific work to be performed with the use of such robotic assets.

In general, significant steps forward in platform development and relative robot's interconnection have been reached in the area of infrastructure inspection and maintenance, creating an important showcase to show the feasibility of the technology and for the further exploitation of such results.

1.2. Scope of the report

This report details the outcome of Task 7.1 – "Social, economic and environmental impact analysis". Main references to the stakeholder analysis were made, evaluating main project's measurable objectives defined within WP1 – "Industry-oriented Showcases for Offshore Wind Farms", and to the evaluation of work carried out in the WP5 – "Operation and demonstration of the ATLANTIS Test Centre" and WP6 – "Long-term Strategy, Technology Industrialization and Business Cases".

In this task, important references were made to the two sections 1.1 Objectives and 2.1 Expected Impacts of the Grant Agreement, evaluating the preliminary purposes of the project and quantifying goals completely reached, pointing out also the main criticalities faced in the deployment. Essentially, the range of impacts oversee costs and frequency of validation of robotic technology in near-real environments, demonstration of matured robots operating in a commercial offshore wind farm, and the consortium ability to influence opinion on the project solution take-up. The scope of the deliverable is to summarize in a report such analysis, starting from the lessons learnt in the project and providing a list of recommendations for improving outcomes and to reach future interested stakeholders.

1.3. Outline of the report

The report is structured as follows.

Section 2 provides a description of the ATLANTIS project and showcases.

Section 3 provides a description of the ATLANTIS expected outcomes.

Section 4 gives an overview of the main updates on the regarding of main IMO and EU policy in the context of robotic technologies for IMR operations.

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Section 5 features the lessons learnt by demonstration, an overview of the project measurable objectives defined within WP1 and impacts forecasted during the proposal phase. Reference will be made to the stakeholder analysis and a general evaluation of work carried out in WP5 and WP6.

Section 5 drafts the results of KPI and quantifies social, economic, and environmental impacts for ATLANTIS developments.

Section 6 runs the conclusion of the analysis, recommendations, and a shortlist of valid options for future development.

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2. ATLANTIS project and demo site

Different and relevant results have been achieved in the field of robotic technologies in the last 10 years, but the complete validation of their prevalent features have not been completely verified. The lack of confidence among end-users and owner infrastructures has not already permitted the complete diffusion and up-scaling of such technologies. The reasons related to this slow application in real environments are mainly due to risky operations which could lead to damages of existing assets, lack of unified and well-established metrics that regulate the benefits of robotic technologies and their safety operational conditions, high costs of manufacturing and related costs for end-users, missing clear regulatory framework.

The ATLANTIS Test Centre is developed with the main ambition to enable the uptake of robotic technologies for the O&M of the offshore wind sector, becoming an infrastructure which demonstrates inspection and maintenance applicability at offshore wind farms.

ATLANTIS promotes the use of robotics in offshore wind farms to reduce the Levelized Cost of Energy (LCOE) by eliminating or marginalising the use of supporting vessels for inspection and maintenance operations at offshore wind farms. The pioneer pilot infrastructure (the ATLANTIS Test Center) for demonstrating key enabling robotic technologies for inspection and maintenance of offshore wind farms is established in the Atlantic Ocean, off the coast of Viana do Castelo, in Portugal. The **Coastal Testbed**, featuring a shore control room and a Floating Structure System (FSS), used by technology developers to de-risk their robotic technologies through rigorous, cost-efficient, and staged testing programmes performed in a near-real environment, for a wide technical and industrial impact.

Testing, validation and demonstration activities that took place at Test Centre were expected to:

- Increase end-user trust in robotic technology.
- Lead changes and know-how in the existing legal and regulatory framework.
- Encourage robots’ developments and manufacturing.
- De-risk robotics technologies in near-real environments.

The Coastal testbed of the ATLANTIS Test Centre (Fig 1) is equipped with a floating structure that simulates an offshore floating structure of a floating wind turbine. The floating structure installed is a decommissioned Catenary Anchor Leg Mooring (CALM) buoy, that provided support to the loading and discharging of liquid product cargo to/from tankers, near onshore or production fields.

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Figure 1 - Views of ATLANTIS Coastal Test Bed (before and after physical enhances performed by the project).

Offshore Testbed encompasses the WindFloat Atlantic (WFA) reported in Fig 2, used for demonstrating robotic technologies within a real commercial wind farm. It contains three cutting-edge wind turbines supported on a floating structure based on Windfloat technology at 20 km from Viana do Castelo. This Testbed provided unique wave, weather and wave conditions of Atlantic Ocean which enabled the testing of robotic technologies in harsh environments, affecting their reliability, risk management, feasibility and efficiency. Different surveys and analysis of the status of key testbed components were conducted to show the feasibility of offshore activities based on heterogenous robots in a multi-domain environment.

Figure 2 - Wind Float Atlantic view[1]

ATLANTIS concept relies so on a Coastal Testbed, which closely reproduces real-world scenarios, providing the robustness and reliability before deployment, and on Offshore Testbed, which offers conditions of paramount consistency with a real offshore wind farm. This complete and

[1] https://www.edp.com/en/innovation/windfloat

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complex ground accelerates the development and on field application of disruptive technology that can transform offshore wind farm operations.

The flexibility of the ATLANTIS Test Centre extends beyond promulgating new ideas: it proposes an infrastructure to customizing existing robotic technologies to meet and fulfil the specific needs of offshore wind farm operators. Robotics developers can adapt their products to the unique challenges posed by these environments. Test centre facilities, including the offshore testbed and its access to actual offshore wind farms, enable the fine-tuning and optimization of robotic solutions. This adaptability ensures that standard technology can be adapted to work effectively and efficiently in the demanding environments of offshore wind farms.

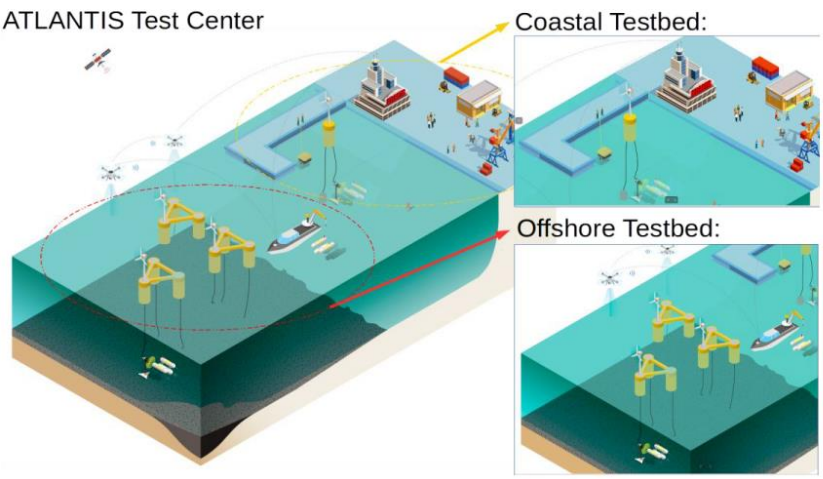

Figure 3 - The ATLANTIS complete Test Center

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3. Expected outcomes

Offshore wind energy provides carbon free MWhs and so, by increasing the sustainability of this sector, ATLANTIS is directly contributing to Paris (COP 21) since that the 96 000 wind turbines installed on land and in the sea will avoid the emission of 436 million of tonnes of carbon dioxide. ATLANTIS is an initiative that will mitigate the needs and fulfil the sustainability expectations of the wind energy sector through robotics where the technical and commercial challenges depicted in ATLANTIS Test Center will be applied to both land-based and offshore projects.

