



Transport & Installation Manual

D5.1

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D5.1 T&I Manual**Modification Control**

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Executive Summary

The purpose of this report is to provide a Transport & Installation (T&I) manual of the multi-use platforms including the mooring systems and focuses only on the floating island configuration of the Mediterranean Sea. It has been concluded by WP3 that in the current island lay-out, without breakwaters, the proposed mooring system is not feasible in the North Sea location. A high level but qualitative evaluation of the differences in T&I operations for the two (2) locations and its accompanying costs has been described in this report (ref 6.4).

The proposed T&I procedure in this report is limited to all activities which take place between the marshalling port (e.g. assembly port) and the offshore site, assuming all floating modules and assets require last checks and commissioning activities before being permanently installed offshore. Section 2 provides a detailed overview on the Engineering, Procurement, Transport & Installation (EPCI) supply chain of the *Space@Sea* project. This T&I manual is only limited to the installation of the *Energyhub@Sea* (ref. WP6) and *Logistics@Sea* (ref. WP7) floating modules as these two (2) setups form the basis of the island. All other setups can be derived from this report by rescaling the basis. Hence, a high level but qualitative evaluation of *Living@Sea*, *Farming@Sea*, and *Wave Energy Converters* has been integrated in this report (ref. 6.3)

This report starts with describing and selecting the most appropriate marshalling port for both the Mediterranean and North Sea location. Based on various evaluation criteria, this report concludes in section 3 that the Port of Marseille is the most suitable marshalling port of the island configuration on the Mediterranean Sea and the Port of Antwerp for the North Sea configuration.

After selection of the marshalling port, a high level T&I planning has been made based on the required offshore activities. In general, two (2) different offshore activities will be executed which start with the installation of the anchor points, consisting of the anchor foundation piles and the mooring lines. Subsequently, the floating modules will be towed from marshalling port to offshore site and connected with both the pre-installed mooring lines and the pre-installed floating modules. Based on these activities, two (2) different T&I planning scenarios have been proposed. The first scenario (I) indicates that all activities can only be executed during the good weather period of a year 20xx, which might lead to a split of the offshore works over two (2) years, whereas the second scenario is limited in project time and suggests to execute all the works in the same year and starting and ending respectively before and after the good weather period, despite the more cost due to more weather delay days.

It has been concluded that the ‘basis’ setup consisting of *Energyhub@Sea* and *Logistics@Sea* can be installed following scenario II (ref. 5.2.2). However, for installing the entire island with all setups, it is highly recommended to consider scenario I (ref. 5.2.1) which divides the two (2) above mentioned offshore works over two (2) years in order to minimize the amount of weather delays and its associated cost. This scenario is also commonly used in the offshore wind business where wind turbine foundations are being installed in two phases to reduce the installation cost (e.g. installation of monopiles and transition pieces).

A detailed description and selection of the proper marine equipment for transport and installation has been analysed based on the design of the mooring system (WP3), the floating modules and their top structures and the connectors between the modules (WP4). This work package (WP5) was highly depending on the results of other work packages. Section 5 provides a detailed transport and installation manual based on the results from other work packages. Values have been frozen since beginning of January 2020. Updates from other WP’s have since then not been integrated in this report, however this report is made such that certain flexibility in design is applicable without major impact on the T&I.

D5.1 T&I Manual

Due to multiple criteria written in the report, it has been concluded to use a heavy lift vessel (HLV) such as but not limited to the DEME owned vessel ‘Orion’ for the first installation activity which is the installation of the anchor foundation and mooring lines. This vessel has the capacity and capability to install the anchor points in only one (1) cycle, resulting in a fast installation time and straightforward installation procedure. A high level but qualitative comparison with the use of another vessel (e.g. Offshore Construction Vessel) instead of the HLV has been integrated in this report.

Three (3) anchor handling tugs and one (1) additional Offshore Construction Vessel (OCV) are required for the second installation activity which is the towing operation and manoeuvring and connection of the floating modules with the pre-installed mooring lines and modules.

In this report, a new state-of-the-art piling technology (vibro-hammering) has been chosen for installing the anchor piles in the seabed of the Mediterranean Sea. It has been proven in this report that this technology reduces the installation times drastically due to faster handling times, resulting in cost reductions. Additionally, this technology requires less investments in installation equipment, which further decreases the total installation cost. A high level but qualitative evaluation on impact hammering has been made to show the differences in technology. Impact hammering is commonly used in the offshore wind business and is highly recommended when the soil type is not optimal. Therefore, impact hammering has been considered as the only right solution for the North Sea configuration.

Based on the selected marine equipment (HLV Orion), driving equipment (Vibro-piling), marshalling port (Port of Marseille) and the associated T&I scenario, it can be concluded that the total project time for transport and installation of the *Energyhub@Sea* and *Logistics@Sea* modules at the Mediterranean Sea takes approx. **5.5 months** with a project start on **01/04/20xx** and **project completion mid-September 20xx including mob-and demobilization**. Two (2) months are required for the first activity and at least three (3) months for towing and offshore installation. This ‘basis setup’ project can be executed according to planning scenario II but it is on the limit. The total duration of the second activity can be drastically reduced if the design limit of installing the rigid connectors offshore (i.e. $H_s = 0.5\text{m}$) can be increased. A maximum wave height of only 0.5m together with a weather window of up to 24 hours results in very low work abilities and high amount of weather delay days. More information can be found in section 6.1.8.1 and 6.2.5

In order to reduce the amount of offshore connection handling and its associated weather delays as much as possible, it is decided in section 5.1.2 to conduct a “triple body towage”. This means that three (3) floating modules will be pre-connected at the marshalling port and towed to offshore site. This minimizes the fuel consumption, decreases the installation time and reduces the amount of weather delays.

It has been estimated in section 6.3 that it takes approx. **11 months, including mobilization and demobilization** to install the complete island configuration of the Mediterranean Sea which doubles the project time from the basis setup. As the average good weather period in one (1) year is only up to five (5) months, It is highly recommended to divide the offshore works over two (2) years and execute the works during the good weather period (e.g. April 20xx – September 20xx). Driving all the anchor points and mooring lines takes approx. **one (1) month** excluding mobilization, and the towage and offshore installation of *Energyhub@Sea* and *Logistics@Sea* takes an additional **three (3) months** excluding demobilization. The installation of *Living@Sea*, *Farming@Sea* includes an **additional two (2) months** and the project ends with the installation of the wave energy converters around the island configuration and takes an additional **two (2) months**. Extra time for mobilization and demobilization should be foreseen and is an additional **three (3) months**. See detailed table below.

A high level but qualitative assessment has been made in section 6.4 on the transport and installation of the North Sea configuration. It has been concluded that this location requires other marine equipment due to its shallow water depths and different soil type. A Jack up Type vessel is required in addition with an impact hammer, which leads to higher costs and longer project time durations.

D5.1 T&I Manual

Below table provides a more visual executive summary on the transport and installation durations for the island configuration of the Mediterranean Sea.

Nr.	Activity	Activity duration	Comments
1	Preparation of HLV Orion in the port of Flushing (NL) and transit to offshore location	1 month	mobilization
2	Offshore installation: vibro-hammering anchor piles	1 month	
3	Transit HLV Orion to NL and demobilization (dismantling)	1 month	Demobilization
4	Preparation of CSV and anchor handling tugs and transit to offshore site	(1 month)	Simultaneous operation with nr. 3
5	Towage and offshore installation Energyhub@Sea and Logistics@Sea	3 months	
6	Towage and offshore installation Living@Sea and Farming@Sea	2 months	
7	Towage and offshore installation WEC	2 months	
8	Transit OCV and Tugs to demobilization port (dismantling)	1 month	Demobilization
TOTAL		11 months	Including mobilization and demobilization

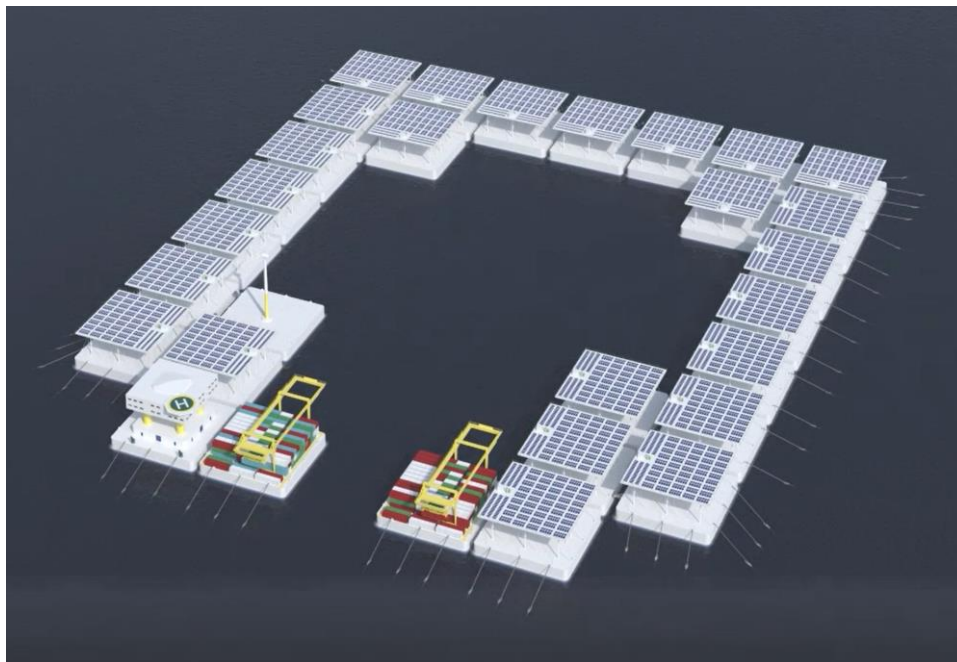


Figure 1 Overview on the installed focus setup (Energyhub@Sea and Logistics@Sea)

Reference is made to the below URL for two (2) transport & installation video's

- HLV Orion installing anchor piles with vibro-hammering
 - o <https://youtu.be/RUD2mTQR8ho>
- Towage and offshore installation with OCV and anchor handling tugs
 - o <https://youtu.be/bSHIBoMdurw>

All below information is subject to further analysis and might change in the future, if design and scope of work changes.




D5.1 T&I Manual**1. Introduction**

In the scope of the *Space@Sea* project, a basic design for a single floater module of the modular island concept has been established. The detailed design with regard to displacement, connections and compartmentation was done in parallel to the work described in this deliverable. Therefore design details were frozen in January 2020 as input to the work described in this deliverable.

At this phase of the project, possible transport and installation procedures shall be evaluated based on the available basic design and a corresponding best practise guideline formulated. The installation procedure is divided into two (2) parts, namely: the pre-installation of the anchoring points in the seabed and the towing operation of the pre-assembled modules to the devised deployment site together with the connection of the modules to the pre-installed mooring system or, if available, to an already moored floating module. These two (2) T&I procedures are the basis through this report.

According to the Grant Agreement, the Transportation and Installation is assessed in Task 5.2 and deliverable D5.1 in a joint effort of the partners DEME OFFSHORE, GICON and TUHH.

Table 1 Scope of work for each partner

Company	Task
	Reporting of installation scenarios and cost & asset requirements
 <small>Technische Universität Hamburg</small>	Responsible for the establishment of guidelines for max. allowable environmental conditions for installation and the coordination of tug maneuvering during installation
	Advisory role based on offshore transport & installation experience in offshore wind (fixed bottom/floating). DEME OFFSHORE is the former GEOSEA

Several conference calls and physical meetings have been organized in order to align towards the content of the deliverable. The three (3) organizations have the necessary knowledge and experience to find a technical solution on how to transport and install the floating modules offshore. It should be noted that this scope is highly depending on input from other work packages and all below topics are still subject to further improvements. This report provides certain methodologies and values which forms only a basis and direction. None of the below provided values and results are binding.

D5.1 T&I Manual**1.1 Definitions**

In the context of this document, the following definitions apply:

Marshalling port	A port in the vicinity of the offshore site where all assets (structures, equipment, tools etc.) comes together before being installed permanently
Island setup	An island setup refers to each five (5) different activities on an island configuration. <i>Energyhub@Sea</i> , <i>Logistics@Sea</i> , <i>Farming@Sea</i> , <i>Living@Sea</i> and <i>Wave Energy Converters</i> are the island setups of <i>Space@Sea</i>
Island configuration	An island configuration is a whole of all island setups together. For the <i>Space@Sea</i> project, there are only two (2) island configurations; Mediterranean Sea and North Sea.
Basis configuration	A basis configuration refers to the two (2) island setups in which this report focuses on.
Anchor point	An anchor point is a term that describes the anchor foundation and the mooring lines. This term has the same meaning as a 'mooring system'.
Mooring line	A mooring line is part of a mooring system or anchor points. It refers to the catenary lines which is attached to the anchor foundation.

