WETFEET

D 7.1 – Logistic requirements associated with the proposed breakthroughs for large scale deployment

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Report on the logistic requirements associated with the proposed breakthroughs for large scale deployment			
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WETFEET

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EXECUTIVE SUMMARY

This report presents Deliverable 7.1 of the WETFEET H2020 project, with the analysis of the selected devices and breakthroughs at large scale deployment, in terms of logistic requirements.

1 Introduction

Despite the considerable progress witnessed during the past decade in the development of wave energy devices, which led to the deployment of a number of prototypes at sea, the technological evolution in the field did not attain the expected trend. The most relevant obstacles that wave energy has faced are related with the following aspects of the WEC design and development processes:

- Reliability of technical components, especially the PTO system;
- Survivability of entire system;
- Long, complex and cost-intensive road to a marketable product;
- Unclear path towards economic competitiveness, including support mechanisms;
- Unclear path towards industrial scalability, meaning the effective possibility of installing farms in the range of hundreds of MW.

The WETFEET project focuses on the specific development and validation of certain features that are expected to contribute to a major breakthrough in ocean wave energy. Although these features can be applied to other wave energy concepts, the project focuses on two specific converter types that have shown potential in different configurations, though with major issues remaining to be resolved. Once successfully validated with these two distinct device types, the 'breakthrough features' are liable to be applied to a significant number of wave energy concepts, thus setting an important step forward for the entire sector. The two technologies considered in the WETFEET project are:

- The OWC spar-buoy: a floating oscillating device of the OWC typology;
- The Symphony: a submerged point absorber that features a water turbine as PTO equipment.

The project is structured around four core scientific work packages (WPs 3 to 6), which investigate the breakthroughs identified in a setup work package (WP2). Work package 7 integrates the knowledge and results from previous work packages to conduct an assessment of the breakthroughs from the standpoint of cross-cutting aspects such as economics, logistics, supply chain and environmental issues, as well as societal concerns at large-scale deployment.

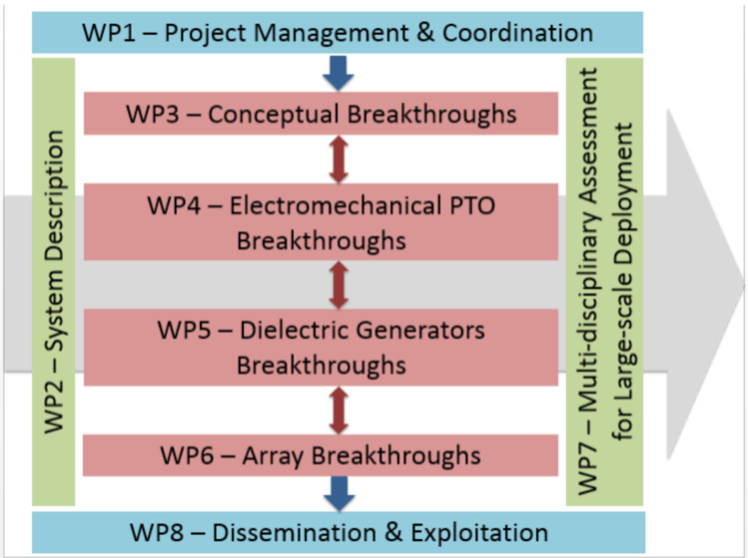

Figure 1:1 Interrelation between the WETFEET work packages

This deliverable aims to provide the analysis of the selected devices and breakthroughs at large scale deployment, in terms of logistic requirements. This analysis was done in parallel with the techno-economic analysis (task 7.2),

by making use of the techno-economic model developed and making an assessment of the logistic requirements for the considered devices and breakthroughs, with special emphasis on the marine operations. For this purpose, a preliminary analysis was conducted focusing on the following topics:

- Mobilization/Demobilization
- Assembly
- Vessel requirements
- Installation operation, complexity and feasibility
- Mooring system installation, complexity and feasibility
- Operation and Maintenance (O&M)

It is believed that the different logistics phases of a wave project will be very similar to those of an offshore wind project. As shown in Figure 1:2, the purpose of offshore lifecycle logistics is primarily to manage the flow of resources required to perform the various activities during the procurement, manufacturing, installation and servicing stages of a project. In particular, ports, vessels and installation equipment represent three essential resources indispensable in the logistic process of a Marine Renewable Energy (MRE) project. Ports, vessels and associated equipment and personnel must be suitable for supporting all the phases of an industrial MRE project.

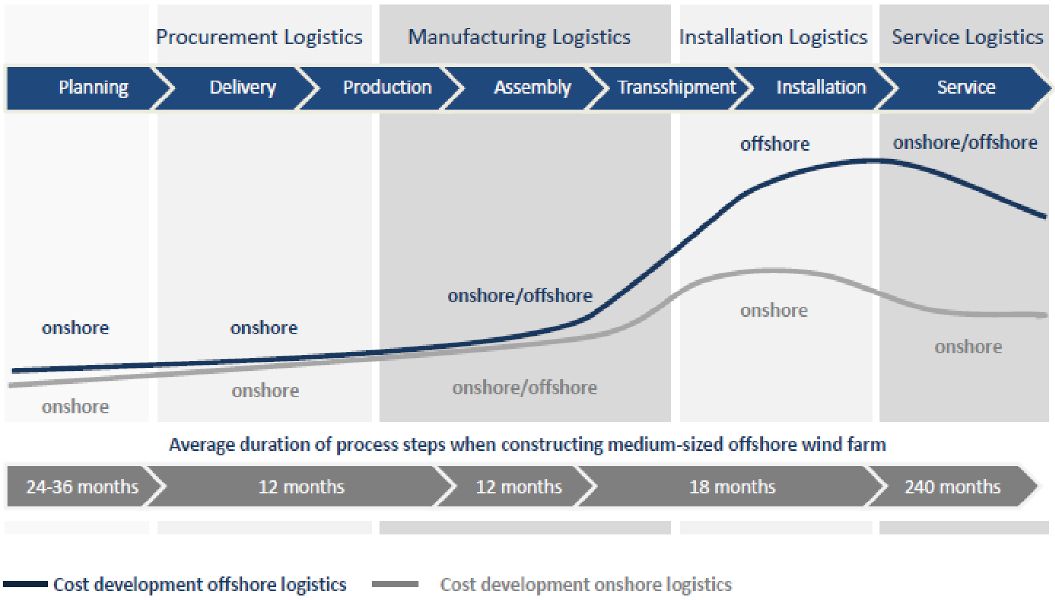

FIGURE 1:2 DEVELOPMENT OF COSTS OVER THE COURSE OF THE INDIVIDUAL LOGISTICS PHASES IN THE ONSHORE AND THE OFFSHORE SECTOR FOR THE OFFSHORE WIND INDUSTRY

Lifecycle logistics costs represent a significant proportion of the overall capital costs (CapEX) and operational cost (OpEX) of an offshore project. The Institute of Shipping Economics and Logistics (ISL) [1], [2] estimates that the share of logistics expenses can reach up to 20% of the total cost of an offshore wind farm with an average value around 15%. While in the long term, one can reasonably expect similar share for the lifecycle logistics of the wave and tidal sector, in the first small pre-commercial arrays the share of logistic costs may be even higher [3]. New concepts that aim to reduce costs are likely to also focus in optimization procedures for installation and operations, and in reducing costs by utilizing cheaper vessels. This is a trend already visible in the tidal sector, with the move away from the utilization of heavy lift vessels in benefit of smaller vessels and towing operations.

The coordination of complex operations such as lifting, towing, positioning and manipulating heavy structures in the open sea environment is challenging. Given the financial importance and high level of complexity of the

logistics for the offshore environment, it is important to anticipate and plan the lifecycle logistics of an MRE farm carefully.

2 METHODOLOGY OF LOGISTICS EVALUATION

The majority of the costs are generally incurred in the installation phase, during which the devices and moorings are carried to site and installed by specialized staff. The main drive of these costs is related to the specific vessels needed, which have high daily rates. Therefore, it is reasonable to target installation logistics as a key component in the logistic chain impact assessment, namely regarding vessel requirements, vessel-time usage, equipment mobilization, and the size of operational weather windows.

2.1 Approach

A reference wave farm case, which does not incorporate any breakthrough, is used to benchmark the logistic impacts of the breakthroughs. The reference wave farm is selected based on a minimum total capacity of 5MW, installed at 50m water depth. This is achieved using 35 devices, each with a rated power of 150kW. The devices are arranged in 5-unit arrays, with a total of 7 arrays installed, reaching a total capacity of 5,25MW.

This is not an effort to make a comprehensive assessment of the logistic effort required for a wave farm, instead, the focus is on selected areas of the logistic chain where the breakthroughs are expected to make an impact. These areas are described in Table 2:1 and Table 2:2 and organized by the logistic phases, according to Figure 2:1.

Based on this approach, the logistic needs of the electrical connection equipment (umbilical's, dynamic and static cables, infrastructure, etc.) are assumed to be independent of the integrated breakthroughs, and as such are not included in this analysis. Furthermore, the project planning and design phase are also considered to be independent of the integrated breakthroughs, and therefore omitted from this first analysis. It can be argued that certain breakthroughs might impact, e.g. the umbilical design or optimal number of offshore substations, however these considerations were omitted from this first analysis since it is not yet clear what the optimum configurations would be for different scenarios. Nevertheless, these factors can play a role, and should be considered in a future analysis.