On an economic point of view, wind farms still only produce 5 % of global energy supply. One of the main barriers or limitations to be overcome is for sure the cost of O&M: their costs can account between 11% and 30% of an onshore wind projects levelized cost of electricity (LCOE), averages between USD 0.01/kWh and USD 0.025/kWh. The O&M costs for offshore wind farms are higher due to the difficulties posed by offshore environment and can be between USD 0.027 and USD 0.048/kWh [1]. Reducing these costs becomes essential to aim for Europe a leading role in Energy transition.



Figure 4 - Some pictures of traditional IMR activities

Most of the time, offshore wind farms are built several kilometres far away from the shore, increasing by this way the costs of installation and relative operational costs, which make arising operational costs to the range of 44 €/kW/y for a land-based plant to 127 €/kW/y for a fixed-bottom [2].
For an utility company operating the wind farm and gaining money from the power production, reducing to the minimum operating costs becomes a top priority, as it directly interests company's bottom line.

ATLANTIS targets an expected savings of 15% in total fuel consumption of support vessel and bring a general reduction of O&M OPEX up to 10% and, consequently, a LCOE reduction of at least 1-2%. This demonstration in terms of reduced O&M would help in a rapid uptake of Offshore wind farms as the driving force in Energy transition.

Another factor which hinders the rise in popularity of Offshore wind farms are the working conditions in the environment which are often harsh and difficult in terms of human involvement. To this purpose, robotic technologies ensure safety of staff and enhance the activities to be performed. The ATLANTIS project fills itself in this pathway, by eliminating the risk for workers, reducing their involvement in actions like diver for foundation monitoring or climbers for turbine power inspections.

The content of this report is to take into account the benchmark of project concept, starting from the criticalities and weaknesses mentioned above, in order to evaluate if social and

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economic impacts obtained in the project are consistent with it. Different analysis brings to the evaluation and quantification of specific objectives and targets, which helps in the objective evaluation of the project outcomes itself.

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4. Relevant IMO, EU policy and roadmaps

Starting from the work performed in WP1 and reported in deliverable D1.2 – "Survey on legal and regulatory specifications for IMR robots operating in offshore wind farms", the main regulations and guidelines at international level have been assessed and review, highlighting if main updates in their content were seen. The work of review provided a clearer understanding about essential legal aspects to comply the safety of operations involving robotic technologies.

Robots represent an innovative and cutting-edge technology, which suffers the lack of tailored legislations able to regulate their deployment in this context of activities. The common approach is to fit these technologies in the already in place regulatory framework, necessary to reduce doubts and risks of these vehicles.

Main international directives reported in the previous work are included in the following Table 2:

Table 1 - Review of main international directives [3].

Context	Directive	Content	Update	Content of the update
OWF	Habitats Directive (92/43/EEC)	Adopted by EU in 1992, aims to protect biodiversity by safeguarding natural habitats, flora and fauna. It asks to identify wild species which require strict protections[2].	October 2021	A guidance document was adopted, providing clarifications on Articles 12 and 16 of the Directive, and it includes good practices and information to help national authorities addressing conflicts between strictly protected species and human activities.
OWF	Birds Directive (2009/147/EC)	Adopted by EU members in 1979, they have to indicate Special Protection Areas (SPA) that benefit rare and vulnerable birds for breeding, feeding or migrating to/from[3]. It does not exclude OWF installation.	April 2009	Member States must conserve, maintain, and restore biotypes and habitats of these birds, creating protection zones and maintaining the habitats, restoring destroyed biotypes and creating new ones.
ROVs	NORSOK STANDARD [4]	The classification made by NORSOK for Remotely Operated Vehicles (ROVs) is adopted, with Class III, IV and V which best suit the scope of ATLANTIS activities.	January 2023	It defines the minimum functional requirements for process systems on an offshore installation and includes recommendations to give additional guidance for the system design[4]. No reference to ROVs technologies from last update in 2003.
ASV	UNCLOS ("United Nations Convention on the Law of the Sea")	The assumption of considering an Autonomous Surface Vehicle (ASV) as a vessel or a ship was assumed in WP1. With this hypothesis, technical	2015	The United Nations General Assembly decided to develop an international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of

[2] https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en

[3] https://environment.ec.europa.eu/topics/nature-and-biodiversity/birds-directive_en

[4] handle.standard.no

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		requirements for registration and legal regime of flagged unmanned vessels are applicable.		areas beyond national jurisdiction (UNGA resolution 69/292)[5].
ASV	COLREG ("International Regulations for Preventing Collisions at Sea")	It is applied to all vessels or watercrafts used as means of transportation in high water sea. In the scope of ATLANTIS, the ASV might be intended as a mean of transportation for the presence of sensors and tools on-board, and for its capability to transport and deploy any other kind of robot needed.	Not foreseen	-
ASV	SOLAS ("Safety of Life at Sea")	SOLAS presents a wide flexibility if research and development are jeopardized by the application of provisions. In that sense, ASV may stand to benefit from this dispensation, but much depends on the attitude of the domestic regulators.	January 2024	- Safe mooring operations by introducing additional requirements to selection, arrangement, inspection, maintenance and replacement of mooring equipment - Modernization of the Safety System, being independent from specific service providers and to remove carriage requirements for obsolete systems - Fault isolation of fire detection systems update so that short circuit do not need to be provided at each individually fire detector - Life-saving appliances - Ships using LNG as fuel[6].

Robotic technologies represent the main product for leading the complete automation of O&M activities, but the lack of clear and tailored directives may cause some delays in the fast and safe deployment in Offshore Wind Farms.

For technologies like AUVs and ASVs it is not possible to follow specific regulations. Some directives are currently in a review phase and others have been recently updated. An opportunity could be the exploitation of the best knowledge and expertise developed in ATLANTIS project, to lead the fitting of these technologies into the existing legal instruments. Some guidelines for the technology certification have been developed in WP5 and beyond project lifetime the International Maritime Organization (IMO) could be reached out in order to develop new standards which enable robots to be consistent and in line with European legal frameworks.