1.2 Abbreviations

In the context of this document

AHT	Anchor Handling Tug
EPCI	Engineering, Procurement, Construction and Installation
DAF	Dynamic Amplification Factor
DNV-GL	Det Norske Veritas – Germanischer Lloyd
DOF	Degree of Freedom
HAZID	Hazard Identification Studies
HAZOP	Hazard and Operability Analysis
HLV	Heavy Lift Vessel
JUV	Jack Up Vessel
LNG	Liquid Natural Gas
MGO	Marine Gas Oil
MWS	Marine Warranty Surveyor
NM	Nautical Miles
O&M	Operations & Maintenance
OCV	Offshore Construction Vessel
SHL	Statical Hook Load
SIMOP	Simultaneous Operation
T&I	Transport and Installation
UXO	Unexploded Ordnance
WP	Work Package

D5.1 T&I Manual

1.3 Work Package description/connection with this report

WP1	Business case
WP3	Design and engineering of a dedicated mooring system for the modular platform concept which can flexibly and efficiently cope with the platform imposed mooring forces
WP4	Design of an optimized standard modular concept for a floating island and engineering of the limiting criteria under different setups.
WP6	Energy hub @ Sea platform which will produce its own power to be self-sufficient, and will be the basis for O&M of offshore wind farm producing the power for <i>Space@Sea</i> .
WP9	Logistics @ Sea platform which will unlock the potential of floating platforms for flexible, modular and enlargeable offshore port.

2. Supply chain

The supply chain of constructing offshore floating island modules is comparable with that of an offshore windfarm consisting of multiple foundations, inter array and export cables, rock placement, turbines and many more. The engineering, procurement and construction (combined EPC) of multiple different structures are often globally provided by different (sub)contractors. All structures are transported to a dedicated area (so called marshalling port) for further commissioning until ready for load out, transport and permanent installation. In this supply chain, the T&I contractor is responsible from the moment the first structures have been loaded out from the quay side of the marshalling port to the installation vessel. Below figure shows an example of a marshalling port used by DEME Offshore for an offshore wind project. All foundations (monopiles and transition pieces) and components are being transported to one (1) dedicated area close to the offshore site where the assets are picked up and brought to the construction site.



Figure 2 Jack Up Vessel Innovation (DEME Offshore) at Marshalling port (Maasvlakte II)

Figure 3 shows a preliminary EPCI supply chain proposal for the *Space@Sea* project. The below figure is pure indicative and is subject to further investigation. This report is only focusing on the route from assembly port to offshore site and forms a basis for further estimations of logistical scenarios from fabrication yard to marshalling port.

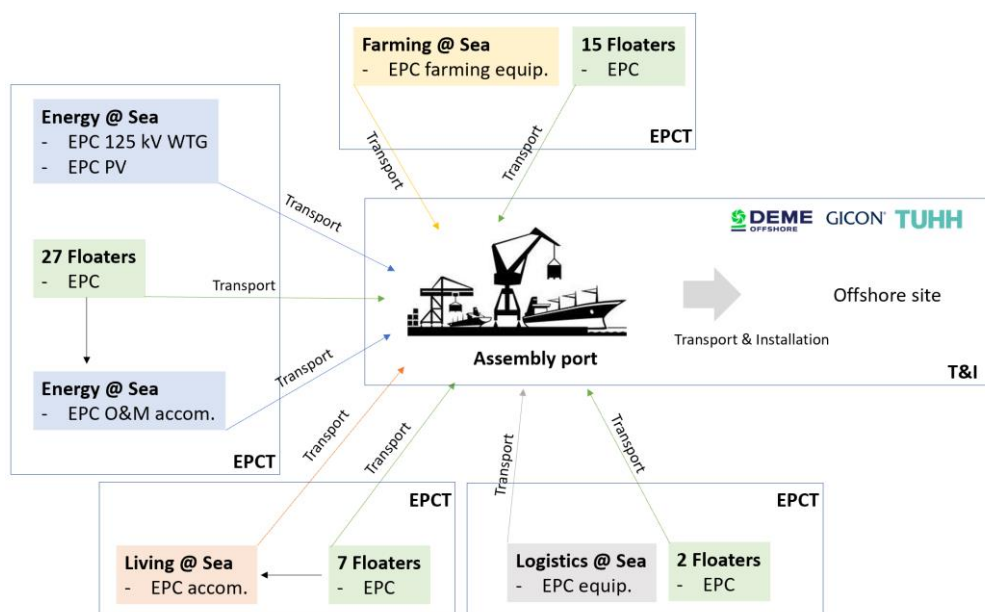


Figure 3 Preliminary proposal of EPCI supply chain *Space@Sea*

2.1 Island configuration focus

The investigation presented in this report focuses on the island configuration of the Mediterranean Sea, as this turns out to become more feasible than the North Sea with respect to the design of the mooring system. Below figure shows the preliminary island configuration of the Mediterranean Sea. In later sections, this report describes high level the T&I scenario for the North Sea configuration.

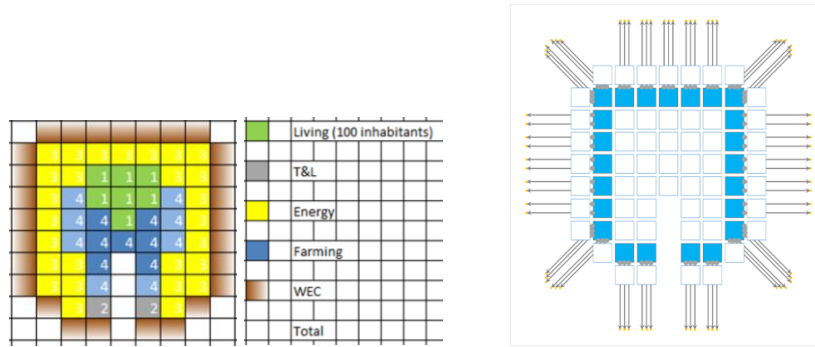


Figure 4 Preliminary island configuration (left with all island setups, right with mooring lines)

The above island configuration figure consists of the following setup;

Table 2 Island configuration

<i>Energyhub@Sea</i>	27 modules
<i>Living@Sea</i>	7 modules
<i>Farming@Sea</i>	15 modules
<i>Logistics@Sea</i>	2 modules
<i>Wave Energy Converters (WEC)</i>	27 modules
TOTAL	78 modules

This report considers only the T&I of surrounding modules consisting of 27 modules of *Energyhub@Sea* and two (2) modules of *Logistics@Sea*. It is these two (2) island setups which have to be connected to the mooring lines.

The installation of these two (2) island configurations (called ‘basis configuration’) implies all necessary offshore activities which are also applicable on the other island setups. This report will describe both in detail the basis configuration and high level the full island configuration.

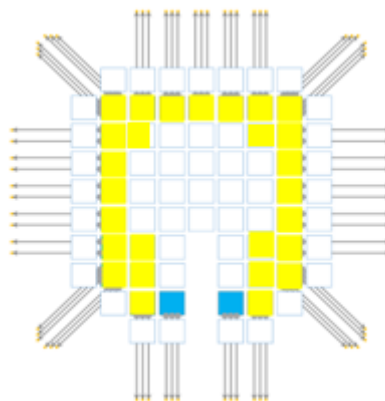


Figure 5 Basis island configuration (yellow: *Energyhub@Sea*, Blue: *Logistics@Sea*)

3.2 Potential marshalling ports

3.2.1 Port of Marseille

The Port of Marseille in the south of France is characterized by its proximity to the installation site of only 70 nautical miles (NM). The port has a large dry dock to carry out work on the floaters in the underwater area. The storage capacity and berthing length can be assessed as good. However, the construction and assembly capacities are very limited and have to be provided by (sub)contractors.



Figure 7 Port du Marseille with large dry dock and berthing area

The results of the evaluation of criteria for marshalling port for the Port of Marseille can be viewed in the table below.

Table 3 Results for marshalling port selection - Port of Marseille

Criteria of Marshalling ports	Results
Address	Port of Marseille Chemin du Littoral 13015 Marseille
Web address	https://www.marseille-port.fr/fr/Accueil/
Position	43°21.12'N, 05°19.9'E
Distance to offshore site	The distance between this marshalling port and installation site amounts to approx. 70 nautical miles. It is almost the same distance compared to marshalling port of Shipyard MB92 in La Ciotat.
Onshore/offshore storage capacity	The onshore storage capacity amounts to approx. 88,600 m ² .
Max.width of storage area	Max.width of storage area: approx. 145 m
Min. berthing length	Min. berthing length: 450 m
Assembly capabilities	The assembly capacity and onshore storage capacity is the same.
Construction capabilities	465 m x 85 m drydock 1 mobile tower crane Mobile cranes
On-site equipment	On-site workshops

D5.1 T&I Manual**3.2.2 Shipyard MB92 in La Ciotat**

The shipyard in La Ciotat in the south of France is located south east of Marseille at the same distance of approx. 70 NM to the offshore site. This shipyard is specialized in the production, conversion and repair of all kinds of motor yachts. It has numerous construction and assembly capacities such as a large dry dock and ship lift. The free storage and berthing capacities are very limited and occupied by the shipbuilding activities of the shipyard. If the shipyard would serve as a marshalling port, special agreements must be contracted with the shipyard beforehand in order to use the shipyard's capacities as a marshalling port. The La Ciotat shipyard could also serve as a supporting shipyard for Marseille.

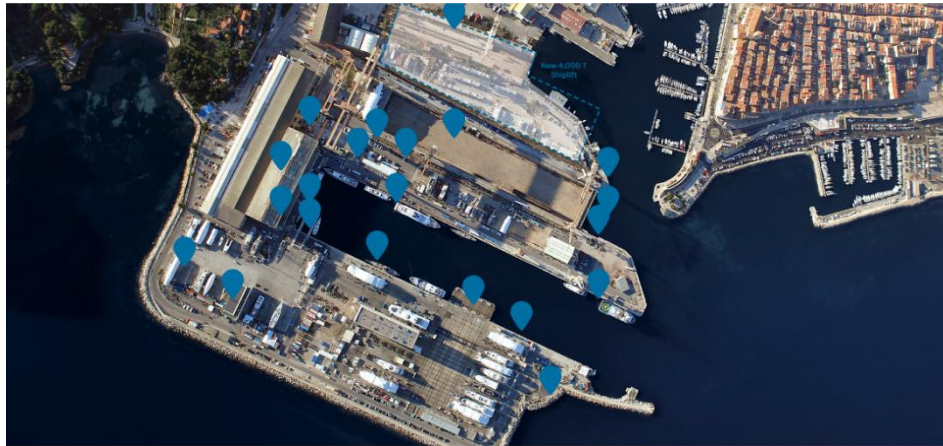


Figure 8 Shipyard MB92 in La Ciotat

The results of the evaluation of criteria for marshalling port for the shipyard in La Ciotat can be viewed in the table below.

Table 4 Results for marshalling port selection – Shipyard in La Ciotat

Criteria of Marshalling ports	Results
Address	46 Quai François Mitterrand, 13600 La Ciotat, France
Web address	https://mb92.com/laciotat
Position	43°10.34'N, 05°36.82'E
Distance to offshore site	The distance between this marshalling port and installation site amounts to approx. 70 nautical miles. It is almost the same distance compared to marshalling port of Port of Marseille.
Onshore/offshore storage capacity	The onshore storage capacity amounts to approx. 52,300 m ² . Most of the capacities are being covered by shipbuilding activities.
Max.width of storage area	Max.width of storage area: approx. 180 m
Min. berthing length	Min. berthing length: 1,600 m; being occupied by shipbuilding activities
Assembly capabilities	The assembly capacity amounts to approx. 174,200 m ² . Most of the capacities are being covered by shipbuilding activities.
Construction capabilities	200 m x 60 m drydock
	2,000 t Syncrolift
	4,000 t Shiplift (future)
	Mobile cranes, 25-600 t (gantry) cranes
	Shore power 400 V, 800 kW/6 kV, 1800 kW
	Dedicated, experienced teams
On-site equipment	Compressed air, fresh & grey water connection, fire prevention system
	On-site workshops

D5.1 T&I Manual**3.2.3 Shipyard MB92 in Barcelona**

The shipyard in Barcelona in eastern Spain belongs to the same group as the shipyard in La Ciotat. The MB92 headquarters are located there. The distance to the offshore site amounts to approximate 130 NM. This shipyard is also specialized in the construction, conversion and repair of all kinds of motor yachts. It has numerous construction and assembly capacities - such as a large dry dock and ship lift. The free storage and berthing capacities are also very limited here and occupied by the shipbuilding activities of the shipyard. If the shipyard would serve as a marshalling port, special agreements must be concluded with the shipyard beforehand.



Figure 9 Ship yard MB92 in Barcelona

The results of the evaluation of criteria for marshalling port for the shipyard in Barcelona can be viewed in the table below.