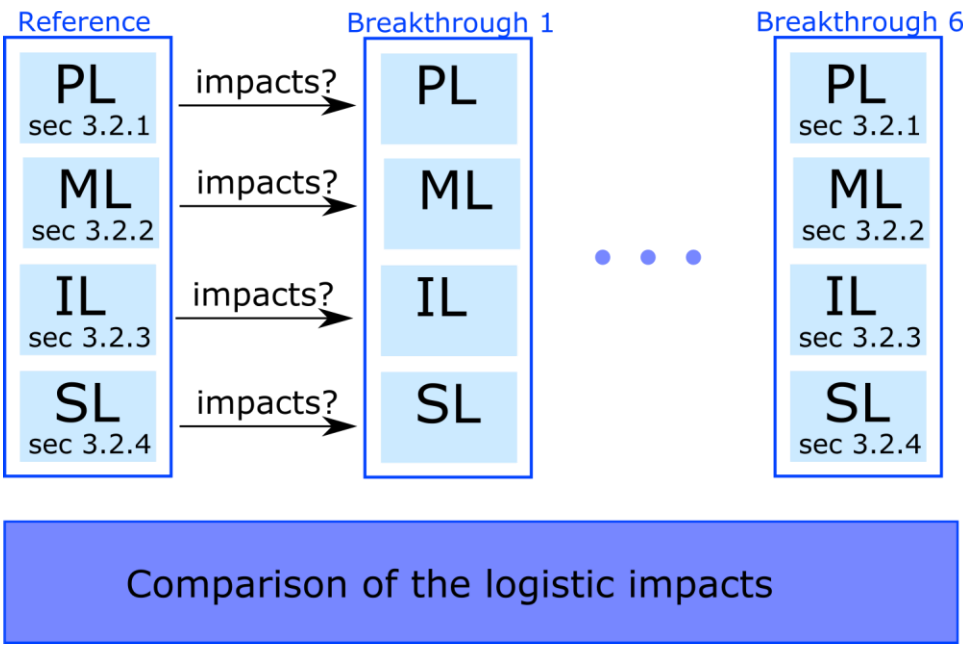

FIGURE 2:1 APPROACH TAKEN TO ASSESS THE IMPACTS OF THE BREAKTHROUGHS

TABLE 2:1 ELEMENTS CONSIDERED FOR THE COMPARATIVE LOGISTICS ANALYSIS OF THE BREAKTHROUGHS: CAPEX

PROCUREMENT LOGISTICS		
Costs related with the purchase and mobilization of raw materials/components/equipment necessary to the wave farm		
Component	***Item***	***Description***
Device	Materials	The steel costs required to manufacture the devices
Device	PTO system	The costs associated with the complete PTO system (mechanical, electric and others)
Device	Ancillary Equipment	Ancillary equipment required to enable the breakthrough, e.g. electrical winches for the survivability submergence.
Mooring	Mooring lines	Costs incurred in the acquisition of the mooring apparatus necessary for the wave farm.
Mooring	Anchors	Costs incurred in the acquisition of the anchors required for the wave farm.
MANUFACTURING LOGISTICS		
Costs related with the assembly and integration of the different components into the final products		
Component	***Item***	***Description***
Device	Substructure Assembly	The costs of assembling the substructures at port site
Device	PTO integration into Structure	Integration of the PTO unit in the device structure at port site.
Device	Ancillary Equipment	Additional requirements needed to accommodate, install and securely fasten ancillary equipment in the device.
INSTALLATION LOGISTICS		
Costs related with the installation of the farm offshore		
Component	***Item***	***Description***
Mooring Installation	Mobilization & Demobilization	Mobilization and demobilization costs associated with the mooring installation campaign.
Mooring Installation	Mooring Preparation	Preparation at port of the mooring apparatus
Mooring Installation	Operations at Sea	Operations needed to successfully install the mooring system. Includes vessel preparation, loading, transport to/from site and mooring installation.
Mooring Installation	Weather Waiting Time	Costs associated with weather downtime.
Device Installation	Mobilization & Demobilization	Mobilization and demobilization costs associated with the device installation campaign.
Device Installation	Device Preparation	Preparation at port of the devices for transport
Device Installation	Operations at Sea	Operations needed to successfully install the devices. Includes vessel preparation, loading, transport to/from site and device installation.
Device Installation	Weather Waiting Time	Costs associated with weather downtime.

Table 2:2 Elements considered for the comparative logistics analysis of the breakthroughs: OPEX

Service Logistics		
Costs related with the inspection/monitoring and repair of the different wave farm components		
Component	***Item***	***Description***
Inspection	Device	Regular scheduled inspections to determine the integrity of the device
Inspection	Ancillary Equipment	Regular scheduled inspections of the additional onboard equipment
Inspection	Moorings	Regular scheduled inspections to determine the integrity of the mooring system
Repairs	Device Structure	Repairs needed to the device substructure
Repairs	Ancillary Equipment	Repairs needed to additional onboard equipment
Repairs	PTO	Repairs related to the complete PTO system
Repairs	Mooring	Repairs to the mooring system

2.2 Breakthroughs brief discussion

2.2.1 OWC Spar Buoy

The implementation of the ***negative spring (NS)*** concept is based on the variation of the inner column sectional area. This geometry variation is the sole difference to the reference case (see Figure 2:2). Therefore, there is no impact on the manufacturing, installation or service logistics. However, for the procurement logistics, the amount of steel required changes slightly when integrating the negative spring breakthrough.

The ***enhanced added mass (EAM)*** concept is also achieved by geometry modifications of the large thickness tube (LTT) (see Figure 2:3). Therefore, only minor variations in the procurement logistics are anticipated.

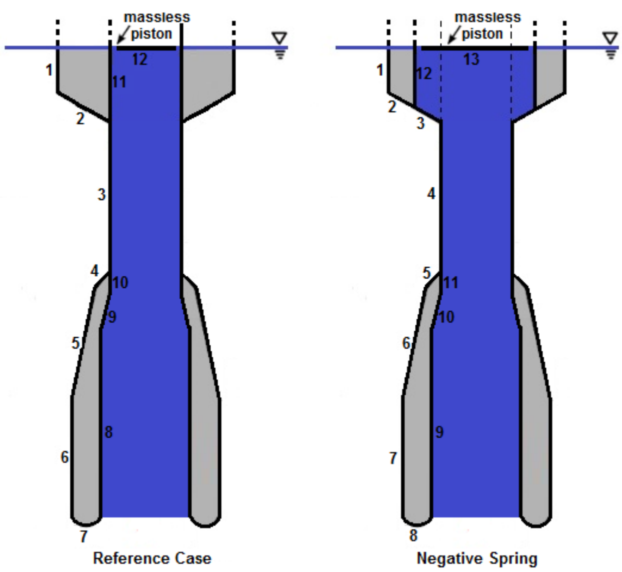

Figure 2:2 Negative spring breakthrough

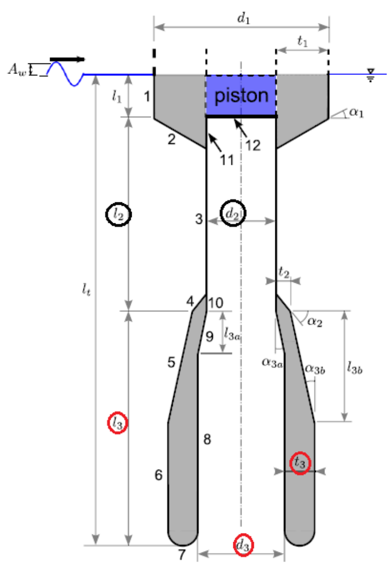

Figure 2:3 Enhanced added mass by optimizing the parameters circled in red

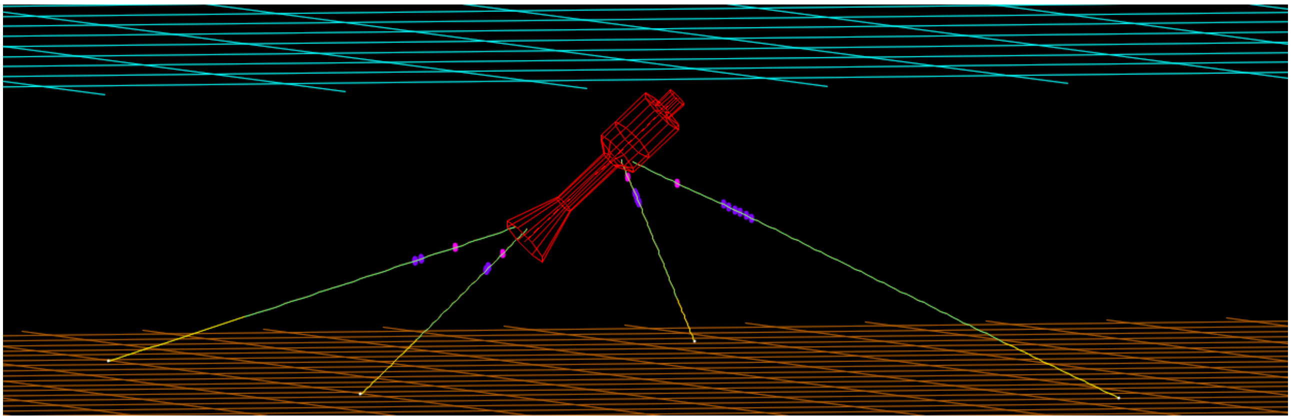

FIGURE 2:4 MODEL OF THE SURVIVABILITY SUBMERGENCE STATE OF THE OWC.