[5] https://www.imo.org/en/ourwork/legal/pages/unitednationsconventiononthelawofthesea.aspx
[6] https://www.dnv.com/news/what-s-new-with-solas-2024--227502

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5. Lessons learnt from demonstrators

This chapter focuses on the presentation of lessons learnt from the two ATLANTIS demonstrators at the Coastal Testbed in the shore of Viana do Castelo and at the Offshore Testbed. The aim is to identify and evaluate the effectiveness of ATLANTIS solution in terms of showing the use of robots in a real offshore wind farm, measurement of IMR activities added value and cost-effective, technological maturity and commercial readiness level, enhancement of robotics supply chain, shorten time-to-market, etc. The activity started from a detailed analysis of activities in two demo sites to identify common challenges and peculiarities, to define lessons learnt on different topics, such as procurement, commissioning, stakeholders' engagement, public perception.

Afterwards, data and experience related to the operation of the demo sites were collected from relevant partners and used to evaluate Key Performance Indicators to properly assess the performance of the demonstrated technologies. The evaluation has been conducted in the last months of ATLANTIS project, so the suppliers of floating structures for turbine, key R&D institutions operating in robotic sectors and industrial partners had the possibility to report and evaluate the full set of activities.

5.1. Key Performance Indicators

With reference to the stakeholder analysis and problem definition of measurable objectives, the analysis aimed at evaluating the work carried out in demonstration phase of the project, with operational activities on demo sites, and as comprehension of industry wide effects of ATLANTIS solution.

In this way, the evaluation was approached in the five steps reported in Figure 5:

1. Gathering information for the analysis required from technical partners involved in the consortium, reviewing the objectives set in proposal phase and with WP1 work carried out;
2. Such information was analyzed and put together to create a survey where technological partners could evaluate and quantify the outreach of each target at the final stage of the project (e.g. target related to reduce the risk of human life was taken into questionnaire to understand if the activities performed in ATLANTIS were consistent);
3. Survey elaboration with specific questions able to assess the specific target;
4. Data collection in excel forms, with the polishing of evaluations received;
5. Realization of the report where feedbacks and outcomes were filled in the survey, with a final shortlist of recommendations.

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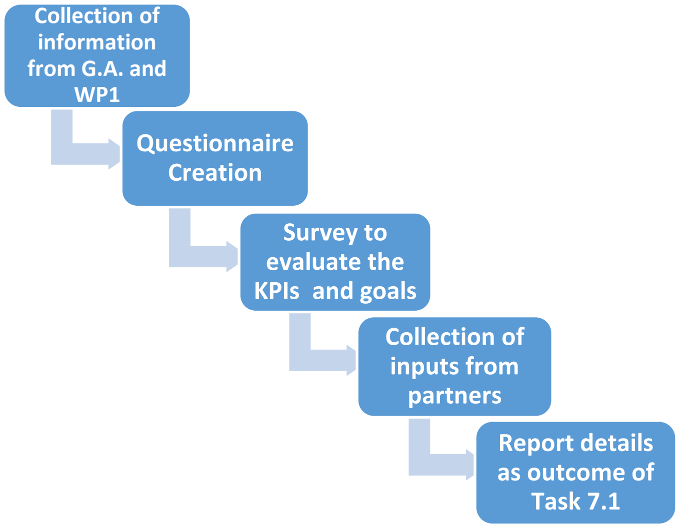

Figure 5 - Methodology for lessons learnt evaluation

5.2. Measurable objectives

The ATLANTIS project addressed the below outlined challenges by looking holistically at offshore wind IMR solutions and high-value services that can be delivered from robotic-based technology in highly realistic operating environments. The overall objective or aim of the project has been assessed by dividing in the following specific objectives.

5.2.1. Obj. 1 - Deployment of a large-scale pilot featuring weather and sea state conditions

Table 2 - KPI 1

Objective	Description	Questions	Partners involved
1	The complete installation of a maritime pilot infrastructure for showing use of robots operating in a real offshore wind farm.	Which is the actual value and technological advancement of such innovation?	INESC TEC, EDP CNET, PPF
		What values do robots bring to offshore wind farm?	

The ATLANTIS project is establishing large-scale pilots capable of demonstrating the use of robotics at scale in actual or highly realistic operating environments: the showcases in real or near-real environments were established and the pilot infrastructure (ATLANTIS Coastal Testbed) was created in Viana do Castelo (Portugal). The Coastal Testbed is a large-scale pilot where robotic assets demonstrated capabilities in a highly realistic operating environment. The testbed is fully equipped to receive robot manufacturers and research teams, covering all their logistic needs, and promulgating outstanding scenarios for testing robots' performances. In particular, a real offshore refurbished platform, the "DURIUS", was installed in a sheltered section of the Viana do Castelo port, enabling real use case testing of IMR related methodologies and technologies.

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5.2.2. Obj. 2 – Design of a new industry-oriented showcases

Table 3 - KPI 2

Objective	Description	Questions	Partners involved
2	Set of at least 4 showcases formally defined for turbine maintenance, export and array cable maintenance, foundation inspection and offshore logistics.	In the showcases operation, were the I&M activities facilitated? If yes, how were the activities facilitated?	INESC TEC, EDP CNET, PPF

The Coastal Testbed structure consists in a decommissioned Catenary Anchor Leg Mooring (CALM) buoy, considered suitable to enable the main features for the 4 showcases deployment. It has been installed to the ATLANTIS Coastal Testbed site in Viana do Castelo. The structure was completely refurbished, to better account for the testbed's user needs and to provide a stable platform for testing robotic technologies in the years to come, even beyond ATLANTIS' lifetime.

The full and complete descriptions of industry-oriented showcases were created in the first months of the project (WP1), presenting a set of four showcases focused on IMR of Offshore wind farms. Moreover, the technical requirements for such demonstrations have been specified. The WP1 provided requirements and specifications about user expectations and technology demonstrations that originated from the industry-oriented showcases. The WP1 has been divided into four main tasks with the following steps:

a) Principle Power has led a joint effort with all the consortium members that culminated with the execution and approval of D1.1 – "Showcase assessments and technical requirements for IMR robotics" [5];
b) Assets state-of-the-art for IMR activities in the offshore energy industry;
c) Emerging robotic technologies that may be able to respond to industry requirements and make it more agile and cost effective;
d) Regulatory requirements for robotic applications to the offshore wind energy industry with links to other maritime industries.

5.2.3. Obj. 3 – Develop a new demonstration methodology

Table 4 - KPI 3

Objective	Description	Questions	Partners involved
3	A new demonstration methodology capable to measure the added value	Were the 6 scenarios fully validated?	INESC TEC, PPF

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	and the risk of IMR activities performed by robots to secure long term future for offshore wind.	The IMR activities performed by robots were in every case successful and was it always possible to implement them?	