Table 5 Results for marshalling port selection – Shipyard in Barcelona

Criteria of Marshalling ports	Results
Address	Passeig Joan de Borbó, 92 08039 Barcelona, Spain
Web address	https://mb92.com/barcelona-2/shipyard
Position	41° 22' 20.626" N 2° 11' 15.864" E
Distance to offshore site	The distance between this marshalling port and installation site amounts to approx. 130 nautical miles.
Onshore/offshore storage capacity	The onshore storage capacity amounts to approx. 14,800 m ² . Most of the capacities are being covered by shipbuilding activities.
Max.width of storage area	Max.width of storage area: approx. 140 m
Min. berthing length	Min. berthing length: 1,100 m; being occupied by shipbuilding activities
Assembly capabilities	The assembly capacity amounts to approx. 49,300 m ² . Most of the capacities are being covered by shipbuilding activities.
Construction capabilities	220 m x 40 m drydock
	2,000 t Syncrolift
	4,800 t Shiplift (future)
	Mobile cranes, Travellifts
	Shore power 400 V, 800 kW/6 kV, 1800 kW
	Dedicated, experienced teams
On-site equipment	Compressed air, fresh & grey water connection, fire prevention system
	On-site workshops

D5.1 T&I Manual**3.3 Selection of marshalling port Mediterranean Sea**

The ‘Port of Marseille’ has been chosen as the marshalling port of the Mediterranean Sea island configuration. It is characterized by its proximity of only 70 NM to the offshore site. The port has a large dry dock to carry out work in the underwater area of the floaters. The storage capacity and berthing length can be assessed as good in order to be able to store the equipment and offshore spread of the T&I (sub)contractors respectively of their installation vessels, anchor handling and towing tugs. The construction and assembly capacities have to be provided by subcontractors. The shipyard MB92 in La Ciotat could be used as a support and alternative port. The following table shows all three destinations at a glance.

Table 6 Comparison of potential marshalling ports

Criteria of Marshalling ports	Port of Marseille	Shipyard MB92 La Ciotat	Shipyard MB92 Barcelona
Address	Port of Marseille, Chemin du Littoral, 13015 Marseille	46 Quai François Mitterrand, 13600 La Ciotat, France	Passeig Joan de Borbó, 92 08039 Barcelona, Spain
Web address	https://www.marseille-	https://mb92.com/laciotat	https://mb92.com/barcelona-2/shipyard
Position	43°21.12'N, 05°19.9'E	43°10.34'N, 05°36.82'E	41° 22' 20.626" N 2° 11' 15.864" E
Distance to offshore site	The distance between this marshalling port and installation site amounts to approx. 70 nautical miles. It is almost the same distance compared to marshalling port of Shipyard MB92 in La Ciotat.	The distance between this marshalling port and installation site amounts to approx. 70 nautical miles. It is almost the same distance compared to marshalling port of Port of Marseille.	The distance between this marshalling port and installation site amounts to approx. 130 nautical miles.
Onshore/offshore storage capacity	The onshore storage capacity amounts to approx. 88,600 m ² .	The onshore storage capacity amounts to approx. 52,300 m ² . Most of the capacities are being covered by shipbuilding activities.	The onshore storage capacity amounts to approx. 14,800 m ² . Most of the capacities are being covered by shipbuilding activities.
Max.width of storage area	Max.width of storage area: approx. 145 m	Max.width of storage area: approx. 180 m	Max.width of storage area: approx. 140 m
Min. berthing length	Min. berthing length: 450 m	Min. berthing length: 1,600 m; being occupied by shipbuilding activities	Min. berthing length: 1,100 m; being occupied by shipbuilding activities
Assembly capabilities	The assembly capacity and onshore storage capacity is the same.	The assembly capacity amounts to approx. 174,200 m ² . Most of the capacities are being covered by shipbuilding activities.	The assembly capacity amounts to approx. 49,300 m ² . Most of the capacities are being covered by shipbuilding activities.
Construction capabilities	465 m x 85 m drydock	200 m x 60 m drydock	220 m x 40 m drydock
	1 mobile tower crane	2,000 t Syncrolift	2,000 t Syncrolift
	Mobile cranes	4,000 t Shiplift (future)	4,800 t Shiplift (future)
		Mobile cranes, 25-600 t (gantry) cranes	Mobile cranes, Travellifts
		Shore power 400 V, 800 kW/6 kV, 1800 kW	Shore power 400 V, 800 kW/6 kV, 1800 kW
		Dedicated, experienced teams	Dedicated, experienced teams
On-site equipment	On-site workshops	Compressed air, fresh & grey water connection, fire prevention system	Compressed air, fresh & grey water connection, fire prevention system
		On-site workshops	On-site workshops

3.4 Selection of marshalling port North Sea

The envisaged North Sea installation location of the *Space@Sea* project is located outside the delta of the river Scheldt close to the coast of the Netherlands as can be seen in Figure 10. A number of large ports are available within less than 60 NM from the site, such as the ports of Antwerp, Rotterdam and Dunkerque which all have shipyards with sufficient dimensions of dry docks and berths to host the *Space@Sea* modules. A list of dry docks with appropriate dimensions is shown in Table 7.

It should be noted, that unlike the dock in the port of Marseille, which mostly focusses on the repair of cruise vessels, the North Sea docks host all vessel types and may therefore show a higher degree of capacity utilization per year. It may therefore still be necessary to allocate dedicated building and assembly locations for the *Space@Sea* modules if they are to be built at the Marshalling Port.

In terms of viability, the port of Antwerp, where the facilities of Engine Deck Repair are located, seems a suitable choice for a marshalling port. Since the *Space@Sea* North Sea configuration installation is planned to extend the capacities of the Port of Antwerp container hub, the transits between Antwerp and the floating island offer the possibility of exploiting synergies in the transport of cargo and routes to be taken for crew transfer and maintenance.

The port of Antwerp is therefore chosen as marshalling port for the *Space@Sea* North Sea configuration. All below provided data and calculations are based on this location. A more detailed analysis of the available capacities will have to be conducted once a more detailed layout of a North Sea logistic hub is generated.



Figure 10: Location of North Sea installation site and possible Marshalling Ports

Table 7: European ship yards with sufficient dry dock capacity in vicinity to North Sea installation site

Ship Yard	Country	Distance	Dock Length	Dock Width
Engine Deck Repair	Belgium	50nm	312m	50m
ARNO Dunkerque	France	45nm	310m	50m
Damen Rotterdam	Netherlands	56nm	307m	46m
Damen Verolme	Netherlands	52nm	405m	90m

4. Basis of design

4.1 Anchor point and mooring line design

It has been concluded by WP3 to use fixed anchor piles as foundation for the island configuration of the Mediterranean Sea. Taking into account the most predominately encountered soil types in the Mediterranean being either clay or sand or being found inter layered, an anchor pile provides the most viable and cost effective anchor point solution. The justification for selecting the anchor pile as being most viable and cost effective solution are due to the following;

- The design and installation method can be fully engineered eliminating the overall installation risk and therefor reducing the risk of overrun on the installation cost.
- An optimal pile weight is achieved once the soil strength parameters at each location are known. This can be achieved by optimizing pad-eye elevation and pile length for the same diameter so the installation equipment can remain the same for all conditions.
- That the system can cope with a wide range of soil strength values so one anchoring method is only required for mooring the entire island irrespectively of whether the actual soil conditions are known.

Below table provides the technical parameters;

Table 8 Design parameters anchor point Mediterranean Sea configuration

Parameter	Unit	Value
Outside Diameter	[m]	1.8288
Pile Wall Thickness	[mm]	30-50
Overall Pile Length	[m]	45
Distance pad-eye to pile top	[m]	± 15
Pile Top Elevation	[m]	Level with Seabed
Embedded Pile Section	[m]	45
Estimated Pile Weight (Including pad-eye structure)	[tonnes]	90
Estimated weight mooring line	[tonnes]	493 kg/m
Length mooring line	[m]	± 750

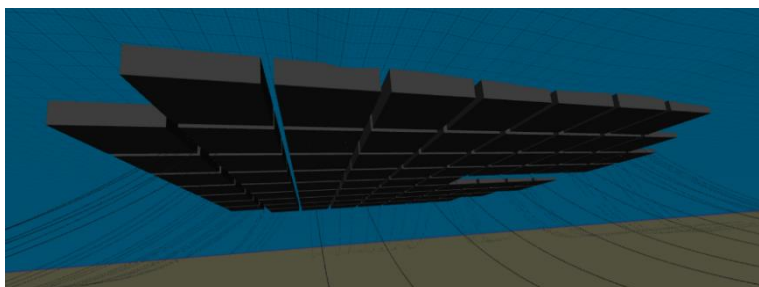


Figure 11 Floating modules and mooring lines (indicative)

4.2 Floating module design

The calculations in this report are only based on the 45 by 45 meter floating module configuration and not on the 90 by 90 meter. It should be noted that the 90x90m configuration will require higher bollard pulls resulting in larger tugs and increased installation cost. The bollard pull calculations, further described in this report, are based on data from below figure, provided by WP6 and is subject to further improvements when more details on the dimensions and weight are available.

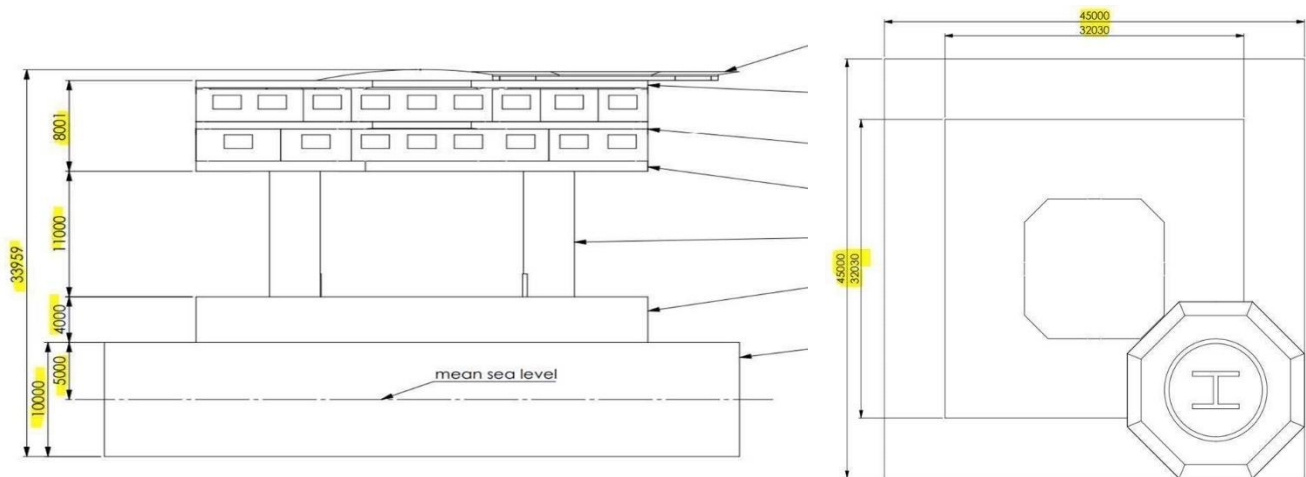
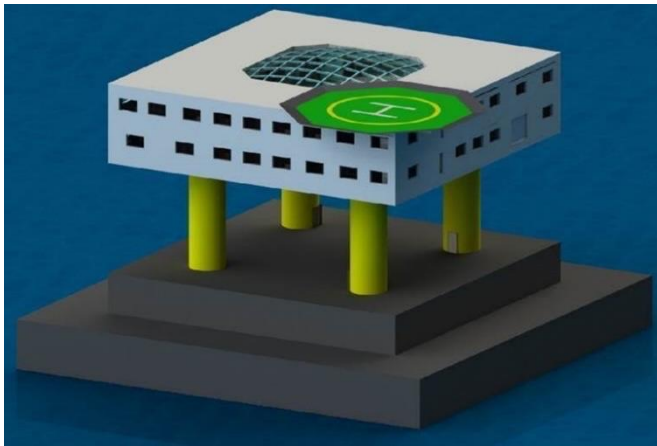


Figure 12 Design floating module Energy hub @ sea

5. Transport & installation setup – Mediterranean Sea

This section provides a detailed overview on the transport and installation (T&I) of the *Energyhub@Sea* and *Logistics@Sea* configuration in the Mediterranean Sea. The T&I consists of following offshore main activities:

1.	Pre-installation of the anchoring points: driving subsea anchor piles, pulling and pre-tensioning of mooring lines
2.	Transport of the floating modules from marshalling port to offshore site: Single and Triple towage
3./4.	Positioning of the first set of the floaters at offshore site, connection of first set of floaters with mooring lines
5.	Connection of floaters with pre-installed floaters and connection of mooring lines

Reference is made to Figure 13 *Transport & Installation – main offshore activities*