The ***survivability submergence breakthrough*** tackles a conspicuous issue for WECs: their survivability and resilience. This breakthrough allows the device to be submerged in case of severe weather, sheltering it from external aggression. This is achieved by a combination of electrical winches, additional mooring lines and sea water ballast and de-ballasting through onboard sea pumps. This additional equipment and moorings increase the procurement and manufacturing costs. Conversely, they might reduce the environmental demands on the device, allowing for savings in the structural design and/or mooring system, however these possible benefits are not incorporated in this analysis. The installation of the additional mooring lines and ancillary equipment will increase the installation effort. It is assumed that the device design allows for the equipment to be serviced. Although additional maintenance is required for the winches, sea pumps and extra mooring lines, it is expected that the overall service costs will be reduced due to the lower exposure to harsh conditions, which will be translated in smaller failure rates of key components.

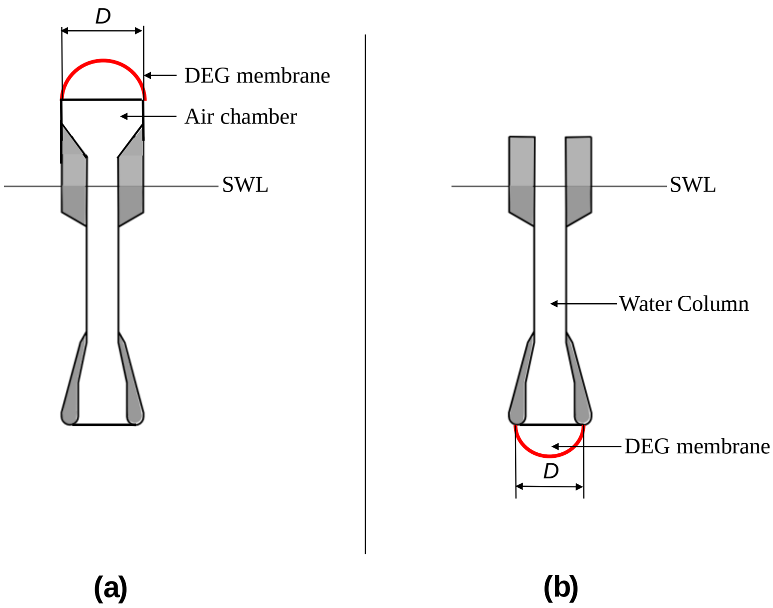

FIGURE 2:5 TWO POSSIBLE IMPLEMENTATIONS OF DEGS

The ***Dielectric Elastomer Generators (DEGs)*** is a promising new technology for wave energy applications. Due to its early development phase, the estimated impact of this technology on the logistic chain has a larger uncertainty than other breakthroughs. The procurement and manufacturing logistics of these components is still rather

unexplored territory, with some challenges regarding the manufacturing scalability. However, it is expected a simplification of the assembly, installation and maintenance, when compared to a turbine based PTO.

From a wave farm perspective, where multiple devices are to be installed, using a ***shared moorings* approach**, might be a cost-effective solution. This can be achieved by sharing mooring lines and/or anchoring points between nearby devices, as seen in Figure 2:6. This option has an impact in the procurement, installation and service costs, as less mooring apparatus needs to be acquired, installed and monitored/repaired.

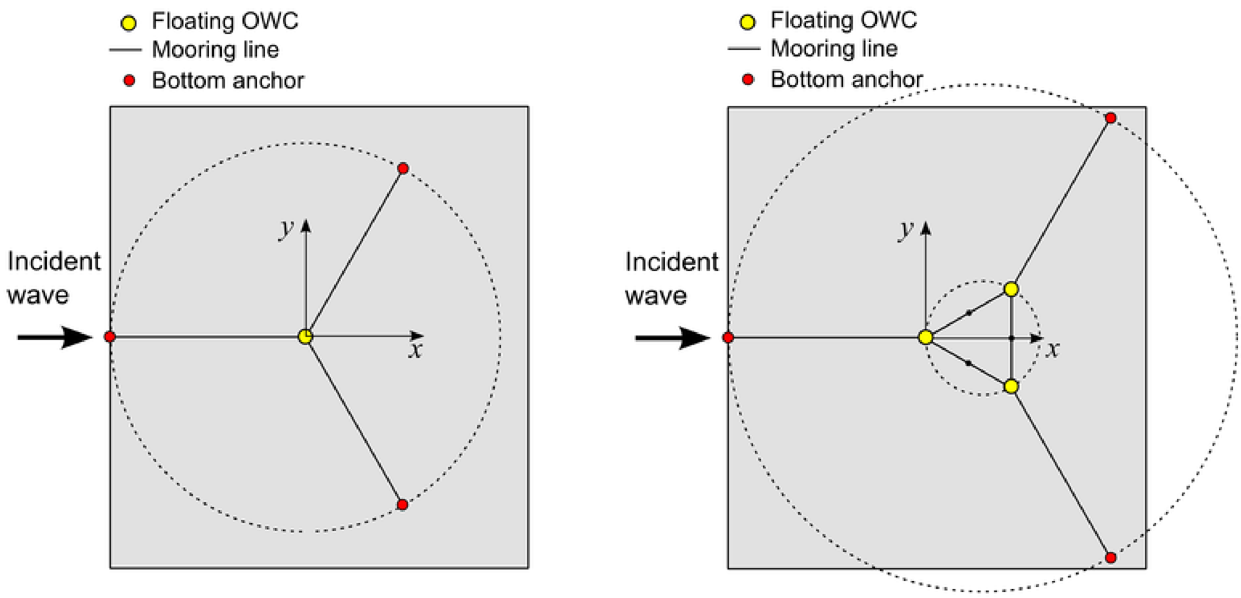

FIGURE 2:6 EXAMPLE OF REDUCTION OF MOORING SYSTEM BY USING A SHARED MOORING APPROACH

The new ***tetra-radial air turbine*** is a new turbine design with significant improvements in efficiency when compared to the standard Wells turbine. This efficiency gain is achieved at the expense of a more complex design. No significant design changes to the buoy are required to accommodate this new turbine. The logistic costs are expected to increase due to the more complex turbine. The failure rate of a PTO system based on this breakthrough cannot be obtained due to lack of data, however it was assumed to be larger than the standard Wells turbine.

2.2.2 Symphony

Dielectric Elastomers (DEs) represent a potential breakthrough for WEC technology, as they might drive towards reduction in costs and better adaptability to sea environment. Nonetheless, their effectiveness has to be first assessed by identifying possible architectures for their implementation, evaluating relevant parameters (involved amounts of DE material, performance) and analysing engineering issues associated with this new technology (e.g., DEG survivability and lifetime, manufacturability of large DEGs stacks).

A modified architecture for the Symphony, which features a DEG PTO contacting the inner water volume on one side and sea water on the other is shown in Figure 2:7. This modified architecture will have influence in the procurement logistics.

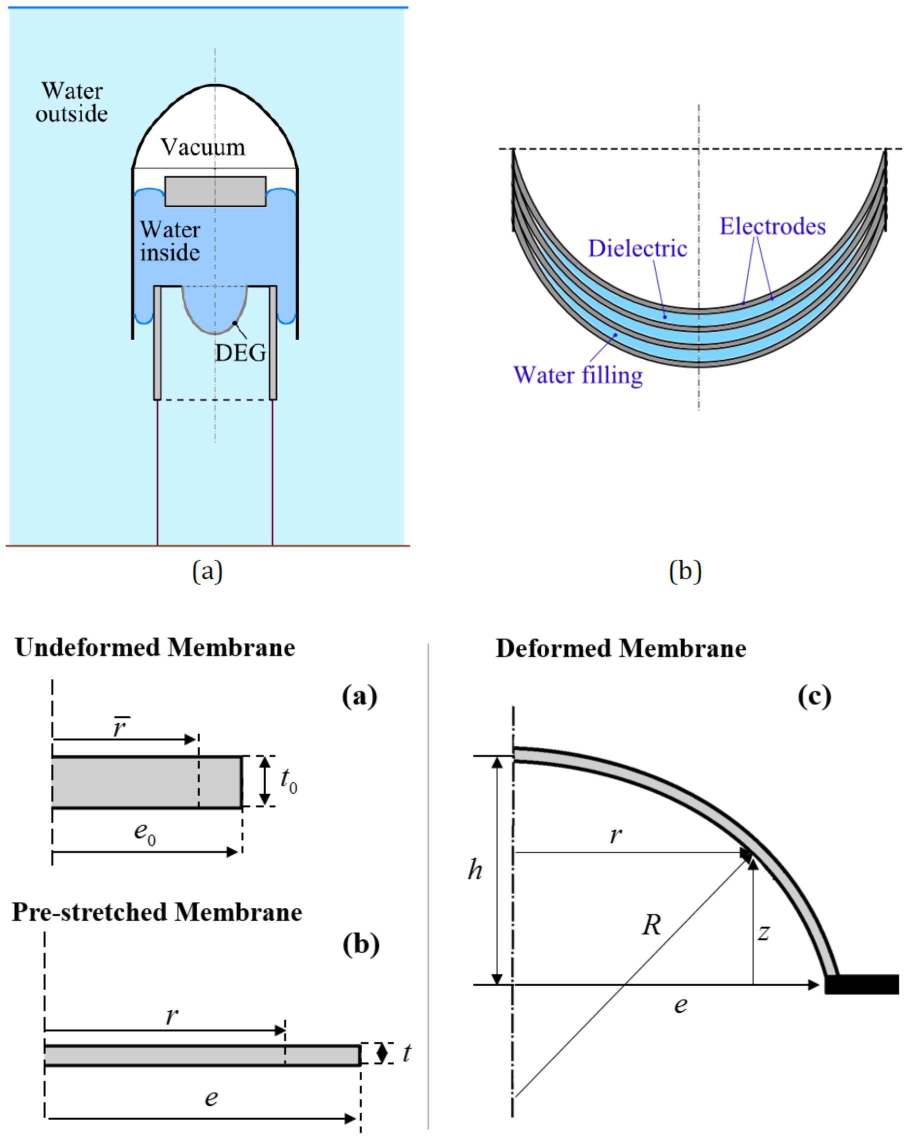

FIGURE 2:7 (A) SCHEMATIC OF THE SYMPHONY FITTED WITH A DEG WITH WATER ON BOTH SIDES (SEA WATER ON THE BOTTOM, INNER OPERATIVE FLUID ON TOP). (B) ARCHITECTURE OF THE SYMPHONY DEG PTO. DUE TO THE LARGE REQUIRED VOLUMES OF POLYMER AND THE SMALL DIAMETER, THE DEG SHOULD BE IMPLEMENTED USING SEVERAL MODULES, EVENTUALLY SEPARATED BY WATER.