In the context of ATLANTIS project, methodologies for robotics use in O&M activities have been identified by RINA-C, by leveraging on the experience gained in consolidated inspections methodologies typical of O&G sector. A two-fold approach has been pursued:

- Evaluation of O&M tasks needed for offshore installations starting from O&G sectors (in the case of underwater applications) and from onshore wind applications (for aerial drones), understanding which ones could be also implemented for Offshore Wind Farms.
- Analysis of the robotics applications provided from the partners. In this way, the defined inspections methodologies potentially performed have been also reviewed from a regulatory and standardization/certification point of view, reporting main groups of regulatory frameworks. The methodologies have then been checked and updated during the demonstration phase.

During the infrastructure's design process in WP3, partners carefully assessed the technical and operational requirements that require to be demonstrated for each scenario in the Testbed. The evaluation and technical specifications of candidate structures layout for the refurbishment of the Coastal Testbed were conducted. A full set of features were taken into consideration and the current and proposed methodologies were incorporated into the design. This comprehensive list of parameters enabled the successful demonstrations, to occur in successive phases of increased complexity. They allowed a clearer understanding of the added value, the unique value proposition and of the risk involved in the operation of robots when performing IMR activities.

5.2.4. Obj. 4 – Improve heterogenous robots for IMR activities

Table 5 - KPI 4

Objective	Description	Questions	Partners involved
4	Reach technological maturity and commercial readiness level.	Did the mix of different robotic assets provide a commercial readiness level?	INESC TEC, PPF, ECA, IQUA
		How many mobile robots out of 5 were upgraded to operate for extended time periods?	

The Key Performance Indicator foresaw a set of at least 5 mobile robots subjected to an upgrade, in order to operate for extended time periods on surface, air and underwater. The project overperformed: indeed, a total number of nine robots were modified. Two autonomous surface vehicle (ASV) - SENSE and NAUTILUS -, three unmanned aerial vehicle (UAV) - ROOK, CROW, and

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RAVEN -, one remotely operated vehicle (ROV) - ROVING BAT -, and three autonomous underwater vehicles (AUV) - Girona 1000, SPARUS II and RAYA – were upgraded in their performances (e.g. time of deployment, set of skills, efficiency).

5.2.5. Obj. 5 – Promoting robotics in supply chain

Table 6 - KPI 5

Objective	Description	Questions	Partners involved
5	Robotics in supply chain by demonstrating the benefit role in terms of increased IMR efficiency and reduced of life-cycle costs.	Was it possible to prove this benefit role of robotics in supply chain?	VTT, EDP CNET, PPF, IQUA
		Are the forecast for 25% by 2025 possible?	

ATLANTIS project succeeded in the goal of showing the full applicability of robots to offshore O&M wind farms. Main results led to decreasing the amount of Operating Expenditures (OPEX), reducing the risks related to O&M activities and increasing the easy accessibility to the wind farms.

In the context of WP6, a complete analysis was performed for each scenario, focusing on the actual timings and necessary economic resources to carry out IMRs activities. The ATLANTIS methodology was compared with the conventional one: the first refers to offshore activities fully robotised or with a hybrid approach, while the latter refers to human operators normally involved in the actions. Some common parameters were gathered from the different scenarios, with a special focus on duration of IMR operations and on economic impacts for planned and unplanned missions. At the end of the analysis, it was seen how introduction of robots in offshore O&M practices result in a less uncertain planning of the task, reported for several conditions, such as inspection and cleaning of floating structure. Planning of the mission with a lower grade of uncertainty is so reached, with a general increased workability on site, driving also towards a successive estimation of downtime costs in case of failure, which permit to estimate the low impact of the same [6].

5.2.6. Obj. 6 – Develop a sustainable ecosystem through the involvement of key stakeholders

Table 7 - KPI 6

Objective	Description	Questions	Partners involved
6	Establish an infrastructure to shorten the time-to-market of new technology and create business opportunities for SMEs. Demo activities up to 6 start-ups and SMEs.	How many SMEs participated in the activities?	INESC TEC, EDP CNET,
		Was the development of a sustainable ecosystem feasible?	
		Did the new business opportunities arise for the SMEs thanks to the established infrastructure?	

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Several phases have been led to properly define and obtain the reduction in time-to-market for robots: major role was performed by the Coastal Testbed, which represents a baseline capable of hosting different technological providers robots and testing performances and main features in a close-to-real environment. This dedicated platform becomes of high importance for exploring new activities even beyond the project lifetime, with the possibility to gain the role of demonstrator for offshore environment.

ATLANTIS promoted and reached out different stakeholders from the international offshore wind energy sector and robotics I&M provider, engaged through key networking events. Main events targeting principal groups of stakeholders and small and medium enterprises (SMEs) were conducted, and further events guaranteed the dissemination of main results and outcomes of the project, with relevant players in the field of IMR.

5.2.7. Obj. 7 – Establish an efficient cross border cooperation

Table 8 - KPI 7

Objective	Description	Questions	Partners involved
7	Avoiding loss of lives or permanent injuries caused by IMR activities in the sea and reducing European offshore wind power prices in 15% by 2030.	Is the cross-border cooperation efficient to address the two most important challenges faced: Avoiding the loss of lives and reduction of European offshore wind power prices?	INESC TEC, VTT, EDP CNET, PPF, IQUA
		What is the further scope of reduction of LCOE to push down wind power prices even more?	

To fulfil this aspect of cross border collaboration, a group of collaboration protocols was created with Robotics for Infrastructure Inspections and Maintenance (RIMA) network, in order to implement a fruitful collaboration and partnership. The other relevant collaboration was led with TEC4SEA, where the use of resources supported part of activities within ATLANTIS project. In particular, the deploy of offshore testbed is supported by TEC4SEA assets, which enabled the generation of a supply chain pipeline, which allowed keeping costs affordable to start-up and SMEs, increasing the overall efficiency of the demonstrations.
Several international collaborations were implemented during project lifetime, including with participants of the open call. The ATLANTIS project has also become a member of the SPRINT Robotics Community.

5.2.8. Obj. 8 – Develop a new certification roadmap

Table 9 - KPI 8

Objective	Description	Questions	Partners involved

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

8	Develop a new certification roadmap and risk assessment models derived from O&G offshore platform and on-shore wind farm.	The relationship between the new certification roadmap and ecological effect or property damages. What makes integration of performance indicators with risk assessment models beneficial?	INESC TEC, RINA

Even though there have been significant improvements in new and existing robotic technologies, their testing and validation are not catching up at the same pace. Due to a lack of testing and demonstration in a realistic environment, there is not a consolidated trust among end-users and asset owners which hinders the mass uptake in current IMR practices. Unreadiness of testing is due to different reasons, mostly the safety of testing in close-to-reality environments, the reluctancy from end-users to provide access to real environments for high risk of damaging existing assets, lack of a recognized and transversal metric that quantifies the benefits of robotic technologies as well as their operational safety.