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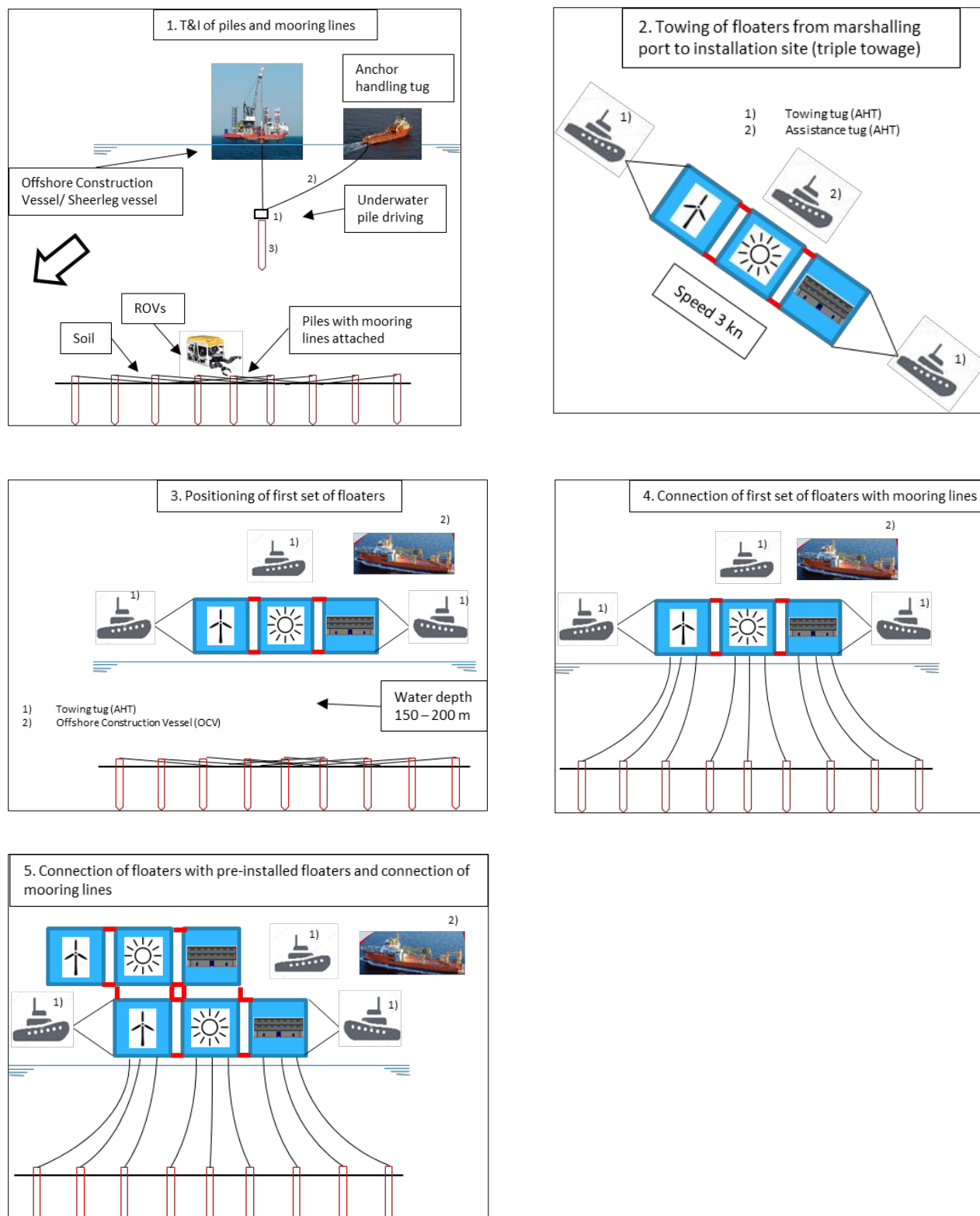


Figure 13 Transport & Installation – main offshore activities

5.1 Transport & installation of marine equipment

Based on the provided foundation design parameters (ref. 4) received from WP3 and the proposed Transport and installation setup (ref. 5), the most appropriate installation vessel has been selected to install the anchoring points offshore and support the towage and installation of the floating modules.

5.1.1 Pre-installation of anchoring points

For driving the anchor piles into the seabed, there are three (3) different types of vessels which are able to perform the works:

- Jack up Vessel (JUV)
- Heavy Lift Vessel (HLV)
- Offshore Construction Vessel (OCV)



Figure 14 JUV Innovation (DEME), HLV Orion (DEME), OCV (DEEPOCEAN)

The offshore site in the Mediterranean Sea reaches water depths of up to 200 meters, which limits the selection of vessels to only floating applications. Jack up Vessels are not applicable in this island configuration but are considered for the North Sea (ref. section 6.4)

An HLV has a large deck size which enables it to transport many (heavy) structures such as but not limited to: foundation structures, mooring lines, installation equipment etc. Due to its large dimension, this type of vessel has the capability to install all foundations in one trip and pull and pre-tension the mooring lines without the need of an additional vessel. This results in faster installation times, lower project management and installation costs and an increased installation flexibility due to the single vessel approach. These positive aspects must be outweighed against the relatively high day rates compared to OCV's.

OCV's are able to store foundations on deck but are still limited and require one or more additional vessels to feed the piles offshore (e.g. tug and barges). Due to the heavy weight of the mooring lines (493 kg/m), a heavy lift crane with a capacity of around 500 tons is required on the vessel, which limits the selection of vessels drastically. This type of vessels offers a lower charter day rate than heavy lift vessels, but requires an extra anchor handling tug with sufficient bollard pull to pull and pre-tension the mooring line up to 300 tons. The extra vessels for pile and mooring line feeding and extra bollard pull reduce the installation flexibility and increase the total installation time. Below table shows a high level comparison between a heavy lift vessel and an offshore construction vessel with support vessels.

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Table 9 Comparison matrix HLV and OCV

Heavy Lift Vessel (e.g. HLV Orion DEME)	Offshore Construction Vessel (e.g. OCV Deepocean)
	
 <p>1 x HLV</p>	 <p>1x OCV</p>  <p>2x barges and 2x tugs</p>  <p>1x Anchor Handling Tug (150 BP)</p>
<p>Single vessel Approach</p> <ul style="list-style-type: none"> - Transport - Offshore Installation - Pulling & pre-tensioning 	<p>Multiple vessel Approach:</p> <ul style="list-style-type: none"> - Transport piles and mooring lines by 2 tug and barges. OCV has not sufficient deck space for piles and mooring lines. - Installation by OCV with sufficient crane capacity (up to 500 mT) - Extra anchor handling tug (150 BP) for supporting OCV during pulling and pre-tensioning
<p>High level day rate HLV: 200 000 € / day (excl. fuel)</p>	<p>High level day rate OCV: 120 000 € / day (excl. fuel)</p> <p>High level day rate 2x Barge: 10 000 €/day x 2 = +20 000 €/day</p> <p>High level day rate 2x Tugs: 15 000 €/day x 2 = +30 000 €/day</p> <p>High level day rate AHT 150 BP: +25 000 €/day</p>
<p>1 cycle (no transfer back and forth to marshalling port)</p> <ul style="list-style-type: none"> - Load out all piles and mooring lines from quay side to vessel - Transit HLV to offshore site - Upend piles and vibrate - Connect mooring line - Pulling & pre-tensioning - Go to next position 	<p>Multiple cycles (back and forth to marshalling port)</p> <ul style="list-style-type: none"> - Load out piles and mooring lines from quay side to barge(s) - Transit OCV and tug & barges to offshore site - Barge connection with vessel - Upend piles and vibrate - Connect mooring line - AHT connection with OCV - Pulling & pre-tensioning by OCV and AHT - Go to next position
<p>Flexible, straightforward installation</p>	<p>Complex installation</p>

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It has been concluded to use Heavy Lift Vessel Orion to install all the anchor points for the following reasons;

- Installation of all light-weight foundation piles and the heavy catenary lines requires sufficient crane capacity, deck space and deck load.
 - o HLV Orion has sufficient deck space and capacity for loading the piles and mooring lines. The main crane has sufficient capacity to lift the heavy mooring lines to the gypsy winch. The vessel has sufficient deck space inside to store extra mooring lines.
 - o An OCV does not have sufficient deck space and deck load to store all piles and mooring lines and requires extra tug and barges for feeding the vessel. Importantly, this requires extra offshore handling time (and associated weather limits) and sufficient crane capacity for lifting the heavy mooring lines to the gypsy winch. This type of OCV with crane exists but is very rare.
- Single vessel approach.
 - o HLV Orion is able to install all piles and perform the pulling and pre-tensioning of the mooring lines
 - o An OCV requires an additional AHT for providing sufficient pulling capacity up to 300 tons. This requires extra offshore handling time.
- Flexibility
 - o HLV Orion has certain flexibility due to its independency of other vessels. This has also a positive impact on the weather delays as only the HLV limits are the limiting factor.
 - o Using multiple vessels creates low flexibility due to its dependency on other vessels and introduces additional weather delays. Offshore pile feeding from barge is here very critical.

More details on the installation of the anchor points with a HLV or OCV can be found in section 6.1.8

5.1.2 Transport of floating modules to offshore site

The regulations on offshore transport operations of large structures usually differentiate between dry and wet tow operations. Dry towage refers to operations where the transported object is stored on a floating support structure, as for example a barge, as is shown in Figure 15. If the transported object provides floatation by itself, the tow procedure is defined as wet tow.

In this study, only wet tow scenarios of the *Space@Sea* floating modules are considered. Since the bodies are designed for a long-term deployment in an offshore environment, their characteristics regarding stability and strength are deemed sufficient for the operation. With regards to hydrodynamics, the estimated resistance of these bodies is not deemed to have a major impact on the economic viability of the operation, since tow velocities are small, travel distances are comparatively short and the hydrodynamic properties of barges are not highly superior since their hull shape does not differ much from the currently envisioned *Space@Sea* floater design. A dry towage would further require two lifting operations, as well as the rental of a large size barge, hence increasing the cost of the transport operation. Therefore, only the wet tow transport option is investigated in this report.

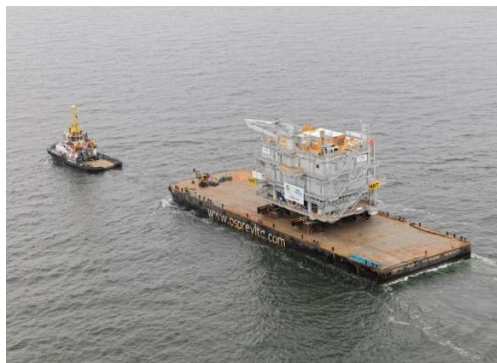


Figure 15: Tow operation of a top-site at open sea (dry towage)

A wet tow operation is conducted using one or multiple tug vessels which pull the object behind them. Depending on size and shape of the towed object as well as the environmental conditions along the towing route, one or more additional tugs at the rear may be required for manoeuvring purposes or to ensure course stability.

As a large number of floating modules will have to be transported from marshalling port to the offshore deployment site, the simultaneous towage of two (2) or even three (3) modules has been considered. A reduction in drag of the rear modules could decrease the cost of transport per module.

The large dimensions of the towed modules are inherent with considerable forces when exposed to environmental influences such as wind and waves. Therefore, in order to guarantee the safety of the towing crew and the integrity of the convoy, the distance between the towed objects should be large to prevent collision or entanglement of towing lines. By increasing the distance to realistic dimensions, the benefits of the multi-tow configurations regarding reduced drag are significantly diminished. This applies to all multi-tow scenarios covered in the current classification regulations shown in Figure 16.

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Double tow (typically for benign weather scrap tows) (side view)	
Tandem (Very benign weather only) (side view)	
Bifurcated tow (Extremely benign weather only and additional safety measures - side view)	
2 tugs in series (smaller leads - sheltered waters) (side view)	
Multiple tugs in parallel (Plan view)	

Figure 16: Multiple wet towage types according to DNVGL-ST-N001

However, when preassembling the floating modules using the rigid or flexible connection system that has been designed by the companies *ICE* and *Mocean* in the scope of WP4 of the *Space@Sea* project, a safe and more efficient tow operation may be achieved. Since the tow operation will be conducted in much less severe sea states than the design sea state of the modules at the deployment site, stability and structural integrity of modules and connectors are adequate for the loads experienced during tow.

A main consideration for the application of this “multi”-tow is not only the decrease in fuel consumption, which may be obtained during transport due to the lower resistance of the new configuration. Same as for the single towage of three modules, three tugs will be required for safe tow and manoeuvring of the pre-assembled three-floater configuration. The main difference is the pre-installation establishment of the connection between adjacent modules. The pre-assembly of floaters can be conducted in sheltered waters at the marshalling port, hence reducing the work to be conducted at sea. Furthermore, since virtually no down-times are to be expected for the protected harbour or coastal waters, the risk level of the operation is reduced and less equipment is needed.



Figure 17 Triple towage with three (3) tugs

Due to the decreased need for offshore operations and the inherent reduction in associated risk the triple-tow configuration is deemed most advantageous for the installation procedure and will be considered in the following sections of this document when overall operation periods and cycle-times are investigated.

D5.1 T&I Manual**5.1.3 Offshore installation of floating modules**

Floating module towage and offshore installation should be seen as a whole, as these two (2) activities are considered to be installed in one (1) installation window. Towing the modules without offshore installation will never occur. If the weather allows for towing the modules but not to install, the execution will be cancelled.

The three (3) tugs, used for towage, will be used for manoeuvring the single or triple body to the exact position. An additional OCV is used to connect the floating modules to the mooring lines and/or to other modules. The considered OCV is a dynamic positioning vessel with a large crane on deck in order to winch up the mooring lines from the seabed and perform the connections of the mooring lines to floaters and assists during the connection of the floating modules.