Another PTO in development for the Symphony device is a **water turbine**, with bi-directional and irregular flow speed inside the turbine. There is no off-the-shelf solution for these operational requirements, which is why a novel water turbine as part of the power take off for a Symphony WEC has to be developed. This represents impacts in the procurement and possibility manufacturing logistics.

Furthermore, both PTOs proposed are at an early stage of development, which will likely mean that the service logistics are going to focus on more inspections, and failure rates may also be increased.

The Symphony consists of two parts separated by a **membrane**. The hydrostatic pressure of passing waves pushes the upper part (outer cylinder) down. This results in a decreasing inner volume of the Symphony. The decreasing volume creates an internal water flow through a turbine driving a generator. At the same time the inner pressure

in the Spring Chamber builds up due to the decreasing volume. The counter movement, the Outer Cylinder moves up again, happens under a wave through as the inner pressure is larger than the hydrostatic pressure. The internal water flow is reversed through the turbine.

Although the primary function of the membrane is the separation between the two parts of the Symphony, its overall functionality is much more. While acting as a seal to enclose the inner pressure/volume, it also acts as a bearing for the cylinder. More precisely, the membrane is the variable volume 'breathing' under the waves. The inner volume changes due to the difference in the width in which the upper and lower part of the membrane roll up and down. Due to a specially designed (inner) hull shape, the membrane also acts as end stop.

The following 3 main functions are to be fulfilled by the membrane:

- Sealing: the membrane acts as a sealing, protecting the internal components from the ocean water and preventing water to flow in the upper part of the hull;
- Bearing: the membrane functions as a bearing in-between the moving hull and the fixed compensation tank. It is important that the membrane centres the hull radially to exclude possible collision between the hull and the compensation tank;
- End stop: The membrane will be used as an end stop. The end stop will be realised by narrowing the wall geometry on the inner (static) side of the contact area.

The structural membrane will have influence in the procurement logistics.

The final breakthroughs for the Symphony device that had been identified is the continuous submergence, and removal of critical components from the device without dismounting the complete wave energy converter. As a submerged floating structure, the Symphony concept has a potential edge over surface-floating devices, since it is less exposed to extreme loading under storm conditions and to brisk movements in operating conditions. However, the continuous submergence of a wave energy device naturally implies a fail-safe philosophy of sealing elements, as well as a new approach to access. The **control cocoon** containing the vital parts of PTO and communication is the key to this approach.

The control cocoon contains the critical parts of the Symphony and can be removed without transporting the complete device to shore. The cocoon, shown in Figure 2:8, includes the following parts:

- Turbine.
- Generator
- Electronics and control system:
- Spring adjustment tan
- Compressed air tank
- Winch or other mechanism.

The control coon has significant impact on the service logistics, as it can be removed without the need of specialized vessels, and without needing to tow the device back to shore.

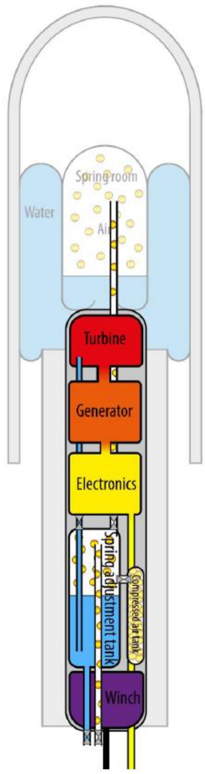

FIGURE 2:8 SCHEMATIC VIEW OF COCOON HOUSING VITAL COMPONENTS AND CONTROLS OF SYMPHONY

3 Results

3.1 OWC Spar Buoy

The logistics analysis was done for the Leixões site. While the cost of specific logistic phases will differ from the EMEC site due to different distances, the logistic operations are the same.

3.1.1 Procurement logistics

The procurement logistics for the reference case are summarized in Table 3:1. A detailed description on how each item was analyzed is given below.

Table 3:1 Summary of the procurement costs for the reference wave farm.

Procurement Logistics Costs of the reference case			
Costs related with the purchase and mobilization of raw materials/components/equipment necessary to the wave farm			
Component	***Item***	***Costs (k€)***	***Costs (k€/kW)***
Device	Materials	35972	6.85
Device	PTO system	8133	1.55
Device	Ancillary Equipment	0	0
Mooring	Mooring lines	7086	1.35
Mooring	Anchors	2240	0.4
Total Procurement Logistics Costs		**53430**	**10.18**

<u>**Device Structure**</u>

The reference device considered for the wave is shown in Figure 3:1. Its structure can be divided into three substructures. It is assumed that the entire device will be made of steel, with concrete ballast[1]. The material costs for each substructure are estimated in Table 3:2. This cost estimation was made by considering the surface area, plate thickness, average steel density and the unitary steel price:

$$C_{structure} = A_s \times t_p \times \rho_{steel} \times C_{steel} + C_{Ballast} \quad \text{(Eq. 1)}$$

With the values considered given in Table 3:3. In addition, a contingency of 10% of the total costs is added to reach the final value.

[1] Different variations with composite or concrete for the structure and water for ballast were evaluated, but they were considered less favourable than steel structure with concrete ballast.

TABLE 3:2 TOTAL DEVICE SUBSTRUCTURE COSTS. CONTINGENCIES ESTIMATED AT 10% OF TOTAL COSTS.

Item	Surface area	Plate thickness	Steel price	Costs
	[m²]	[mm]	[€/ton]	[k€]
Substructure 1	1094			482
Substructure 2	245	15	3500	102
Substructure 3	751			350
Contingencies	-	-	-	10%
Total				**1028 k€**

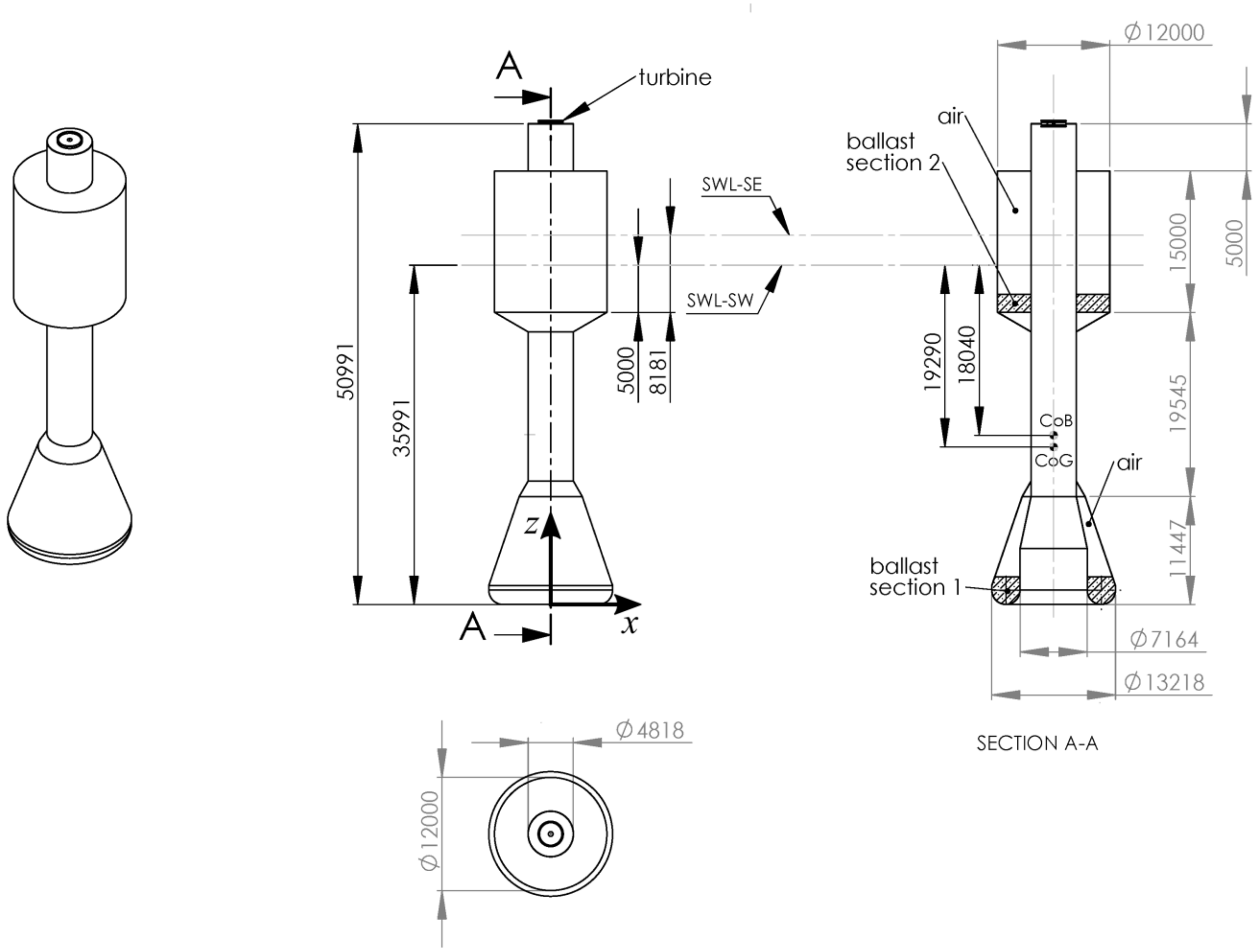

FIGURE 3:1 OVERALL DIMENSIONS OF THE OWC DEVICE.