The development of robotic technologies itself is a recent topic, which brings intrinsically the theme of innovation in their deployment. The grade of complexity increases when applying these assets in a new and challenging field of application as offshore wind farms, where operation and maintenance activities have to deal with harsh environments. Mixing the two innovative aspects lead to something that it is not already standardized, and it requires much effort to assess it.

Novel technologies are generally not adequately covered by established codes and procedures. Indeed, offshore O&M activities are not yet standardized and technical normative do not yet exist, especially if we refer to the use of robots, whose own regulatory framework is under construction and very linked to the field of application.

The first approach followed in ATLANTIS to face this issue was firstly to review common directives which regulate the O&G sector, due to its similarity with offshore wind farms in terms of operating environment, but no applicable standard to the field of operation was identified. Then, to measure the impact of adverse ecological effects or property damages due to uncertainties of robotic-based I&M, a new certification roadmap was developed and inspired by the O&G sector. A set of guidelines towards certification and standardization was created, focusing on fundamental aspects as safety, reliability, accuracy and robustness for distinct working environments and weather conditions.

The proposed guideline not only addresses traditional maintenance issues but offers a point of interest for future uses of robotic technologies in the field of inspection and maintenance. Today, the main applications are visual inspections, non-destructive testing, cleaning, small measurements, and limited maintenance activities. It has to be noticed how the guidelines could lead to significant benefits in similar technical field, as the HSE one.
Within the ATLANTIS project there was no opportunity to start a qualification process towards robotic technology developers: it requires time and huge effort, but it is important to stress how the current guidelines may pose the basis for a future development of such standards.

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5.3. Expected Impacts

The impacts of ATLANTIS project are detailed below which range over cost and frequency of validation of robotic technology in near-real environments, demonstration of matured robots operating in a commercial offshore wind farm, and the consortium ability to influence opinion on the project take-up.

5.3.1. Impact 1 – Demonstrate the potential for robotics to impact at the scale of O&M activities of the offshore wind energy

Impact	Description	Questions	Partners involved
1	The offshore demonstration provide evidence of expected improvements in efficiency and cost savings for the IMR activities for offshore wind energy farms O&M.	Are the results obtained aligned with projected savings??	INESC TEC, VTT, EDP CNET, PPF, ECA ROBOTICS, IQUA ROBOTICS,

Within the ATLANTIS project, demonstrations took place demonstrating the capabilities of robots when performing IMR operations. ATLANTIS is crucial in this context since it involves the actual design and installation of the Coastal Testbed where robots at low TRL will be deployed. During the structure's design process, both the IMR requirements and the capabilities of existing robotic technologies were taken into account, creating the ideal scenario where technology can be benchmarked and new developments can safely be evaluated in a representative manner. In particular, the Testbed was envisaged to include all 3 domains (aerial, surface and subsea), integrating specific structural features that enable that representativeness to be implemented. Therefore, this activity gives a decisive contribution towards showcasing the potential of robotics in O&M activities by considering the most representative industry challenges for IMR

5.3.2. Impact 2 – Reduced technical and commercial risk in the deployment of services based on robotic actors within the selected application area

Impact	Description	Questions	Partners involved
2	(a) The customization of robotic systems for IMR aims to cope with offshore assets inspection' requirements which will be specified by energy	(a) Did you feel a huge difference between robotics systems for IMR and offshore assets' inspection requirements?	INESC TEC, IQUA ROBOTICS, ECA ROBOTICS, EDP CNET, PPF

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	operators of offshore wind farms and by international classification societies. (b) Support vessel: savings of 15% in total fuel consumption. (c) Increase TRL for specialized IMR services: the matured version of ROVING BAT will remove need for divers and reduce the use of expensive supporting vessels (cost per day of 15k€) by 50%. (d) Better situation awareness, navigation and intervention capabilities will provide a continuous knowledge of the subsea assets conditions.	(b) Fuel consumption saving achieved for real? (c) The role of supporting vessel was still fundamental? (d) This continuous knowledge can be translated in a lower frequency of inspections performed by humans?	

The work developed in ATLANTIS clearly demonstrated how the ATLANTIS project can assume a pivotal role in the offshore wind operation and maintenance activities either by de-risking technologies or offering a new set of robot-based services. In this sense, it was pinpointed that the ATLANTIS test centre provided the technology developers with the instruments to test their technologies in a unique environment, thus reducing the technical and commercial risk of each solution. In addition to this, the project has developed a roadmap for the testing of robotic technologies that aims to support the development of robotic solutions to market. Furthermore, the project has proposed a set of tools and procedures that contribute to minimisation of the risk associated with any operations utilizing robotic solutions in offshore environments. In this way, the ATLANTIS provides a streamlined methodology for the testing of robotic solutions that verifiably reduces the risk associated with the offshore deployment.

5.3.3. Impact 3 – Greater understanding from the application stakeholders of the potential for deploying robotics

Impact	Description	Questions	Partners involved
3	(a) Exploiting EU knowledge from the O&G sector for what it concerns structural offshore engineering and maintenance/inspection approaches. (b) In-person, manual inspections are subject to human error and can take	(a) How was this knowledge in O&G sector beneficial for a better grasp of structures and maintenances technics? (b) Are the instrument errors of the robots negligible?	PPF, INESC TEC, ECA ROBOTICS, IQUA ROBOTICS,

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	up to a full day for a single tower and months for a full fleet.		

The work developed in ATLANTIS has been of utmost importance to screen Offshore Wind stakeholders that could benefit from the results of this initiative. When computing the LCOE for an offshore wind power plant where O&M activities are performed accordingly to the ATLANTIS methodology, the annual O&M costs will be reduced by a 10% factor. The screening of the stakeholders brought a clear prospect of their needs and current technological and/or economic barriers, which were fundamental to outline how ATLANTIS initiative can benefit each one of these group of stakeholders. The ATLANTIS Testbed design accounts for representative showcases where the robotic technologies can be deployed. Thus, the validation of these technologies in the Testbed help to establish its trustworthiness, by increasing the level of trust demanded by relevant industry players and leading them to integrate these technologies in the scope of their operations.

5.3.4. Impact 4 – Demonstrated platforms operating over extended time periods in near realistic environments and promotion of their use.