Figure 18 Offshore Construction Vessel 'Edda Freya' (Deepocean)

CAPACITIES	
CARGO DECK AREA	2300 m ²
FUEL OIL	2200 m ³
BALLAST WATER	6800 m ³
FRESH WATER	1000 m ³
DEADWEIGHT (MAX DRAUGHT AND OPEN MOONPOOL)	10000 t
DECK STRENGTH (AFT OF MAIN CRANE)	15 t/m ²
DECK STRENGTH (FWD OF MAIN CRANE)	10 t/m ²
DECK LOAD CAPACITY	Approx. 6000 t
MAIN ENGINES & GENERATOR SET	2 x MaK 8M32E 2 x MaK 6M32E 2 x MaK 6M20C
ELECTRICAL SYSTEM AND POWER MANAGEMENT	Siemens BlueDrive PlusC 4 x 130 kWh Battery banks Integrated EMS System
THRUSTERS	2 x 1500 kW Brunnvoll Retractable Azimuth Thruster 4 x 2050 kW Brunnvoll Tunnel Thruster
MAIN PROPULSION	Scana Volda CP95/AG TS1000 Reduction Gear: 2 x AG TS1000 (Twin input-single output) Power: 2 x 4200 kW Propeller speed: 145 rpm Propeller diameter: 4300 mm
AUTOMATION	Kongsberg K-Chief 700 Siemens RCS for Thrusters and Propulsion
MOONPOOL	2 x ROV moonpool 6,3 m x 4,2 m net opening 1 x Work moonpool 7,2 m x 7,2 m net opening

Figure 19 Technical leaflet Edda Freya (Deepocean)

5.2 Transport & installation planning

5.2.1 Scenario I – T&I only during the good season Mediterranean Sea

Scenario I assumes to start in the good weather window of year 20xx (green zone) with the pre-installation of the anchor points and mooring lines. The good weather window is supposed to be optimal as from May and ends in the end of August. This scenario foresees to perform the offshore works only during the good weather window of the year which may result in a split of all offshore works to a minimum of two (2) years. This scenario limits the extra costs caused by weather delays but is inadequate for projects where time is limited.

Figure 20 shows an example of splitting the offshore works over two (2) years wherein in 20xx the anchor points are considered to be installed and in 20xx+1 the transport and installation of the floating modules. This type of scenario is common in the offshore wind industry with respect to the installation of wind turbine foundations.

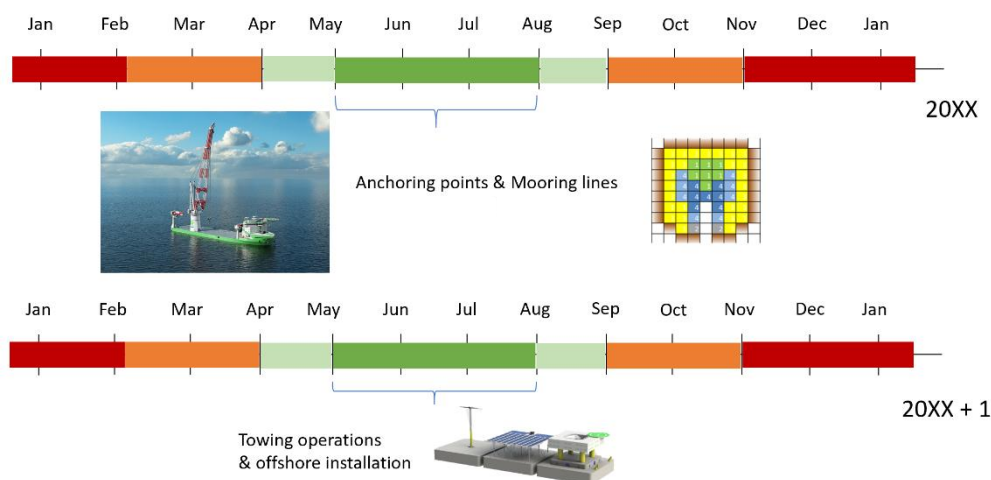


Figure 20 T&I scenario 1 divided over 2 years (indicative)

5.2.2 Scenario II – T&I during the entire year Mediterranean Sea

Scenario II takes into account the project time restriction and assumes to perform the offshore works, consisting of installation anchor points and transport & installation of floating modules, during year 20xx regardless of the weather. This scenario implies more installation costs due to more weather delays. Figure 21 shows an indicative example of scenario II.

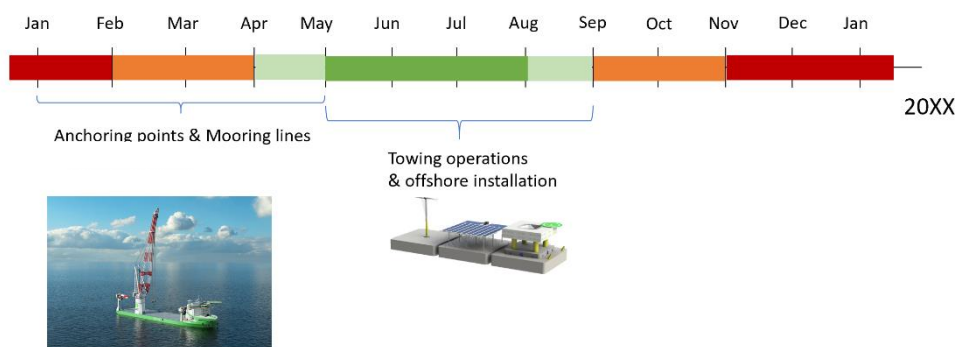


Figure 21 T&I scenario II during one year (indicative)

Based on the results of section 6.1.8.1 **Error! Reference source not found.**, it has been concluded that Scenario I is the most appropriate T&I planning for the *Space@Sea* project. It is recommended to install the full island

configuration according to Scenario I. It should be noted that the above provided good weather windows are average and each location varies in start and end date.

5.3 Transport & installation cycle time calculations

5.3.1 Cycle times – net duration

Cycle times will be generated using a custom-made calculation tool made by DEME Offshore. The calculation tool allows to estimate the netto durations of the whole T&I procedures. The tool is linked to weather data of the specific offshore location in order to calculate the amount of weather delays the installation vessels will encounter, based on the period of execution.

A variety of scenarios will be worked out to assess which vessel is the most (cost) efficient solution for performing the offshore works in combination with the different planning scenarios. Reference is made to chapter 6.

5.3.2 Cycle times – weather downtimes

For every offshore activity or combination of activities, a weather (time) window is defined that is required going from safe-state to safe-state by not exceeding operational weather limits such as:

- Significant wave height
- Swell period
- Wind speed
- Combined Wind speed / Significant wave height
- Combined Significant wave height / Swell period
- Current speed/direction
- Visibility
- Etc.

The considered operational weather windows for this project can be found in Table 18 and Table 19

The operational limits for towage are defined by the motion analysis and design properties of the floating modules with its large and heavy top-structures. By performing a persistency analysis on the available time series data, persistency tables (= workability tables) will be generated for every combination of:

- Weather window (Combined or single activity)
- Operational limits
- Month of installation
- Percentiles to be considered (P50, P75, P90)

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The persistency analysis is carried out in Matlab using the software ORCA (by Deltares) in combination with some in-house DEME developed software (for the percentiles). Persistence refers to the time for which a storm of a given severity or a period of calm weather is likely to persist. In order to derive the statistics of the persistence of storms or calm periods it is necessary to have a time series over a sufficient long period. A weather window has a continuous time interval of specified minimum duration and with specified conditions like maximum wave height, wind speed or a combination. The analysis is capable of determining continuous periods of favorable or unfavorable conditions and the occurrence of these specific weather windows in a specific month.

The outcome of the persistency analysis may be an average over the entire time series. However, to know the variability of the persistence analysis from year to year, percentiles can be calculated as well. For example, the 95th percentile (or P95) gives the percentage of persistency (for a certain duration and condition) for which 95% of the years from the entire time series is equal or better. The P50 gives the median percentage of all years.

As an example, suppose we have a time series of 10 years (1990-2000). We are interested in a specific working window of 12 hours during which the wave height (Hs) should be lower than 1 meter (per month). First, the percentage of time that such working windows exist per year and for each month separately is being calculated. For a certain month (in this example January) this results in the following table (NB: this is an example with fictive numbers):

Table 10 percentage of time that working windows exists per year

YEAR	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
JANUARY	5%	1%	4%	0%	2%	7%	3%	12%	10%	5%

From the above it follows that 1993 was a very ‘bad’ year without any working window in January. The year 1997 is an example of a ‘good’ year with working windows during 12% of time.

Next the percentiles can be calculated by sorting the 10 percentages from the table above and calculate the exceedances:

Table 11 exceedance calculations

Rank	Workability	Exceeded by	Percentile
1	0%	95%	P95
2	1%	85%	P85
3	2%	75%	P75
4	3%	65%	P65
5	4%	55%	P55
6	5%	45%	P45
7	5%	35%	P35
8	7%	25%	P25
9	10%	15%	P15
10	12%	5%	P5

The value in the middle (i.e. the median) is than the P50, in this case it is the average of the 5th and 6th value (or the average of the P45 and P55, so 4.5%). The P95 is the value that is exceeded by 95% of the data points, in this case it

will be 0%. For the *Space@Sea* project, a percentile of P50 has been used. The underlying considerations to be made for each individual part of the installation procedure are elaborated in the corresponding parts of section 6.

6. Transport & installation (T&I) Manual – Mediterranean Sea

6.1 Pre-installation of mooring system (anchor points & mooring lines)

6.1.1 Preparatory works & Engineering

6.1.1.1 Preparatory works

Prior to the transport and installation operations, T&I Contractor has to arrange all marine engineering works necessary for the correct and safe installation of the foundations such as but not limited to;

- Site specific soil data;
- Agreed metocean data;
- Side scan sonar survey and any additional geophysical survey required;
- UXO survey and confirmation of clearance of UXO's

Based on the above information and together with detailed design information, T&I Contractor will arrange for marine engineering such as:

- Prepare passage plans
- Prepare and arrange towing plant, provide details on equipment and vessels used
- Prepare transportation method statements and risk assessments
- Perform a Site Specific Assessment for the installation vessel (defining operational and survivability limitations)
- Pile driveability and stability studies
- Lifting studies including DAF (Dynamic Amplification Factor) analysis due to splash effect
- Sea-fastening studies
- Design of grillage for lifting equipment
- Design of grillage for foundation components

The above marine engineering preparations will be presented to a Marine Warranty Surveyor (MWS) for review/feedback. The following preparations will be made prior to the first installation:

- Assignment of project team (project manager, works manager, project engineer, etc.)
- Pre-job meetings with The Employer, subcontractors, etc.
- Conducting HAZID's and HAZOP's
- Preparing detailed method statements, quality plans, HSE plans, etc. (including calculations, drawings, details of equipment used etc.)
- Acceptance of method statements, quality plans, HSE plans, etc. by the Employer and Marine Warranty Surveyor (MWS)
- Mobilisation, preparation and testing of installation vessel, lifting equipment, driving equipment and other required equipment

After completion of the above mentioned steps the first installation can start. The following preparations will be completed prior to every installation:

-
- Check condition of installation vessel and other equipment
 - Check operational conditions (weather forecasts)
 - Check permissions (port control, MWS, etc.)
 - Check target coordinates for installation vessel

6.1.1.2 Engineering – environmental conditions during transport

The transport operation of cargo such as piles and mooring boxes via sea is subject to a number of regulations which can be applied. A transport on the HLV falls under the category of dry transport and requires the certification of several aspects of the transport operation to ensure all necessary precautions were taken to guarantee safety of vessel, crew and cargo.

In general, a three-dimensional motion analysis of the vessel including the deck-mounted cargo shall be conducted at zero and at service speed for a range of encounter angles between vessel and waves in design wave conditions. This serves to assess the maximum motion amplitudes and accelerations the vessel is exposed to. The assessment of accelerations is necessary to ensure an appropriate dimensioning of sea-fastenings to store the transported cargo on deck of the vessel and to check whether vessel stability is given under all relevant environmental conditions. Furthermore, the sea-fastenings have to be designed in a way that allows to remove single parts of the cargo without affecting the secure fastening of other objects during installation of the piles. While this calculation procedure has to be conducted for all aspects of the installation procedure, i.e. transport, pile installation, tow operation etc., it is introduced in detail here and then applied identically in the later sections of this report.

The following paragraphs provide a brief introduction into the motion analysis required for the assessment of limiting conditions. It should be noted that due to confidentiality reasons a generic hull form similar to the HLV Orion is used to demonstrate how the operational limits of the vessel are assessed. In this case, the software Ansys AQWA has been used to compute the vessel's response to waves. The vessel is sailing at design sailing speed as listed in Table 15, since the evaluation has to be conducted for this velocity according to regulation. For zero-speed condition, a similar evaluation has to be conducted for this and the pile installation operation and is thus presented in the later pile installation section.

Figure 22 shows a discretized surface model of an HLV hull in AQWA, as used for computation. A frequency domain analysis is conducted to compute the linearized vessel response for a wide range of discrete wave frequencies and directions. The response is computed in form of coefficients – so called Response Amplitude Operators (RAOs) that represent the induced vessel motion per incident wave height for each degree of freedom for a discrete wave frequency and encounter angle.