TABLE 3:3 STRUCTURE COST CALCULATION

Component	Abrv	Value	Source	Notes
Surface area	A_s		Calculated	Simple geometry calculation based on the fundamental shapes
Plate thickness	t_p	15 mm	[4]	Assumed constant thickness. Source cites 15 mm for a buoy converter up to 50 mm for a tidal device.
Steel density	ρ_{steel}	7800 kg/ m³	[5]	Depending on the alloy considered, a range between 7750 and 8050 kg/ m³ is common
Steel cost	C_{steel}	3500 €/ton	[5]	Values range from 3400-3600 €/ton
Ballast cost	$C_{Ballast}$	70 €/ton	[5]	Concrete ballast of 964 ton considered

PTO system

The PTO costs for a standard Wells turbine are estimated based on the methodology proposed by [6]. In this approach, the costs of the mechanical equipment (turbine, valve(s) and ducting system) are estimated as a quadratic function of the turbine rotor diameter, which is based on experimental data from the Pico OWC power plant:

$$C_{mech,Wells}(D) = C_{mech,0}\left(\frac{D^3}{D_0^3}\right)^{\frac{2}{3}} \quad \textbf{(EQ. 2)}$$

Where $C_{mech,0}$ is the costs of the PTO system for the Pico plant, $D_0$the rotor diameter of the Pico plant and D the rotor diameter of the PTO system whose costs are to be estimated. The electrical components (generator, power electronics, transformer, circuit breakers, etc.) costs is taken as a function of the unit rated power:

$$C_{elec} = 3.3P_{rated}^{0.7} \quad \textbf{(EQ. 3)}$$

Using the above approach, the procurement costs for the standard wells PTO are given in Table 3:4.

TABLE 3:4 PTO COSTS FOR THE REFERENCE DEVICE

Component	Abrv	Value	Source
Pico costs	$C_{mech,0}$	330 k€	[6]
Pico rotor diameter	D_0	2,3 m	[6]
Reference rotor diameter	D	1,4 m	Figure 3:1
Steel cost	C_{steel}	3500 €/ton	[5]
Total mechanical costs	$\boldsymbol{C_{mech,Wells}(D)}$	**122 k€**	**(Eq. 2)**
Device rated power	P_{Rated}	150kW	
Total electrical costs	$\boldsymbol{C_{elec}(P_{Rated})}$	**110 k€**	**(Eq. 3)**
Total PTO Costs	$\boldsymbol{C_{PTO,ref}}$	**232 k€**	

Mooring System

Each device is assumed to be individually moored to the sea bed by three mooring lines, at 120 degrees offset. An array of 5 units, individually moored, is shown in Figure 3:2. Each mooring line includes a rope section, with a buoy and weight, chain section and a deadweight anchor, as shown in Figure 3:3. The costing model used for the procurement costs of the mooring system is given in Table 3:5.´The length of each mooring component is scaled to the reference farm water depth. While the final mooring design can be further optimized, it is sufficient for the purpose of this analysis to use approximate values.

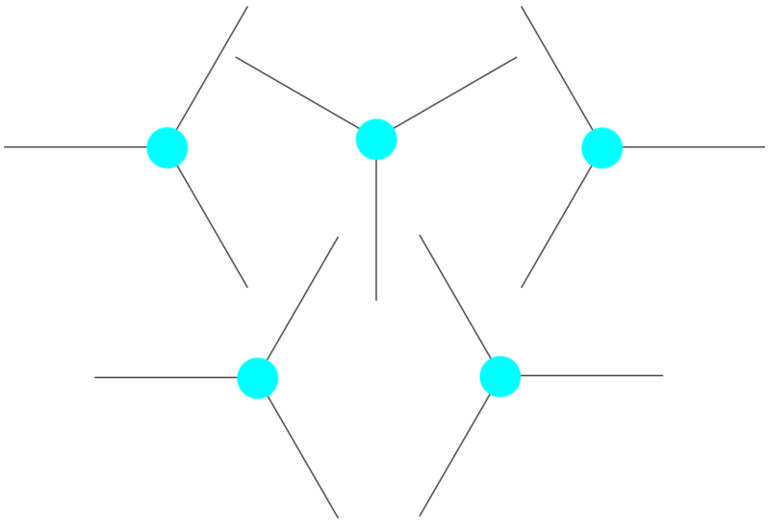

FIGURE 3:2 INDIVIDUALLY MOORED 5 UNIT ARRAY. THE CIRCLES REPRESENT THE DEVICES AND THE LINES THE MOORING LINES

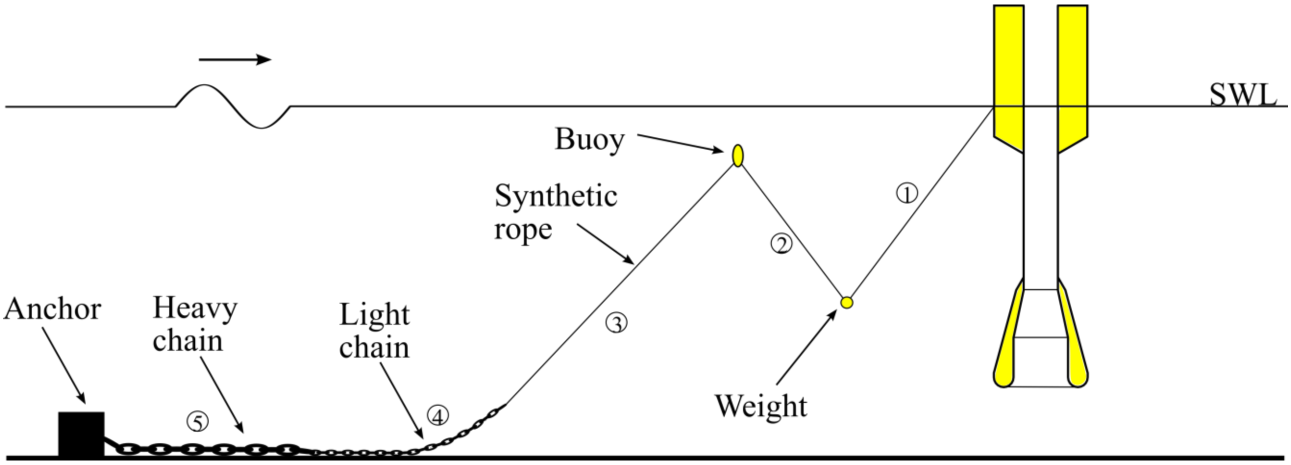

FIGURE 3:3 MOORING LINE CONFIGURATION

TABLE 3:5 COSTING MODEL OF THE MOORING SYSTEM FOR THE REFERENCE WAVE FARM

Component	Abrv	Value	Source	Notes
Rope average length	L_r	648		Per device
Rope cost per length	$C_{rope,0}$	123 €/m	[7]	Considering a 120mm rope
Chain average length	L_c	507 m		Per device
Chain cost per length	$C_{chain,0}$	142€/m	[7]	Considering a 180 mm diameter studlink chain
Total mooring costs (excl. Anchoring)	$C_{moor,dev}$	**152 k€**		**Per device (excluding buoy and weight)**
Gravity based anchor weight	W_{anchor}	40 ton		
Cost of anchor per weight	$C_{anchor,0}$	200 € / ton		
Total anchor costs	$C_{anchor,dev}$	**64 k€**		**8 anchors per device**
Total Mooring Costs	C_{moor}	**216 k€**		**Per device**

Comparing across the different breakthroughs (Table 3:6), Overall, all breakthroughs show saving in the procurement logistics. The EAM and NS show a lowering of costs in terms of materials, due to a smaller device.

The SS breakthrough, although it has an increase in ancillary equipment and PTO, still achieved cost savings in moorings, which balance out.

The SM breakthrough show excellent results in terms of cost saving in the mooring system.

The DEF has improvements in terms of PTO cost.

TABLE 3:6 PROCUREMENT LOGISTICS SUMMARY

			REF	EAM	NS	SS	SM	DEG
			Relative to the reference case (%)					
Device	Structure	*Materials*	0%	-8%	-16%	0%	0%	0%
	PTO	*PTO system*	0%	0%	0%	3%	0%	-17%
		Water tightness criteria	0%	0%	0%	Increase	0%	0%
	Other	*Ancillary Equipment*	0%	0%	0%	Increase	0%	0%
Mooring		*Mooring lines*	0%	0%	0%	-53%	-84%	0%
		Anchors	0%	0%	0%	-25%	-50%	0%
			0%	-5%	-11%	-5%	-13%	-3%

3.1.2 Manufacturing logistics

The manufacturing logistics are summarized in Table 3:7, with a more detailed description of each item given below.