Impact	Description	Questions	Partners involved
4	(a) The Coastal and Offshore Testbeds will capture one of the most challenging weather and environment conditions in the world in terms of wind, weather, visibility, waves, tides and marine growth from the Atlantic Ocean.	(a) Is 4 days in an offshore test bed enough to simulate a real working environment where the robots will operate?	INESC TEC, EDP CNET, ECA ROBOTICS, IQUA ROBOTICS, PPF

The ATLANTIS team has designed and built a new docking station for the SPARUS II AUV, to demonstrate the capabilities of autonomous underwater robots to perform multi-day missions as well as enable future permanent deployment solutions. The SPARUS II AUV autonomously dock, undock, perform underwater inspection with a sonar, charge, and report data to the surface, during a multi-day experiment located around the ATLANTIS Offshore Testbed.

5.3.5. Impact 5 – Developed an ecosystem around the prioritised application areas to stimulate deployment

Impact	Description	Questions	Partners involved

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5	(a) ATLANTIS provides piloting and demonstration environment to new solutions in a cost-efficient manner (~13k€/day in a tentative expectation) since that the maritime experimentations is costly in today's market (~60k€/day). This crucial advantage of ATLANTIS since the frequency and duration of experiments can be increased in at least by 50%. (b) ATLANTIS will promote offshore engineering expertise in order to promote both consulting and certification services afterwards in its industrial exploitation intentions beyond ATLANTIS project end. (c) ATLANTIS will create a programme to European SME and start-up companies (up to 6) by granting a free access to a suite of robotic solutions and solutions	(a) Was it possible to achieve the expected reduction in cost of maritime experimentation? (b) What are some of the advancements in offshore engineering or O&M which were inspired from ATLANTIS (c) How can further oppurtunities be created for SMEs?	EDP CNET, INESC TEC, PPF, IQUA ROBOTICS,

The development of an ecosystem of stakeholders relevant to the application areas is essential for the promotion of uptake and deployment of robotic solutions in offshore wind IMR. As such, it was made one of the aims of the project. With respect to knowledge institutions, ATLANTIS has created links with research centres, such as CATEC, and various universities and higher education institutions, such as the Polytechnic Institute of Viana do Castelo, University of Limerick and University of Castilla-La Mancha, which can provide and develop novel solutions to be applied to the OW sector. In terms of technology integrators, the project has established links with SMEs, such as Voliro and EOLOS, as well as service providers, such as Fugro, Ocean Infinity and Navantia, that integrate novel technologies into robotic solutions that can be tested at the ATLANTIS Test Centre. Links have also been established with end-users, such as Ocean Winds, WindPlus, ENGIE and EDPR, that are able to provide knowledge and requirements in terms of the needs for IMR operations.

5.3.6. Impact 6 – Improved international rules or regulations.

Impact	Description	Questions	Partners involved

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6	(a)The development of standards/certification on the topic can bring a general reduction of O&M OpEx up to 10% and, consequently, a LCOE reduction of 1-2%.	(a) Were the CAPEX and OPEX reduction targets met?	INESC TEC, EDP CNET, PPF

All the robotics O&M activities in the scope of this project has been analysed from a regulator point of view also considering the naval, maritime and aerial regulation, even if this part is subject to EU Member States/countries differences. The activities provided a solid assessment around regulatory requirements to be met and to enable the deployment of robotic solutions in offshore wind farms. Moreover, all regulations, laws and guidelines at both international and national level have been considered to ensure that all business models associated with new or improved robotics-based services were developed considering the operations' safeness. With this basis and considering the expected technical developments that will take place during the project lifespan, the project has created a good ground for accomplishing yet another objective related with the promotion of guidelines for certified autonomous drones based IMR applications.

5.3.7. Impact 7 – Actions will contribute to UN Sustainable Development Goals & 2030 Energy Strategy

Impact	Description	Questions	Partners involved
7	(a) ATLANTIS will promote the energy transition in its business moving R&D and expertise assets from fossil based energy sectors to Renewable based ones.	(a) How does Atlantis plan to facilitate the energy transition and promote the shift from fossil-based to renewable-based energy sectors through its R&D and expertise assets?	VTT, INESC TEC, EDP CNET, PPF, , ECA ROBOTICS, IQUA ROBOTICS,
	(b) ATLANTIS represents an optimal balance between economic competitiveness and decarbonisation of the energy sector providing an indirect contribution to Paris (COP 21	(b) How does ATLANTIS aim to achieve this balance between economic competitiveness and decarbonisation of the energy sector?	

The work produced by ATLANTIS is actively contributing to SDGs since activities of this project are increasing efficiency of offshore operations, decreasing the LCOE of offshore energy and contributing to the global decarbonization objectives and UN sustainable goals.

Specifically, the results of the project are expected to contribute to goals 7, affordable and clean energy, and 14, life below water, through the reduction of energy costs, increasing the competitiveness of renewable energies and reduction the impact of offshore activities on the environment and marine ecosystems.

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6. Results from demonstration phase

6.1. Results of targeted objectives

The current section has the scope to quantify the Key Performance Indicators starting from the experience gained by consortium members during the demonstration phases and, more in general, in the context of the project. In the previous chapters, each objective description and the specific background descriptions have been reported, with a small summary of the work carried out. With the following Table 11 instead, an evaluation of the results fulfilled is reported, with a specific focus of lead beneficiaries' work. In this way, project social and economic impacts are evaluated.

Table 10 - KPI impacts analysis

No.	Targeted Objective	Final / Future Outcomes
1	The complete installation of a maritime pilot infrastructure for showing use of robots operating in a real offshore wind farm.	The added value of the Test Centre consists in allowing the de-risking and demonstration of the technology, increasing the trust allowing the certification path of robotic technology. It is the first infrastructure to allow the testing of robotic technology for floating wind and it enabled lower operation costs, increased worker safety, increased operational time windows. The establishment of such maritime pilot infrastructure is of primary relevance to accelerate the roll-out of robotic technologies for the offshore wind O&M sector. In particular, the combination of a coastal testbed and an actual operating offshore wind farm make it possible, for the robot developers, to test their technologies in environments with increasing and apparently insurmountable challenges (i.e. harsher weather conditions, difficulty of operations, uncertainty of activities planning). The values that robots can bring to the offshore wind energy sector are linked namely to the de-risking IMR operations, lowering the cost of such activities and the plant downtime, gradually advance in the solutions' TRL. This Test Center will hopefully enable new technologies to develop and to increase respective TRL's and enable its rout to market. A big impact is foreseen on real offshore operations and ultimately represents progress within the normal offshore IMR operations for similar projects all over the world. In general, such solutions increase the safety in offshore activities and the overall efficiencies of the operations, boosting the uptime.