Using these coefficients, arbitrary wave spectra may be applied and the actual vessel response computed in frequency and time domain by superposing the individual response components for each wave frequency and direction and all degrees of freedom. For this investigation, frequency domain simulations were conducted, as the vessel response of interest is of statistical nature, which may be considered using the frequency domain approach for a first estimate. It should be noted that as this approach is chosen, the most severe combination of maximum motion amplitudes for all individual degrees of freedom has to be combined, which will likely result in a very conservative design condition, while time domain analysis allows to include phase information of the respective Degree of Freedoms (DoF) and may lead to a reduction in design loads.

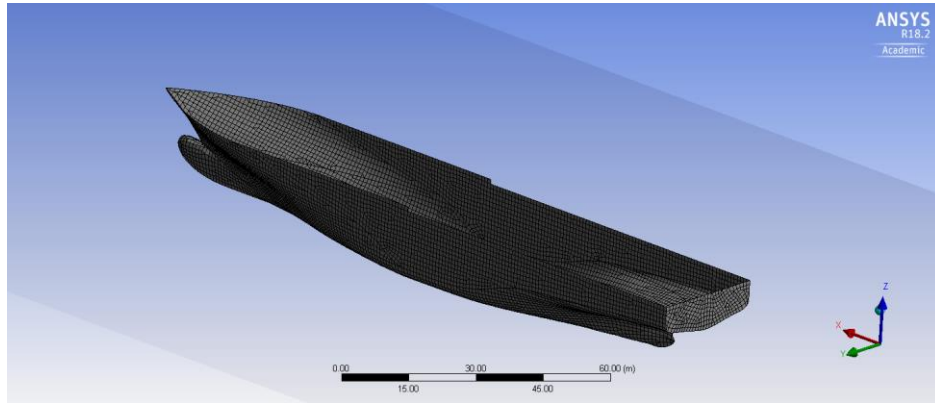


Figure 22: Exemplary mesh of a Heavy Lift Vessel in a 3D panel code used for time domain motion analysis

While all six degrees of freedom have to be analyzed, specific values like the maximum roll angle and maximum roll acceleration are of main interest, since these may lead to large heeling moments and large forces acting on the sea-fastenings of the deck load. The following paragraphs outline how the limiting values of a specific motion component may be determined for a given operational reference period, a design sailing speed and a given vessel load case.

Assuming a discrete wave spectrum with a known spectral density function $S_{\zeta}(\omega)$ and a respective set of transfer coefficients $\widehat{Y}_{a/\zeta}(\omega)$, a discrete response function $S_a(\omega)$ for a degree of freedom a can be computed as:

$$S_a(\omega) = |\widehat{Y}_{a/\zeta}(\omega)|^2 \cdot S_{\zeta}(\omega)$$

The values of the transfer coefficients, the RAOs, are determined using the Green Function based 3D panel code Ansys AQWA. A JONSWAP spectral description of a wave spectrum is used for $S_{\zeta}(\omega)$. Using the spectral density distribution of the computed response spectrum $S_a(\omega)$, the zeroth moment of the spectrum m_0 can be computed by integrating the discrete values over the range of frequencies, thus computing the area under the spectral density curve of the response function.

When only considering the extreme values of a time-domain response, e.g. the maximum roll amplitude or roll acceleration per wave encounter, only one peak will occur per wave period. The value of these extrema can be statistically assessed. For long durations, the probability distribution of maxima of the response can be modelled as a small-banded Rayleigh-density function (Blendermann, 2001). For Rayleigh-type spectra, the probability distribution function may be described as:

$$F(a_{max}) = 1 - \exp\left(-\frac{1}{2} \frac{a_{max}^2}{m_0}\right).$$

This formula describes the probability that the amplitude a_{max} of an arbitrary degree of freedom is exceeded. This function can be rearranged to compute a value, which on average is only exceeded every n amplitudes or every n waves:

$$\frac{a_{1/n}}{\sqrt{m_{0,a}}} = \sqrt{2 \ln n}.$$

Prior to applying this formula, the zero-th moment has to be computed for the respective degree of freedom. E.g. if one wants to compute the quantile $z_{max,0.999}$, as a heave motion amplitude which on average is only exceeded every thousand oscillations - since one extremum occurs per oscillation - the value is computed as:

$$z_{max,0.999} = \sqrt{2m_{0,z} \ln 1000},$$

with

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$$m_{0,z} = \int S_z(\omega) d\omega.$$

The number of oscillations n to be considered here is calculated as the operation reference period of the transport voyage T_R divided by the zero up-crossing period of the sea state.

$$n = T_r/T_z$$

As the vessel's response to a sea state will vary depending on the encounter angle, the maximum response $a_{1/n}$ has to be computed for a range of directions. Since the vessel's response will depend of the characteristics of the sea state, a range of $H_s - T_p$ combinations is tested.

Table 12 shows a scatter diagram for the *Space@Sea* Mediterranean Sea installation site. The table shows ranges of significant wave heights H_s and peak periods T_p and the probability of their combined occurrence in per cent of the year. The wave data was analyzed in 3 hour time windows and fitted to a JONSWAP spectral distribution function. As can be seen, the vast majority of sea states has peak periods below 6s-7s and significant wave heights of less than 2m.

Table 12: Scatter diagram showing the statistical occurrence of specific H_s - T_p combinations in % of the year for the Mediterranean Sea installation site. Source: MetOceanView

$H_s[m]$ \ $T_p[s]$	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12
0 - 0.5	0.53	0.14	7.59	14.21	7.59	2.75	1.38	0.41	0.08	0.03	0.00	0.00
0.5 - 1	0.00	0.00	0.78	10.72	12.23	5.90	2.18	1.01	0.36	0.08	0.02	0.01
1 - 1.5	0.00	0.00	0.00	0.40	9.18	7.73	2.15	0.68	0.33	0.17	0.02	0.00
1.5 - 2	0.00	0.00	0.00	0.00	1.17	6.95	2.38	0.50	0.13	0.06	0.01	0.00
2 - 2.5	0.00	0.00	0.00	0.00	0.03	1.52	2.04	0.44	0.07	0.03	0.01	0.00
2.5 - 3	0.00	0.00	0.00	0.00	0.00	0.13	0.59	0.42	0.07	0.01	0.00	0.00
3 - 3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.20	0.04	0.01	0.00	0.00
3.5 - 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.04	0.01	0.00	0.00
4 - 4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00
4.5 - 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 23 shows the maximum responses for pitch and roll statistically encountered every 1000 transport operations for a range of $H_s - T_p$ combinations. From the plots it becomes obvious that in transit conditions the roll motion in quartering beam seas are likely the most critical scenario. Motions leading to an exceedance of the sea fastening design load have to be avoided and hence the $H_s - T_p$ combination leading to these motions represent the weather limit of the specific operation.

It should be noted that in order to compute the design loads of the sea fastenings, the loads resulting from each individual degree of freedom have to be added to obtain the total design force. This can be considered a rather conservative approach, since the maximum forces of all degrees of freedom will in reality not necessarily occur at the same time.

Optionally, a time domain analysis can be conducted to directly assess the combined influences of all degrees of freedom on the accelerations experienced at a specific point. While more accurate, this type of assessment requires significantly more time as a reliable prediction of the maximum load can only be made if long time windows are simulated. Applying either path, limiting operational conditions are obtained. These are compared to the environmental data available for the sites of operation to estimate the expected down times and hence compute the average cycle times, as presented in section 6.1.8.1.

In the planning of offshore operations, a safety factor α is usually employed to account for uncertainties in prediction and in order to account for the statistical nature of the environmental conditions. The value of the α -factor depends on the sensitivity of the operation, the level of weather forecasting reliability and the planned operation period. For transport, lifting and subsea installation procedures, a weather forecasting level B (moderate) can be applied.

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Depending on whether the design loads are determined using allowable stress design (ASD) or load and resistance factor design (LRFD), the values for the safety factor can be taken as 0.59 or 0.66 for wave induced forces and as 0.62 or 0.7 for wind induced forces. A detailed description on the selection of appropriate α -factors is provided in DNVGL-ST-N001.

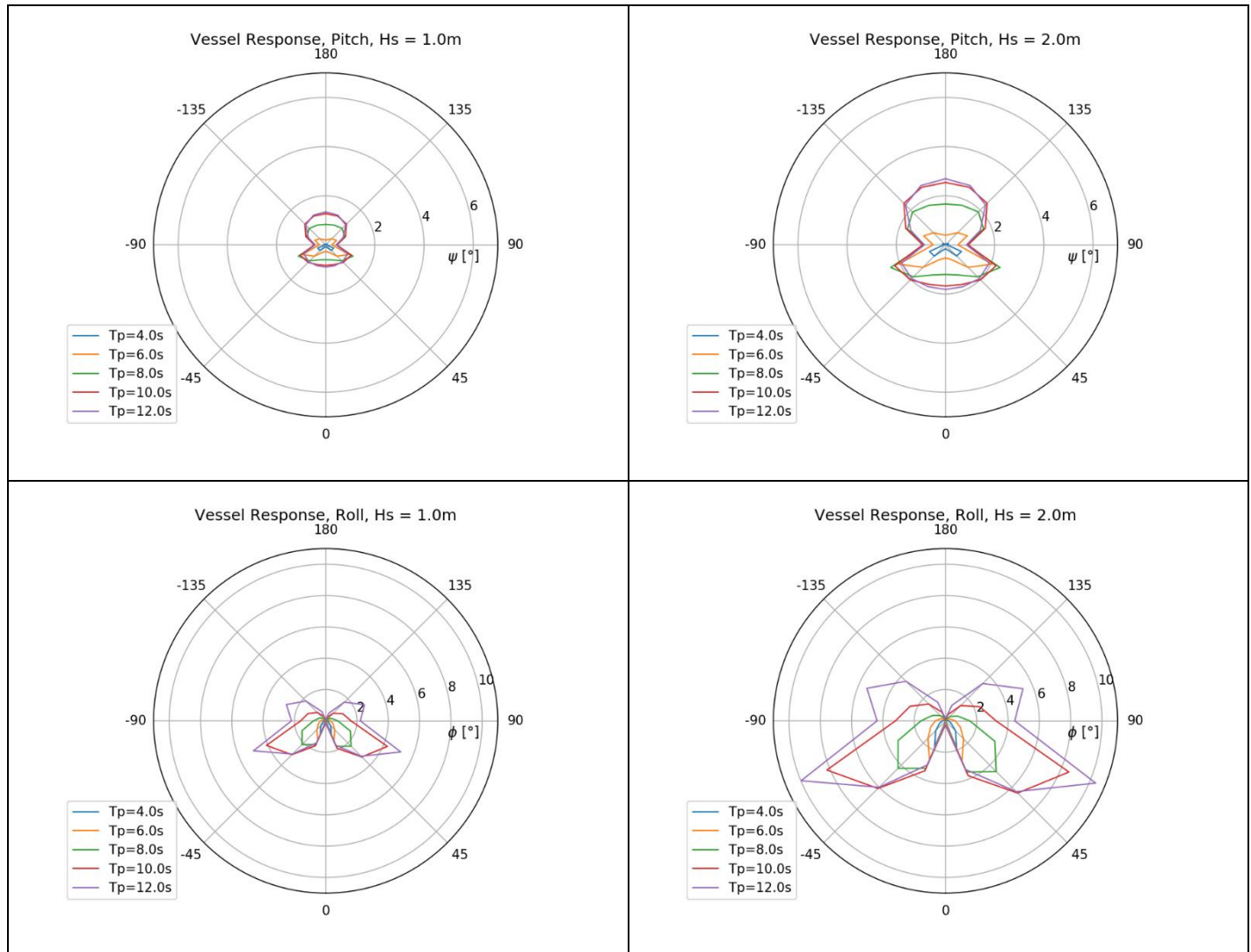


Figure 23: 99.99 Percentile maximum response for Pitch and Roll in two different significant wave heights for a generic HLV at service speed

For the storage of the piles aboard the transport vessel, a specific section is devoted to the transport of tubular structures in DNVGL-ST-N001, section 11.9.9.2. However, a detailed analysis of pile positioning would go beyond the scope of this installation manual and can be conducted upon demand based on the steps provided by the classification societies for this type of standard procedure. The maximum sea fastening loads to be considered also depend on the type of sea fastening that it chosen by the operator. A detailed description of the sea fastening design procedure is given in DNV-OS-H202.

6.1.1.3 Engineering – environmental conditions during transport offshore pile installation

The installation of piles which serve as an anchor for offshore-based floating structures is a procedure which is performed at increasing occurrence over the last decade. Especially due to the increased interest in deployment of floating offshore wind turbines, classification societies have devoted more attention to the definition of rules and recommendations for this type of operation.

The main concerns to be considered here are the precise positioning of the vessel and crane while lowering the piles down to the sea bed and the safety of the vessel crew and equipment when lifting heavy loads over deck. The lift operation can be divided into five steps:

1. Lift-off of load object from deck
2. Positioning of object in air
3. Transit of splash zone
4. Lowering object to full depth of submergence
5. Landing on sea bottom
6. During driving operation

Additionally, the position of the lifting vessel has to be maintained throughout the procedure. A detailed step-by-step description of the procedures is given in sections 6.1.8.