TABLE 3:7 SUMMARY OF THE MANUFACTURING COSTS FOR THE REFERENCE WAVE FARM.

MANUFACTURING LOGISTICS COSTS OF THE REFERENCE CASE			
Costs related with the assembly and integration of the different components into the final products			
Component	***Item***	***Costs (k€)***	***Costs (k€/kW)***
Device	Substructure Assembly	3597	0.69
Device	PTO integration into Structure	813	0.16
Device	Ancillary Equipment	0	0
Total Procurement Logistics Costs		**4410**	**0.84**

Substructure Assembly

It is assumed that the structure assembly is done at the shipyard, in its horizontal position. The concrete ballasting is also done at the yard to reduce the complexity of the offshore operations. It is assumed that the ballasting and assembly in horizontal position have been considered during the design phase. Due to the simplicity of the geometries to be assembled, and the availability of yard lifting cranes the costs associated with the substructure assembly were estimated as 10% of the total procurement costs of the substructure.

PTO Integration into the Structure

The PTO system is considered to be available as a ready to install unit, and the costs for this item are related with the integration of the PTO system into the substructure and securely fasten all the equipment. Note that this

operation is also done with the device in its horizontal position at the shipyard. For consistency, the costs are estimated as 10% of the procurement costs associated with the PTO system.

Ancillary Equipment

This item accounts for the installation and fastening of all the additional onboard equipment, such as monitoring equipment, and for the survivability submergence case, also winches or pumps. For the reference case, no costs are considered for this item.

Since the manufacturing logistics are obtained as percentage of the procurement costs, the differences across breakthroughs are similar to the ones presented in the previous section.

3.1.3 Installation logistics

A summary of the installation logistics is given in Table 3:8 . The considered items are further detailed throughout this section.

TABLE 3:8 COST SUMMARY OF THE INSTALLATION LOGISTICS OF THE REFERENCE CASE

INSTALLATION LOGISTICS COSTS OF THE REFERENCE CASE			
Costs related with the installation of the farm offshore			
Component	***Item***	***Costs (k€)***	***Costs (k€/kW)***
Device Installation	Mobilization & Demobilization	272	0.05
Device Installation	Device Preparation	1067	0.2
Device Installation	Operations at Sea	1417	0.27
Device Installation	Weather Waiting Time	369	0.070
Total Device Installation Costs		**3475**	**0.66**
Mooring Installation	Mobilization & Demobilization	0	0
Mooring Installation	Mooring Preparation	0	0
Mooring Installation	Operations at Sea	2714	0.5
Mooring Installation	Weather Waiting Time	501	0.95
Total Mooring Installation Costs		**2193**	**0.42**
Total Installation Costs		**10642**	**2.03**

Device Installation: Mobilization and Demobilization

The fleet required for the installation of the device is given in Table 3:9. This fleet choice was not optimized based on the needs of the operations, but instead was taken as an input to this analysis, and kept constant for all the breakthroughs considered. With this fleet, 5 devices can be simultaneously installed, reducing the installation offshore time to 14 working days (12hr/ working day). Furthermore, it is assumed that the same fleet is used both for the mooring and the device installation. A duration of 48 hours was taken for the duration of the fleet mobilization/demobilization, which given the assumed fleet, is sufficient to cover a distance between 1200 km and 600 km, for the AHTS and ROV inspection, respectively. The resulting costs are given in Table 3:10.

TABLE 3:9 FLEET USED FOR THE INSTALLATION OPERATIONS

Vessel type	Number of vessels	Vessel rate	Source	Notes
AHTS	5	9467 €	[8]	Ranges from 9k€ to 46k€.
Multicat	5	3400€	[8]	Ranges from 3k€ to 10.3 k€
ROV inspection	5	4920€	[8]	
Fleet daily rate		**121,9 k€**		

TABLE 3:10 MOBILIZATION & DEMOBILIZATION COST BREAKDOWN

Operation	Fleet Daily rate (mobilization rate)	Duration	Costs
Mobilization	68 k€	48 *hr*	136 k€
Demobilization	68 k€	48 *hr*	136 k€
Total Mobilization & Demobilization		**96 hr**	**272 k€**

Device Installation: Device Preparation

Two possible load-out strategies can be used since the device is to be wet towed: the device is deployed in the ocean using a lifting load-out strategy with a land-based crane; the device is assembled in a dry-dock that is later flooded. From a comparative analysis of the breakthroughs point of view, the choice is not relevant since no specific impact of the breakthroughs is foreseen for one load-out strategy. The device is to be wet towed in the horizontal position by using an auxiliary floater [10], as shown in Figure 3:4. For the device preparation, it is considered the time to perform the selected load-out strategy and to attach (not inflating) the auxiliary floater to the device. A working day of 12 hours is assumed, the total operation duration is rounded up to nearest number of working days. The specifications of this operation are given in Table 3:11.

TABLE 3:11 DETAILED CALCULATION OF THE DEVICE PREPARATION COSTS

Operation	Duration	Total nº of operations	Total working days	Total Costs	Source	Notes
Device Preparation at port	2 hr	35	8.75	1067 k€	Table 3:9	Assuming the fleet daily rate

Device Installation: Operations at Sea

In this section, the operations carried out at sea required for the installation of the device are considered. The summary is given in Table 3:12. The following assumptions were taken:

- Each device is installed after its respective moorings have been successfully installed.
- The AHTS vessel is the towing vessel and the ROV inspection and Multicat are auxiliary vessels.
- The installation of each device requires 1 AHTS vessel, 1 ROV inspection vessel and 1 Multicat vessel, therefore, 5 devices can be simultaneously installed with the fleet given in Table 3:9.
- The distance from port to site is 100 km
- A 12hr working day are assumed.

The vessel preparation and loading includes: preparing the AHTS vessel for the wet towing, safely inflating the auxiliary buoy(s), connecting the vessel to the device, and safely navigate out of port. This operation can be done on port side in sheltered waters. The wet tow strategy, accomplished by towing the device horizontally with an auxiliary floater inside the device and additional floaters for rotational stability has been briefly described in Deliverable 2.1[10].

The transport between port and site is the time needed for the vessel to cover the 100km distance between both locations. For safety reasons, it was assumed that the average velocity while towing the device is 60% of the maximum towing velocity. When returning to port this restriction no longer applies.

The vessel positioning at site includes the time needed achieve and keep the desired position for the device installation, while the device positioning & connection estimates the time needed to upend the device and hook-up and connect the mooring lines.

With the allocated fleet (see Table 3:9), it is possible to simultaneously install 5 devices per roundtrip. Therefore, a total number of 7 roundtrips are required to install the complete 35 devices that constitute the reference wave farm. This reduces the total offshore working days required to an average of 15 days (14 working days + 1 day of weather downtime).

TABLE 3:12 ESTIMATED DURATION AND COSTS OF THE OPERATIONS AT SEA

Operation	Duration per device	Total nº of operations	Total working days	Costs	Source	Notes
Vessel preparation & loading	10 hr		35			
Transport port to site	2.25 hr		7.88		[8]	60% of the maximum towing velocity
Vessel positioning at site	1 hr	35	3,5			
Device positioning & connection	2 hr		7			
Transport site to port	1.35 hr		4.7		[8]	
Total Operations at Sea	**6.6 hr**	$\frac{\mathbf{58}\ days}{\mathbf{5}} = \mathbf{12}\ days$		**1417 k€**		**For the fleet operating simultaneously**

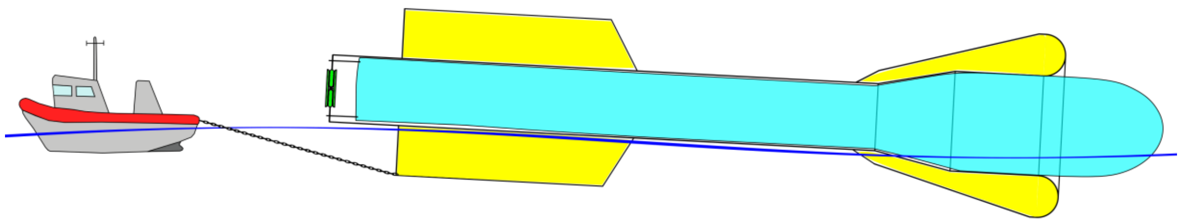

FIGURE 3:4 REPRESENTATION OF THE WET TOW OPERATION, INCLUDING THE AUXILIARY FLOATER INSIDE THE DEVICE. TAKEN FROM [10]

Device Installation: Weather waiting time

The estimation of the weather waiting time assumes a limiting sea state of Hs=2m and the weather data of the Wave Hub site. It is assumed that the operations are carried out during summer time (May- September). The average time at sea per round trip that is subjected to waiting time does not include the vessel preparation & loading at port, since this operation can be carried out in sheltered waters. The weather waiting time is rounded up to the next integer number of days.

TABLE 3:13 WEATHER WAITING TIME ESTIMATION FOR THE DEVICE INSTALLATION OPERATION

	Time	Costs
Average time at sea, per roundtrip	6,6 hr	
Average waiting time per round trip	10.4 hr	
Total Waiting Time	**3 days**	**369 k€**

Mooring Installation: Mobilization & Demobilization

It is assumed that the same fleet is used, both for the device and mooring installation. Therefore, the fleet only needs to be (de)mobilized once. These costs were already accounted for in the device installation item, and therefore are not included here.