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2	Set of at least 4 showcases formally defined for turbine maintenance, export and array cable maintenance, foundation inspection and offshore logistics.	The Test Centre is equipped with all needed infrastructures for the testing of the showcases. Additionally, access to a real floating wind farm allowed the complete validation of technologies for all the four conditions showcased. Robots were namely beneficial for de-risking the full set of operations, as no rope access technicians nor divers were involved in the activities, and all the crew operated from the vessel. Showcases created showed they were well defined and covered most of the activities to be considered in typical offshore IMR operations. Showcases explored blades and tower inspection, IMR activities on floating structure, the repair of underwater floating wind turbine cables protection systems, underwater monitoring over extended time periods for foundations and scour protection systems, O&M operations supported by crewless vessels. Each showcase was validated according to the former scenarios.
3	A new demonstration methodology capable to measure the added value and the risk of IMR activities performed by robots to secure long-term future for offshore wind.	It was always possible to implement the different scenarios, but not all the time they were fully completed. Main methodologies for robotics use in O&M activities were identified by RINA-C, starting from traditional O&M and inspections methodologies typical of O&G sector. Such inspections methodologies by robotics/drones have also been analyzed from a regulatory and standardization/certification point of view. In WP5, the full list of methodologies was verified and updated during the demonstration of robotic platforms: • Scenario 1 - UAVs autonomous navigation towards inspection of blades and tower. • Scenario 2 - ROV and ASV adjustment for inspection, maintenance and repair (IMR) of the transition piece or the floating structure. • Scenario 3 - Pick-and-place algorithms for autonomous underwater manipulation skills to enable the repair of underwater floating wind turbine cables protection systems. • Scenario 4 - Docking station and autonomous navigation of AUV for underwater monitoring over extended time periods.

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		• Scenario 5 - subsea imaging systems integrated with commercial ROVs and AUV navigation algorithms for underwater foundations close-range inspection. • Scenario 6 - Multi-domain mapping algorithms for underwater monitoring of scour protection interventions. • Scenario 7 - ASV developments for enabling O&M operations supported by crewless vessels. • Scenario 8 - Development of decision-making tools for supporting the optimization of robotic-based operations. This comprehensive set of features will help in making the demonstrations occurring in successive phases of increased complexity, which allows a clear understanding of the added value and risk involved in the operation of robots when performing IMR activities.
4	Reach technological maturity and commercial readiness level.	In ATLANTIS, 9 robots were upgraded. In particular, the RAVEN UAV was upgraded to increase typical drone operating time from 20-30 min to 1h. The development of a docking station by UdG has allowed instead the deployment of the SPARUS II in multiple day operations, as well as the G1000 as autonomous underwater vehicles. The ROVING BAT can operate for extended time periods but with some limitations: it is still a prototype ROV, but it has demonstrated very good capabilities during coastal training.
5	Robotics in supply chain by demonstrating the benefit role in terms of increased IMR efficiency and reduced of life-cycle costs.	The increase in IMR efficiency seems clear and the relative reduction in costs comes from an increased efficiency and reduction of personnel. Nevertheless, autonomous technologies can be very expensive[7]. Partners showed some concerns about the concrete possibility of impact on costs of IMR activities on 25% by 2025. The major concern is related to the proof of a technology that has still to be fully validated on a commercial scale. Indeed, the TRL of most developed technologies is too low for being fully operative in 2025, even though automation and robotics technology represent a consolidated trend in European market. All partners agree that cost reduction target of 25% is too optimistic at this stage.

[7] https://markets.ft.com/data/etfs/tearsheet/summary?s=ARKQ:BTQ:USD

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6	Establish an infrastructure to shorten the time-to-market of new technology and create business opportunities for SMEs. Demo activities up to 6 start-ups and SMEs.	During the project lifetime, 2 external SMEs and 2 external universities concluded the opening call trials, testing their technology in the ATLANTIS Test Centre. A total of 35 demonstrations were performed during the project (32 in the Coastal Testbed and 5 in the Offshore Testbed), by consortium members and/or external entities. These demonstrations showed a shortening of the time-to-market (e.g., 50% of development time for the Nautilus ASV, compared with previous ASVs). In these demonstrations, are included tests from the University of Castilla – La Mancha, the University of Limerick, IEP and CATEC, which were supported by the project. However, it is expected that new business opportunities will arise for the SMEs, as there is a significant involvement of wind farm operators in the testing.
7	Avoiding loss of lives or permanent injuries caused by IMR activities in the sea and reducing European offshore wind power prices in 15% by 2030.	In ATLANTIS, the main scope of LCOE reduction to push down wind power prices even more is related to the removal of human presence from offshore and further increasing of potential operational windows for robotic operations, which finally impact directly on turbine down-time. Indeed, evolution of the technologies for generating the wind power could really impact in the prices, more than the reduce of IMR themselves. One example to corroborate it is using crewless supply vessels to support IMR operations which means reduced personnel costs and increased use of assets. On this aspect, one main limitation is represented by regulation, which poses barriers to fully deployment of such vessels. In general, cross border cooperations took place across the whole value chain, from operators to technological developers. Two main events for reaching out groups of stakeholders and small-and-medium enterprises (SME) consist of WindEurope, which promotes wind energy in both Europe and globally with more than 400 members, including EDP, PPF and VTT, or Sprint Robotics, as an industry-driven initiative promoting the development, availability, and application of Inspection & Maintenance Robotics around the world. Additionally, through the dissemination of the project in multiple events, hosted by RIMA, contact has been established with relevant players in the field of

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		IMR, which are potential stakeholders of the project. National and international stakeholders were reached out since the first months of activities of ATLANTIS project, with showcases events in Viana do Castelo. The project was presented to organizations such as West Sea, Fugro, Ocean Winds, Ocean Infinity, etc. Public awareness was increased on project outcomes, including every time also some demonstrations or workshop. The ATLANTIS Test Center permits the technological validations across the entire range of TRL, as the testing occurs in a near-real environment. Due to tests performed and duration of the same, estimated costs for SMEs were provided: for coastal testbed, around 1000 euro per day. With reference to Offshore Wind Farm, in which a real environment is available, it is targeting towards robots technologies of higher TRLs, allowing for the validation and demonstration to operators and technology users. All activities were supported by Mare Profundo assets, with an estimation of total costs for its deployment close to 6000 euro per day.
8	Develop a new certification roadmap and risk assessment models derived from O&G offshore platform and onshore wind farm.	The use of these elements allows for a unified certification process that provides potential users of the technologies (service providers and end-users) with a clear scale of their risk vs benefit. Additionally, through this process, the aim is to better understand how riskier technologies and solutions can be made safer without compromising their performance. The approach to qualify the technology is called Technology Qualification (TQ) and it consists in verifying if a technology meets specified requirements for its intended service, through a systematic and documented analysis. It includes the examination of the design, engineering skills and testing programs. The qualification process consists of various steps: • Definition of Qualification basis • Technology Assessment • Selection of Qualification Methods • Data Collection • Functionality Assessment. The certification of robotic technologies at the Coastal Testbed of the ATLANTIS Test Center can be achieved by the above mentioned certification scheme. This scheme is based on the "Technology

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		Qualification" applied to the Coastal Testbed and it includes following steps: • Authorizations • Checking of Safety procedures • Checking of Deployment and Recovery procedures • Verification of Insurance and Liability documentation • IMR activity validation • Verification of Collected data This certification scheme was developed in the context of the ATLANTIS project and can be applied to the technology developers interested in offshore IMR activities.