6.1.1.3.1 Lifting loads

The assessment of the lift-off operation needs to consider the wave induced motion of the vessel and hence the boom tip which holds the cargo object. Due to the small weight of the piles (approx. 90t) compared to the vessel displacement, the effects of the moving load on the vessel do not have to be considered. The motion analysis can be conducted based on a 3D time domain model to simulate the wave induced motion of the vessel and a multi-body dynamics tool to simulate the motion of the cargo when suspended from the crane. In all cases, it should be avoided to allow a motion excitation in the vicinity of the natural frequency of the hanging load, which for a simple pendulum may be estimated as:

$$T = 2 \pi \sqrt{\frac{L}{g}}$$

In this formula, L represents the length of the line and g refers to the gravitation acceleration. If a typical wave period encountered at the installation site is around 6s, a line length of approximately L=871m has to be avoided. As can easily be derived, this exceeds the necessary lifting height by far and thus is rather uncritical for this operation. Nevertheless, higher order harmonics should be considered.

A further aspect to consider is the maximum load each component of the lifting gear is exposed to. This includes but is not limited to: the hook, pad eyes, line, sling, etc. In addition to the weight of the lifted object, loads due to motion of the vessel and object have to be considered by applying a factor to the original load. This factor is called the Dynamic Amplification Factor (DAF) and can be defined empirically based on DNVGL guidelines:

$$DAF = 1 + 0.25 \sqrt{\frac{100}{SHL}}$$

wherein SHL refers to the Static Hook Load in tons. This formula is applicable to Static Hook Loads between 3t and 100t, whereas static coefficients are used for heavier loads. The vibro-hammer and equipment are assumed to have a

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total mass of approx. 10t. If the actual mass exceeds this estimate, the above formula will provide a conservative estimate, since for lifts with >100t total lift load, a static DAF of 1.25 is applied. By applying the DAF factor to the combined weight of the pile and equipment, a total load of 125t is obtained. As the main crane of HLV Orion has a crane capacity of 3000t for 57m reach, the capacity is deemed sufficient for this operation. As the piles have an open bottom, the effect of wave impact in the splash zone is reduced.

An onboard lift operation has to be conducted in order to position the mooring line boxes for the connection to the pile and the unwinding when lowering the pile to the sea bed. Based on the thickness of the links and the total length of the chain, a weight of approximately 400t is estimated for each mooring box. Due to the large capacity of the Orion main crane and the fact that no transit through the splash zone has to occur, this operation is deemed less critical in terms of overall risk. Nevertheless, it presents the maximum load lift for the crane equipment. For loads between 300t and 1000t static hook load, DNVGL recommends a constant DAF of 1.20. This results in a maximum dynamic hook load of 480t. Since the lever for this operation is small, crane and crane equipment are deemed suitable for this operation.

Table 13: Maximum Design Loads for Crane and Crane Equipment

Operation	Static Hook Load	DAF	Dynamic Hook Load
Lifting of Piles	100t	1.25	125t
Lifting of Mooring Boxes	400t	1.20	480t

6.1.1.3.2 Vessel Motion

A motion response analysis of the vessel should be conducted in order to assess the limiting environmental conditions of the operation. These are defined as the conditions under which the motion excitation of vessel and cargo does not allow safe operation. For this demonstration, a 3D panel method is used to compute the maximum accelerations and motion displacement encountered during 1000 operations for defined $H_s - T_p$ combinations and encounter angles. If the vessel and equipment are designed such that these accelerations and displacements can be tolerated, the operation can be rated with a safety of 99.99%.

As a simplification, only linear wave response is investigated, which is considered appropriate here, as the installation procedure is a highly sensitive operation and will thus only be conducted in conditions when induced motion of the vessel is comparatively small and may thus be approximated well using linear potential flow theory.

The following plot was computed for a generic Heavy Lift Vessel similar to the HLV Orion and should only serve to illustrate the computation-assisted procedure of operation planning. The diagram has been computed for two different significant wave heights and for a range of peak periods, which correspond to the most frequently occurring sea states at the envisaged installation site.

The upper images of Figure 24 show the vessel's pitch response over encounter angle for different combinations of significant wave height and peak period. The lower images show the same for the roll motion amplitude. In order to obtain a more realistic vessel roll response, an empirically defined linear roll damping approach based on Wassermann (Wassermann, 2018) has been used.

As becomes obvious, the roll motion is small in head and stern seas, while becoming large for beam seas. Using the vessels dynamic positioning capacities, the ship orientation may be adjusted to obtain minimal response, i.e. if roll motion is to be avoided, the DP thrusters turn the vessel to an encounter angle of 0°. In this case, only a range of encounter angles from -30° to +30° has to be accounted for in the design of the procedure. This is not applicable for the transit, since during transit only minor adjustments can be made to the ship course and hence the encounter angle without significantly increasing the operation times.

Another aspect to consider in the planning of the operation is the position keeping ability of the vessel. The mean drift forces induced by waves, wind and current should be computed and compared to the dynamic positioning capability of the vessel to ensure that the position can be held during the whole operation reference period.

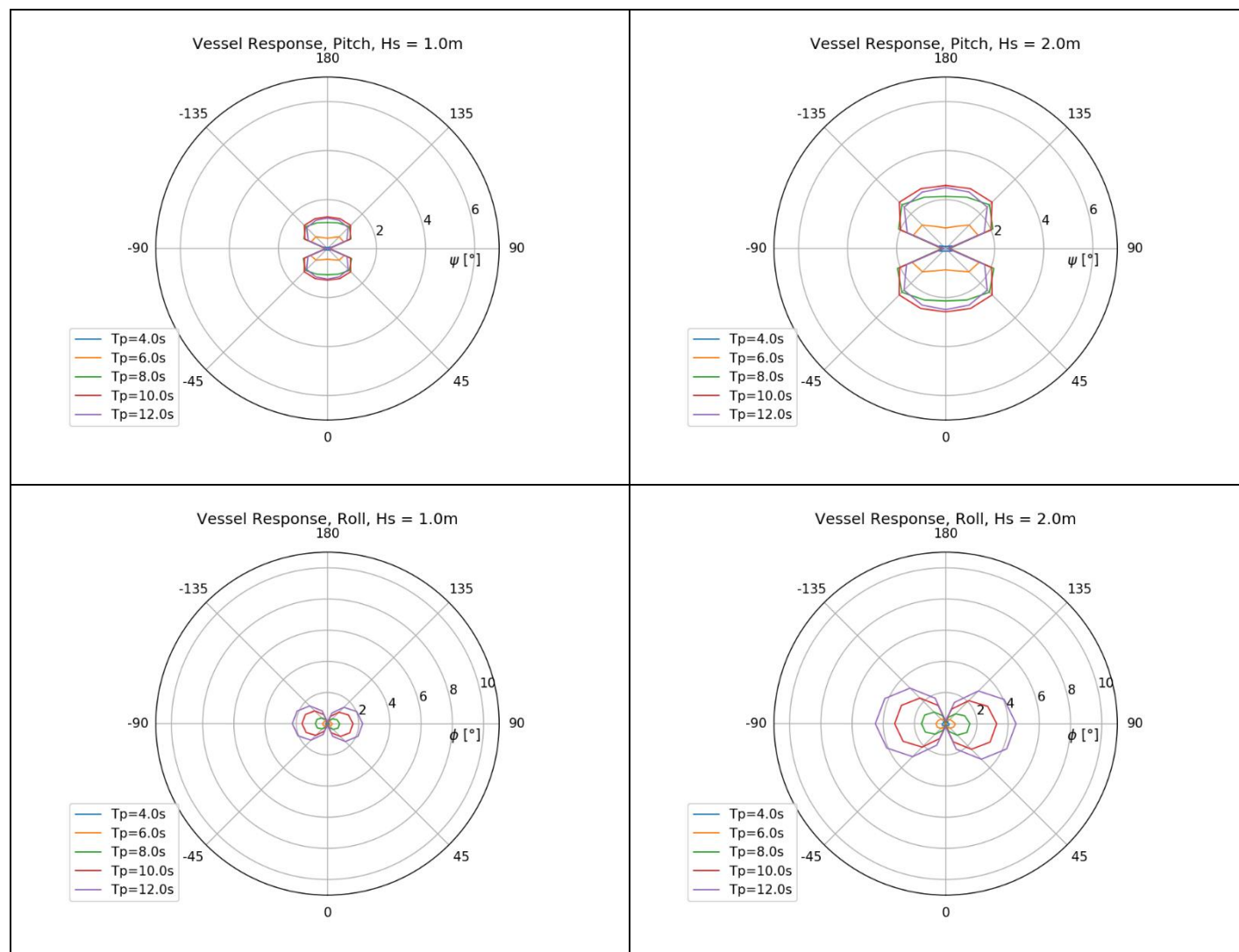
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Figure 24: 99.99 Percentile maximum response for Pitch and Roll in two different significant wave heights for a generic HLV at zero speed

6.1.1.3.3 Current induced displacement

Upon entering the water, the wave and buoyancy induced forces on the lifted object have to be considered. In order to maintain a stable hook load, the piles are not sealed, so that lift due to buoyancy is kept small. Wave conditions should be low enough to ensure that wave impact does not damage the piles or lead to collision of vessel and hanging load. This aspect is of minor concern, since the HLV provides a large crane reach and can thus lower the load with adequate distance from the hull. For smaller vessels with a smaller crane capacity and thus a smaller reach, this should be considered in more detail.

Once submerged, the piles may be subjected to marine currents. Due to the large diameter and height of the piles, a current induced displacement off the vertical hook axis may be induced. The offsetting force may be approximated by the following formula:

$$F_c = \frac{1}{2} \rho u_c^2 \cdot c_D \cdot A.$$

The cross-sectional area A is computed as the product of length and diameter of the pile. For cylindrical bodies with a large length to diameter ratio, the drag coefficient c_D is given with a value of 1 in literature. In order to obtain the resulting offset, an equilibrium has to be established between drag forces and inertial forces, including the reduced weight due to buoyancy.

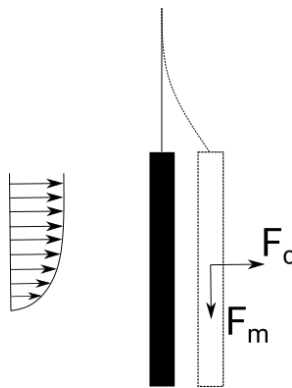


Figure 25: Current induced offset of submerged pending load as equilibrium of current induced drag and gravity

For a pile length of 45m and a diameter of 1.8m, a current induced drift force of approximately 5.2t may be experienced in current velocities of 0.5m/s. It should however be noted that current velocities usually decrease with increasing depth of submergence and rarely reach the value of 0.5m/s for the investigated area. Furthermore, the weight of the pile including the vibro-hammer gear has a weight of about 100t. Thus the resulting angle of the line will be relatively small when not considering the drag forces on the cables, which will also have a minor influence ($\alpha < 2^\circ$).

As two different scenarios of pile driving are evaluated, different limiting conditions apply and the resulting statistical workability is presented in the respective sub-section.

6.1.1.3.4 Conclusion

The above data and results proves that the selected heavy lift vessel will not cause any risk to perform the offshore works. Subsequently, the results show that the alternative installation vessel, an offshore construction vessel, should require sufficient crane capacity and a certain stability for installation. Because this types of OCV's with certain requirements are very rare and limited, it strengthens our advice to opt for a single heavy lift vessel.

6.1.2 Marine equipment

With a total installed capacity of 44 MW, heavy lift vessel ‘Orion’ is equipped with a high-tech crane with lifting capacity of 5,000 tonnes at 35 metres. The loads can be lifted to a height of more than 170 m and is able to install foundations in water depths up to 300m. Deck space has been maximised to provide high transport and load capacity. The 216.5 metres long Orion, featuring DP3 capability, can accommodate a crew of up to 131 people. Technical details of the vessel can be found in Annex 5: Technical leaflet HLV Orion DEME.



Figure 26 HLV Orion (DEME)

Environmental considerations have been an important element of the vessel design. ‘Orion’ has dual fuel engines and can run on natural gas (LNG). It has a Green Passport and Clean Design notation.

MAIN DIMENSIONS	length	216.50 m
	breadth	49.00 m
	depth	16.80 m
CRANE	capacity	3,000 ton at 57 m 5,000 ton at 35 m
POWER & PROPULSION	dynamic positioning	DP3
	propulsion	4 x 4,500 kW Azimuth Thrusters 2 x 4,200 kW Retractable Thrusters 2 x 2,500 kW Tunnel Thrusters
	installed power	44,180 kW (Dual Fuel)
OPERATIONAL CONDITIONS	pay load (max)	30,000 ton
	free deck area	8,000 m ²
	operating draft (max)	11.00 m
OTHER	accommodation	131 persons (extendable to 239 persons)
	helideck	installed
	moonpools	space claim for 19,6 m x 10,5 m
	auxiliary crane	2 x 100 ton, knuckle boom, manriding
	other	8 points mooring system

Figure 27 technical specification HLV Orion (DEME)

6.1.3 Mobilization

The heavy lift vessel will move to the offshore site after execution of its previous DEMA offshore project. Due to the fact that it is unknown when and where the *Space@Sea* project will be executed, it is assumed that HLV Orion will be mobilized from the port of Vlissingen, the Netherlands. In this port, the vessel will be prepared for the project by setting up all the required installation equipment on deck of the vessel. In general, it takes around two (2) weeks to make the vessel ready for execution. Section 6.1.2 shows all the required equipment which needs to be installed on deck of the vessel.