Mooring Installation: Mooring Preparation

It is assumed that no preparation of the mooring apparatus is necessary.

Mooring Installation: Operations at Sea

In this section, the operations carried out at sea required for the installation of the moorings are considered. The summary is given in Table 3:12. The following assumptions were taken:

- The AHTS vessel is the working vessel and the ROV inspection and Multicat are support vessels.
- Each mooring installation roundtrip includes 1 AHTS vessel, 1 ROV inspection vessel and 1 Multicat vessel
- Each mooring line installation includes the anchor installation and respective line, including marker buoys for later recovery.
- The distance from port to site is 25 km.
- A 10hr working day are assumed.

The vessel preparation and loading includes: preparing the vessels for the operation, loading the mooring apparatus onto the vessel, securely storing and fastening of the apparatus onboard. This operation can be done on port side in sheltered waters. Respecting the vessel capacity and limiting each roundtrip to a 12 hour working day, it is possible to install 6 anchors (specified in Table 3:5) and respective mooring tethers per roundtrip.

The transport between port and site is the time needed for the vessel to cover the 9km distance between both locations. For safety reasons, it was assumed that the average velocity while the vessel is loaded is 80% of the transit velocity. When returning to port this restriction no longer applies.

The vessel positioning at site includes the time needed achieve and keep the desired position for the anchor installation, plus the travel time between anchor sites. The anchor lowering operations is the time needed to

correctly install one anchor, and the pre-lay moorings/buoy off includes the time needed to pan out the rest of mooring line including the marker buoy.

With the allocated fleet (see Table 3:9), it is possible to simultaneously install 30 mooring lines per roundtrip. Therefore, a total number of 4 roundtrips are required to install the complete 105 mooring lines that constitute the reference wave farm. This reduces the total offshore working days required to an average of 7 days (6 working days + 1 day of weather downtime).

TABLE 3:14 ESTIMATED DURATION AND COSTS OF THE OPERATIONS AT SEA

Operation	Duration per line	Total nº of operations	Total working days	Costs	Source	Notes
Vessel preparation & loading	1 hr	140	18			
Transport port to site	1.35 hr	140	18.90		[8]	
Vessel positioning at site	1 hr	140	14			
Anchor lowering	1 hr	280	28			
Pre-lay mooring / buoy off	0,5 hr	280	14			
Transport site to port	1.35 hr	140	18.90		[8]	
Total Operations at Sea		$\frac{\mathbf{111}\ days}{\mathbf{5}} = \mathbf{22}\ days$		**2714 k€**		**For the fleet operating simultaneously**

Mooring Installation: Weather waiting time

The estimation of the weather waiting time assumes a limiting sea state of Hs=2,5m and the weather data of the Wave Hub site. It is assumed that the operations are carried out during summer time (May- September). The average time at sea per round trip that is subjected to waiting time does not include the vessel preparation & loading at port, since this operation can be carried out in sheltered waters. The weather waiting time is rounded up to the next integer number of days.

TABLE 3:15 WEATHER DOWNTIME ESTIMATION FOR THE MOORING INSTALLATION

	Time	Costs
Average time at sea, per roundtrip	6,7 hr	
Average waiting time per round trip	3,5 hr	
Total Waiting time	**4 days**	**501 k€**

Looking at the results across breakthroughs (Table 3:16), there are cost savings in the SS and SM variants, coming from the moorings installation.

The EAM and NS breakthroughs, through the use of smaller and cheaper vessels, have cost savings during the operational time. However, the waiting time is increased, which offsets the saving gained.

TABLE 3:16 INSTALLATION LOGISTICS SUMMARY

		REF	*EAM*	*NS*	*SS*	*SM*	*DEG*
		Relative to the reference case (%)					
Mooring Installation	*Mob/Demob*	0%	Increase	Increase	0%	0%	0%
	Mooring Preparation	0%	0%	0%	0%	0%	0%
	Operations at Sea	0%	4%	4%	-25%	-50%	0%
	Weather Downtime	0%	0%	0%	-25%	-50%	0%
		0%	**9%**	**9%**	-25%	-50%	**0%**
Device Installation	*Mob/Demob*	0%	-15%	-15%	0%	0%	0%
	Device preparation	0%	-28%	-28%	0%	0%	0%
	Operations at Sea	0%	-28%	-28%	0%	0%	0%
	Weather Downtime	0%	154%	154%	0%	0%	0%
		0%	**-5%**	**-5%**	**0%**	**0%**	**0%**
		0%	**2%**	**2%**	-25%	-13%	0%

3.1.4 Service logistics

A summary of the service logistics for a 20 year operational life is given in **Erro! A origem da referência não foi encontrada.**. The considered items are further detailed throughout this section.

TABLE 3:17 COST SUMMARY OF THE SERVICE LOGISTICS OF THE REFERENCE CASE

SERVICE LOGISTICS COSTS OF THE REFERENCE CASE			
Costs related with the inspection/monitoring and repair of the different wave farm components			
Component	***Item***	***Costs (k€/year)***	***Costs (k€/kW/year)***
Inspection	Device	569	0.11
Inspection	Ancillary Equipment	104	0.02
Inspection	Moorings	826	0.16
Total Inspections		**1499**	**0.29**
Repairs	Device Structure	7879	1.5
Repairs	Ancillary Equipment	2829	0.54
Repairs	PTO	181	0.03
Repairs	Mooring	310	0.06
Total Repairs		**11200**	**2.1**
Total Service Costs		**12699**	**2.4**

<u>Inspection Fleet</u>

The fleet considered for the service life of the wave farm are given in **Erro! A origem da referência não foi encontrada.**. The fleet chosen was not optimized, and therefore it is possible to save some costs based on that exercise. Nevertheless, this level of detail is sufficient to carry out the comparative analysis of the breakthroughs intended in this study.

Depending on the task at hand, different vessels are mobilized. The vessel(s) mobilized per task are shown in Table 3:19.

TABLE 3:18 FLEET USED FOR THE SERVICE OPERATIONS

Vessel type	Number of vessels	Vessel rate	Mobilization time	Source	Notes
AHTS	1	16726 €	2 days	[8]	Ranges from 9€ to 46k€.
Multicat	1	3400€	1 day	[8]	Ranges from 3k€ to 10€
ROV inspection	1	4920€	-	[8]	
ROV workclass	1	13050 €	-	[8]	
Tugboat	1	3250 €	1 day	[8]	Range from 3k€ to16k€

TABLE 3:19 FLEET MOBILIZED PER SERVICE TASK

<table>
<tr><th>Component</th><th>Item</th><th>Vessel(s) Mobilized</th><th>Daily fleet rate</th></tr>
<tr><td>Inspection</td><td>Device</td><td rowspan="3">1 Tugboat + 1 ROV inspection</td><td rowspan="3">8170 €</td></tr>
<tr><td>Inspection</td><td>Ancillary Equipment</td></tr>
<tr><td>Inspection</td><td>Moorings</td></tr>
<tr><td>Repairs</td><td>Device Structure</td><td rowspan="4">Small repair:
1 Multicat + 1 ROV workclass

Major repair/overhaul:
1 Multicat + 1 ROV inspection + 1 AHTS</td><td rowspan="4">Small repair:
15 450€

Major repair/overhaul:
51320€</td></tr>
<tr><td>Repairs</td><td>Ancillary Equipment</td></tr>
<tr><td>Repairs</td><td>PTO</td></tr>
<tr><td>Repairs</td><td>Mooring</td></tr>
</table>

Inspections

It is assumed that planned inspections to the complete farm (device, ancillary equipment and moorings) are carried out once every year. The distance to inspection port is 9 km. It is assumed that the time at site required to inspect the hull integrity, ancillary equipment or one mooring line is 0,25 hr. The transit to/from port and mobilization costs are calculated as in the Installation logistics section. Since these are planned inspections it is assumed that they are scheduled according to the weather forecasts, therefore no weather waiting time was considered. Based on this information the costs in Table 3:20 are obtained.

It is expected that the inspections will occur for each unit (device + respective equipment + respective moorings) to save travelling time between units. However, for the comparative analysis at hand, it is useful to discretize the costs per element inspected, to better highlight the impacts of each breakthrough.

TABLE 3:20 SUMMARY OF THE INSPECTIONS COSTS

Component	Time Offshore	Roundtrips	Operational Time [working day]	Operations per year	Costs
Device	9.54 h	5	7	2.425	104 k€
Ancillary equip	8.7	9	12	2.425	179 k€
Moorings	9.54 h	5	7	1	104 k€
Over 1 year					1499 k€
Over 20 years lifetime					**29.98 M€**

Repairs

An overview of the failure modes, failure rates and average number of repairs is given in Table 3:28, and the overall costs are shown in Table 3:21.

The time required for the offshore operations follow the same method as used to calculate the installation logistics. When small repairs are considered, the transit time and vessel positioning are added to the estimated repair time. For the major repair and major overhauls, the same time as for the installation operation is considered. In the overhaul case, two roundtrips are considered per event, to bring the device to port from site, and tow it back to site after repairs.