6.2. Results of targeted impacts

To conduct an analysis of expected impacts in a project, it is fundamental to consider various aspects that can be affected by the project's implementation. Not only clarification of project's scope and primary goals is important, but it becomes relevant to assess main impacts they could have. An impact-driven approach was performed in order to better convey expected goals to citizens, legislators and budget authorities.

The impacts aimed to achieve in ATLANTIS and their current status/outcome is reported in Table 12:

Table 11 - Expected Impacts analysis

No.	Targeted Impacts	Final / Future Outcomes
1.	Implement robotics in offshore wind energy O&M activities to achieve significant efficiency gains and cost savings	Results include a reduction in fuel consumption due to increased IMR operation uptime (over 30% increase), increased IMR efficiency and improved maintenance planning (predictive maintenance combined with weather window analysis) which also reduces the downtime. The lower operation costs associated to AUVs allow to think about a dramatic cost reduction in the long run, thereby, there's a complete alignment with the expected savings and further outcomes are anticipated as the project advances.
2.	Reduced technical and commercial risk with an expected savings of 15% in total fuel consumption of support vessel and a continuous knowledge of the subsea assets conditions.	The forecasted reduction in fuel consumption was achieved. By parallelizing operations, there was a reduction in the number of trips required. At the current stage a support vessel is still necessary, in the future, the AUV could be permanently deployed in the windfarm using a docking station or be deployed from a USV, not needing human

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		intervention on site and thereby dramatically reducing operation costs.
3.	Greater understanding from the application stakeholders of the potential for deploying robotics.	By connecting with stakeholders with O&G experience, typical challenges and metrics of offshore operations were accounted in the development of the robotic methodologies for O&M. With regards to robot instrument errors, visibility and water conditions (salinity, currents, etc), impact the performance of the robots. Additionally, the time in operation in a real offshore environment has been limited and has not yet concluded, limiting the data collected to assess this topic.
4.	Demonstrated platforms operating over extended time periods in near realistic environments.	4+ days in an offshore test bed proved to be sufficient to simulate a real working environment where the robots will operate given that this window presents variable weather conditions. Other type of test might take place in more severe weather conditions to test the limit of the Robot.
5.	Developed an ecosystem around the prioritized application areas to stimulate deployment.	The offshore expertise acquired in the project led to the definition of a clear certification procedure that will allow the increase in trust, by offshore wind operators, in robotic technologies. As a result, this, coupled with the robotic developments of the project, will advance inspection operations to include new methodologies and new stakeholders, all related to robotic technology. Offshore testing still needs further work and bureaucracy may need to be reduced if efficiency is a need. Opportunities for SMEs can be created through testing campaigns that connect them with potential users of their technologies (service providers and end-users), and by keeping the ATLANTIS test centre operative and thus attracting more SMEs. Additionally, though the organisation of stakeholder events can provide insight into yet to be resolved problems, providing SMEs new potential development opportunities.
6.	Improved international rules or regulations with the development of standards/certification on the topic.	Theoretically (through analytical simulations) the targets set were met. Work conducted in ATLANTIS has concluded that the reduction target is feasible through the use of robotic platforms in IMR operations. However, this requires consistent use of these solutions, which has not been achieved yet.
7.	Actions will contribute to UN Sustainable Development Goals	Atlantis plan to facilitate the energy transition by leveraging the expertise in offshore O&M

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	& 2030 Energy Strategy and promote the energy transition in its business moving R&D and expertise assets from fossil based energy sectors to Renewable based ones.	collected through the project, ATLANTIS will be able to provide technological solutions to further reduce LCOE and operation costs, while also reducing downtime of the assets. Through the of these, the outcomes of ATLANTIS increase the sustainability of the offshore wind sector, leading to increased energy production at lower cost. Other factors include increasing the wind turbine uptime, more renewable energy can be injected in the grid, thus fostering the energy transition. The first steps taken in Portugal are to be communicated and transmitted, the results must be explained so that the general public loses the "fear" of having offshore facilities installed in their coastal areas. There's a need to do a lot of dissemination focusing on how this new energy can impact positively in the society. By decreasing O&M costs, ATLANTIS would render robotic-based O&M activities as competitive as the traditional ones. Additionally, the use of robotic solutions for offshore O&M contributes towards the decarbonization of the energy sector, through reduced fuel consumption, and carbon footprint associated with the reduction of personnel offshore. Working with lower consumption ships leads to a lower level of contamination and a decarbonization of the energy sector. So, operating AUVs instead of other bigger vehicles implies a direct impact on reducing the carbon footprint. These technologies though, are far from what could be considered commercial so, there is a need to further develop them to make them more robust and usable for the future scenario to be the one envisaged in ATLANTIS goals.

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7. Conclusions

Being an ambitious and disruptive project, ATLANTIS has successfully demonstrated that Offshore wind energy still have room for improvement and thereby contribute to a higher fraction of global energy supply than the current 5%. This report is a testament to these aspects and on how ATLANTIS realized the targeted Objectives and Impacts.

Robots are increasingly being utilized for inspections in industry and O&G sector, with still a small contribution in the field of offshore wind turbines. This project showed and clarified the improved efficiency, safety, and cost-effectiveness in maintenance activities driven by robots. These robots can perform various tasks related to inspection, maintenance, and monitoring of offshore wind turbines, enabling more frequent operations which improve the effectiveness of predictive maintenance.

With reference to ATLANTIS Key Performance Indicators, the added value of the Test Centre was completely explored, by allowing the de-risking of operations and increasing the trust in robots. Showcases created during the preliminary phase showed they were well defined and covered most of the activities in typical offshore IMR operations. A substantial number of robots were upgraded for offshore conditions and reached an outstanding technological maturity level. On the same way, not the complete costs reduction in IMR activities and on LCOE were reached, which create the context of a further exploitation of project main outcomes beyond ATLANTIS' lifetime.

From the targeted and expected impacts point of view, a forecasted of reduction in fuel consumption was achieved along with creation of opportunities for SMEs, and by decreasing the overall O&M costs, ATLANTIS would render robotic-based O&M activities as competitive as the traditional ones.

The lessons learned and challenges overcome pave the way for continued growth and improvement. As we move forward, we remain committed to sustaining and expanding the positive changes initiated by ATLANTIS.

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