TABLE 3:21 SUMMARY OF THE REPAIRS COSTS

Component	N. repairs/ lifetime	Repair Type	Vessel Cost	Component Cost	Cost per year	Total Cost
Electric dynamic cable (MV)	6.4	Small Repair	0.15 k€	0.002 k€	0.15 k€	3 k€
Electric static cable (MV)	1.3	Small Repair	0.15 k€	0.008 k€	0.16 k€	3.2 k€
Electric export cable (HV)	3	Small Repair	0.15 k€	0.57 k€	0.72 k€	14.4 k€
Transformer	0.4	Small Repair	0.15 k€	0.46 k€	0.61 k€	12.3 k€
Chain	10.6	Small Repair	0.15 k€	0.002 k€	0.15 k€	3.1 k€
Rope	6.8	Small Repair	0.15 k€	0.003 k€	0.15 k€	3 k€
Moorings (general/unknown)	0.6	Small Repair	0.15 k€	0.005 k€	0.16 k€	3.1 k€
Anchor	22.7	Small Repair	0.15 k€	0.002 k€	0.15 k€	3 k€
Device structure	35	Small Repair	0.15 k€	0.1 k€	253,3109	5.1 k€
PTO system	70	Small Repair	0.15 k€	0.012 k€	0.16 k€	3.3 k€
Generator	38,22	Small Repair	0.15 k€	0.011 k€	0.16 k€	3.2 k€
Device structure	17,5	Major Repair	0.56 k€	0.51 k€	1.1 k€	21.5 k€
PTO system	35	Major Repair	0.56 k€	0.12 k€	0.68 k€	13.5 k€
Device	1	Overhaul	7.1 k€	0.19 k€	7.3 k€	7.3 k€
Over 20 years lifetime						**98.98 M€**

TABLE 3:22 SUMMARY RESULTS FOR SERVICE LOGISTICS

			REF	EAM	NS	SS	SM	DEG
			Relative to the reference case (%)					
Device	*Hull integrity*			0%	0%	-82%	0%	0%
Electrical	*Additional Equipment*			0%	0%	0%	0%	0%
Mooring	*Mooring integrity*			0%	0%	-84%	-67%	0%
Total Inspection				0%	0%	-77%	-37%	0%
Device	*Structure*	*Hull integrity*		-25%	-27%	9%	0%	3%
Device	*PTO*	*PTO integrity*		-15%	-14%	0%	0%	40%
Electrical	*Electrical*	*Additional Equipment*		0%	0%	0%	0%	0%
Mooring	*Mooring*	*Mooring integrity*		0%	0%	-44%	-92%	0%
Total Repair				-22%	-22%	5%	-3%	12%
				-19%	-20%	-5%	-7%	11%

3.1.5 Summary results

Looking at the different breakthroughs, the EAM and NS cases show the most opportunity for cost reduction associated with the logistics, despite having a higher cost associated with the installation. Most of the saving come from O&M, from using smaller vessels and from lower components costs (due to lower procurement cost).

The DEG show a cost increase in relation to the reference case, despite lower associated initial costs. This is due to the high value of failure rate and the maintenance strategy adopted, which drives the service logistics cost up.

TABLE 3:23 SUMMARY TABLE FOR OWC SPAR BUOY

	REF	*EAM*	*NS*	*SS*	*SM*	*DEG*
	Relative to the reference case (%)					
Total Procurement Logistics	0%	-5%	-11%	-5%	-13%	-3%
Total Manufacturing Logistics	0%	-6%	-13%	4%	0%	-3%
Total Installation Logistics	0%	2%	2%	-13%	-25%	0%
Total Service Logistics	0%	-19%	-20%	-5%	-7%	11%
Total	0%	-16%	-18%	-5%	-8%	8%

3.2 Symphony

For the symphony device a similar approach to that of the OWC Spar buoy was used. In the next section the summary results are presented.

3.2.1 Procurement logistics

In terms of procurement logistics, the main changes are in terms of structural and PTO costs. The mooring system is assumed to be equal in both cases.

TABLE 3:24 PROCUREMENT LOGISTICS FOR SYMPHONY

Component	Category	Subitem	Reference	Symphony	Relative to the reference case (%)
			Absolute Cost (k€)		
Procurement Logistics					
Device	Structure	Materials	69962	42538	-39%
Device	PTO	PTO system	14000	6000	-57%
Device	Other	Ancillary Equipment	0	0	0%
Mooring	Mooring	Mooring lines	1237	1237	0%
Mooring	Mooring	Anchors	5	5	0%
Total Procurement Logistics		**k€**	**85205**	**49781**	-42%
		€/kW	**17041**	**9956**	

3.2.2 Manufacturing logistics

As in the OWC case, the manufacturing logistics are tied with the procurement logistics, so the manufacturing logistics cost reductions are equal as the procurement.

TABLE 3:25 MANUFACTURING LOGISTICS FOR SYMPHONY

Component	Category	Subitem	Reference	Symphony	Relative to the reference case (%)
			Absolute Cost (k€)		
Manufacturing Logistics					
Device	Structure	Substructure Assembly	6996	4254	-39%
Device	Other	Additional Equipment	0	0	0%
Device	PTO	Integration into Structure	1400	600	-57%
Device	PTO	Others	0	0	0%
Total Manufacturing Logistics		**k€**	**8396**	**4854**	-42%
		€/kW	**1679**	**971**	

3.2.3 Installation logistics

No difference in installation method was assumed for both devices. The larger reference device could warrant the use of bigger vessels.

The installation logistics for the mooring system also sees no change, as it its characteristics are equal for both variants.

TABLE 3:26 INSTALLATION LOGISTICS FOR SYMPHONY

	Component	Category	Subitem	Reference	Symphony	Relative to the reference case (%)
				Absolute Cost (k€)		
	Installation Logistics					
0	**Mooring System Installation**					
	Mooring	Installation	Mob/Demob	18	18	0%
	Mooring	Installation	Mooring Preparation	0	0	0%
	Mooring	Installation	Operations at Sea	123	123	0%
	Mooring	Installation	Weather Downtime	182	182	0%
	Total Mooring Installation		**k€**	**323**	**323**	0%
			€/kW	**65**	**65**	
0	**Device Installation**					
	Device	Installation	Mob/Demob	86	86	0%
	Device	Installation	Device preparation	286	286	0%
	Device	Installation	Operations at Sea	303	303	0%
	Device	Installation	Weather Downtime	432	432	0%
	Total Device Installation		**k€**	**1107**	**1107**	0%
			€/kW	**221**	**221**	
Total Installation Logistics			**k€**	**1430**	**1430**	0%
			€/kW	**286**	**286**	

3.2.4 Service logistics

In terms of service logistics, the main difference between the Symphony and the Reference device is in terms of PTO repairs. This is a mixture of a change in failure rate off components, and the control cocoon.

Major repairs of the PTO system for the reference case assume the device is towed back to shore, while in the case of the Symphony only the cocoon is removed, meaning that the operation can be done with a smaller vessel, and in less time.

TABLE 3:27 SERVICE LOGISTICS FOR SYMPHONY

	Component	Category	Subitem	Reference	Symphony	Relative to the reference case (%)
				Absolute Cost (k€)		
	Service Logistics					
#REF!	**Inspection**					
	Device	Structure	Hull integrity	172	172	0%
	Electrical	Electrical	Additional Equipment	172	172	0%
	Mooring	Mooring	Mooring integrity	114	114	0%
	Total Inspection		**k€**	**458**	**458**	0%
			€/kW	**92**	**92**	
#REF!	**Repair**					
	Device	Structure	Hull integrity	7905	7905	0%
	Device	PTO	PTO integrity	1645	1339	-19%
	Electrical	Electrical	Additional Equipment	210	210	0%
	Mooring	Mooring	Mooring integrity	89	89	0%
	Total Repair		**k€**	**9849**	**9543**	-3%
			€/kW	**1970**	**1909**	
Total Service Logistics			**k€**	**10307**	**10001**	-3%
			€/kW	**2061**	**2000**	

3.2.5 Summary results

In terms of logistics, the main benefits of the Symphony device over the reference case come from a lower procurement and manufacturing costs (at about 40% reduction). The savings that come from the use of the control cocoon are small, at a 3% reduction.

		Reference	Symphony	Relative to the reference case (%)
		Absolute Cost (k€)		
Total Procurement Logistics	**k€**	85205	49781	-42%
	€/kW	17041	9956	
Total Manufacturing Logistics	**k€**	8396	4854	-42%
	€/kW	1679	971	
Total Installation Logistics	**k€**	1430	1430	0%
	€/kW	286	286	
Total Service Logistics	**k€**	10307	10001	-3%
	€/kW	2061	2000	
Total	**k€**	**301169**	**256084**	-15%
	€/kW	**60234**	**51217**	

TABLE 3:28 FAILURE RATES PER COMPONENTS ASSUMED FOR THE REFERENCE CASE

Category	System	Item	Failure rate λ [year $^{-1}$]	MTBF $\frac{1}{\lambda}$ [year]	Average nº of repairs during project lifetime	Offshore repair time per event [h]	Repair component cost as percentage of total component cost	Source	Comment
Small Repair	Mooring system	Chain	**1,17e-3**	855	3	2	10%	[11]	Repairs carried out offshore
		Rope	**3,61e-4**	2770	1	2	10%	[11]	
		Connector	**1,51e-3**	662	4	2	10%	[11]	
		Unknown	**9,24e-5**	10823	1	2	10%	[11]	
		Anchor	**8,09e-3**	124	17	2	10%		
	Device	Structure	5e-3	**200**	4	4	10%		
		PTO	1e-2	**100**	7	4	10%		
Major repair	Mooring system	Mooring line	1e-3	**1000**	3	4	100%		Complete replacement of a mooring line offshore
Major Overhaul	Device	Structure		**400**	2	-	100%		Device towed to harbour and damaged component decommissioned and a new one installed
		PTO		**200**	4	-	100%		
		Ancillary Equipment	**0,05**	20	0	-	100%		

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