6.1.4 Vessel transit

HLV Orion will sail from the Netherlands to the allocated marshalling port (ref. section 3) where all structures and components are ready for loading onto the vessel. With an empty sailing speed of approx. 13 knots, the vessel will reach the marshalling port in approx. 7.5 days.

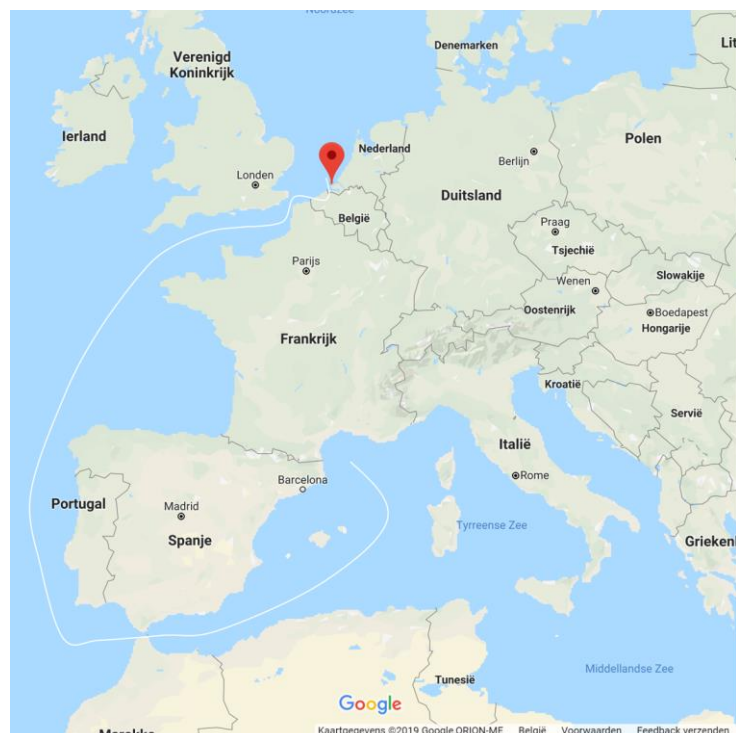


Figure 28 vessel transit from NL to marshalling port (indicative)

6.1.5 Load out at marshalling port

Reference is made to section 3 where the Port of Marseille has been selected as marshalling port. HLV Orion will enter the port, load all the required structures and leaves the port. It has been assumed in this report that the vessel is able to enter and leave the port. The time for loading out the piles and mooring lines on board of the vessel has been included in the cycle time calculations (see 6.1.8). The calculations start when the vessel enters the port of Marseille.

D5.1 T&I Manual**6.1.6 Vessel deck lay-out**

The following equipment is required for executing the offshore works;

Table 14 Required equipment on deck HLV

Nr.	Action	Equipment
1	Driving operation	<ul style="list-style-type: none"> - Base case: Vibro-hammer (VH) - Alternative case: Impact hammer and piling template
2	Foundations	<ul style="list-style-type: none"> - 71 piles (in racks of 4x4) - 71 mooring line in box (partly in deck, mainly on deck)
3	Noise Mitigation	<ul style="list-style-type: none"> - Noise mitigation system (NMS) and/or bubble curtains if use of alternative case
4	To fasten the equipment and piles during transfer and installation	<ul style="list-style-type: none"> - Sea fastening (frames and grillages)
5	Lifting operations	<ul style="list-style-type: none"> - Pile Lifting tool (in case of alternative case) - upending cradles - spreader bars, rigging, slings - etc.
6	Miscellaneous	<ul style="list-style-type: none"> - ROV - Gypsy winch (Figure 31) - etc.

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Below drawing shows an indicative example of the deck lay out HLV Orion for the *Space@Sea* operation with a vibro-hammer, piles and mooring lines on board. The drawing is pure indicative.

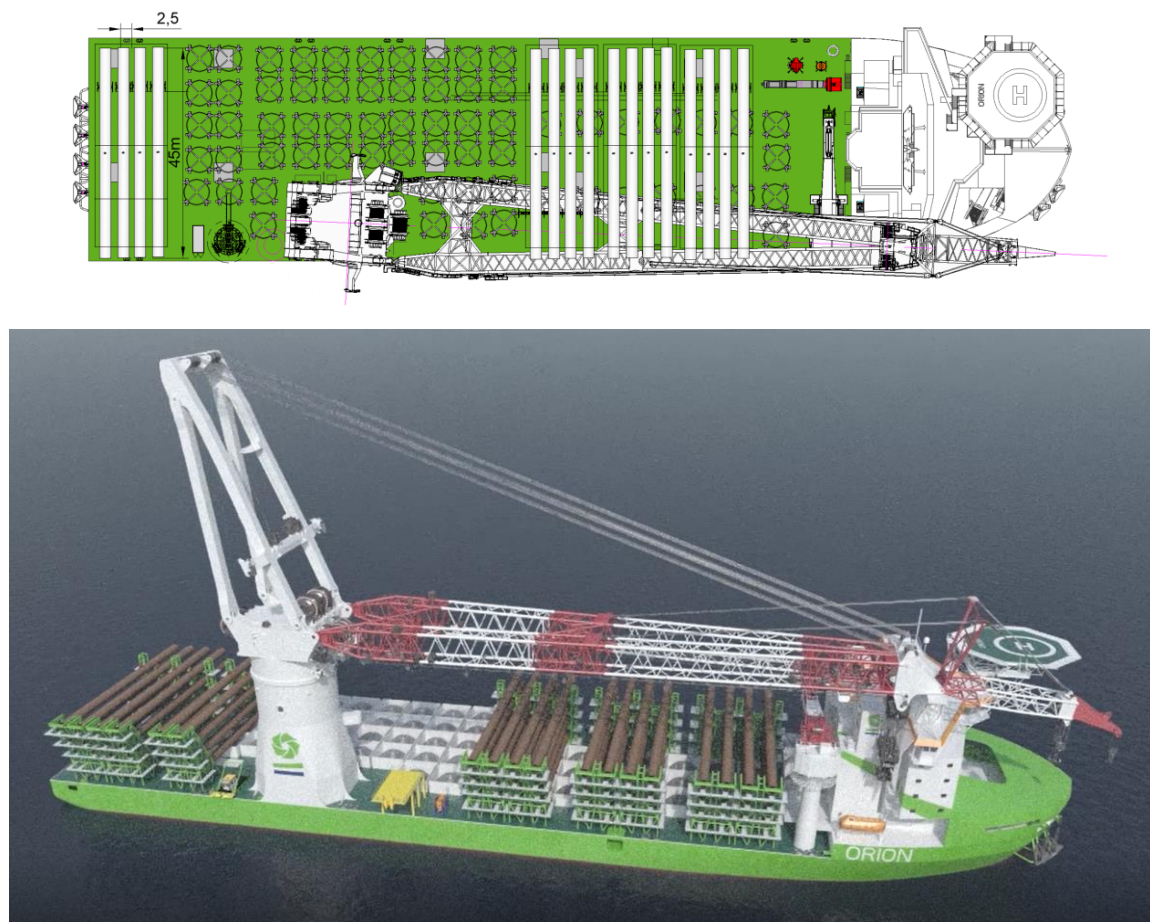


Figure 29 indicative deck lay out HLV Orion

HLV Orion will use for the *Space@Sea* project a purpose made pile foundation rack which carries up to 16 (4 by 4) piles per rack. This pile rack can be controlled automatically and consists of an upending cradle to lift the piles to its vertical position. By having an upending cradle for each piles, it reduces the offshore handling time significantly.

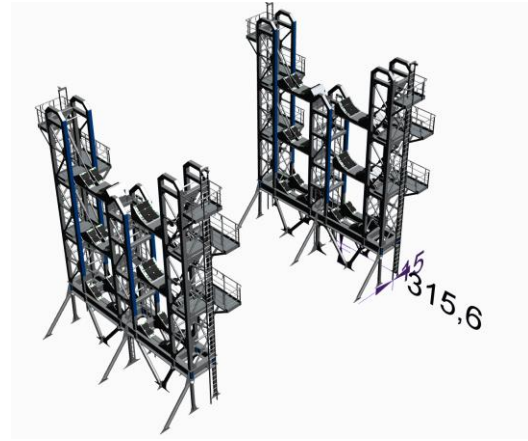


Figure 30 Pile rack on JUV Apollo (DEME) for the Moray East project (UK)

A gypsy winch is required in order to let the catenary line follow the pile during the piling operation. This tool is custom made and depends on the size and weight of the catenary lines.



Figure 31 example of gypsy winch system

6.1.7 Transit to offshore site

The following table shows the total time to transit from marshalling port to offshore site and back. These values are integrated in the cycle time calculations which is shown in the coming sections.

Table 15: Transit times and sailing speed for the transport of piles to offshore site

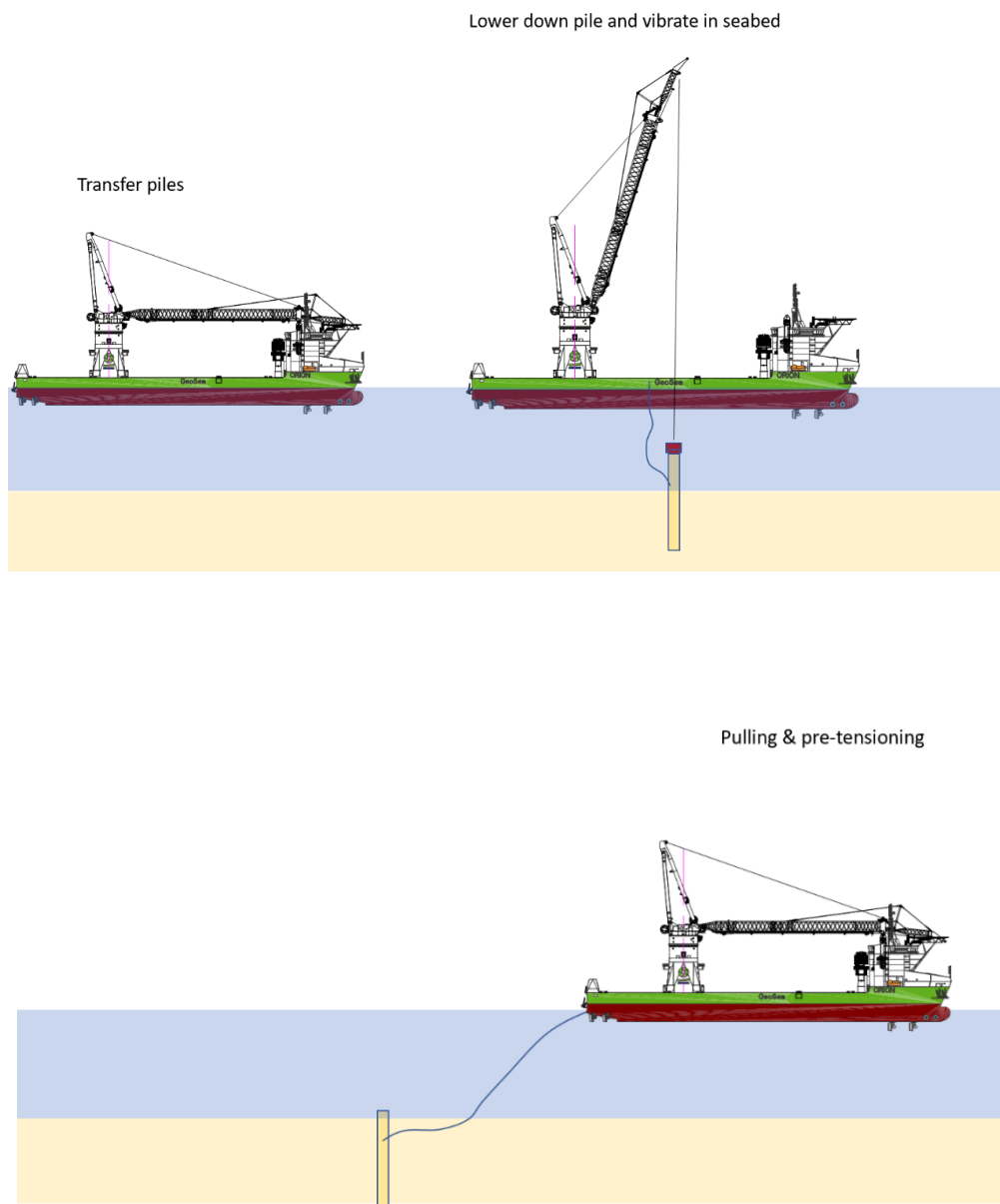
Marshalling port	Port of Marseille
Sailing distance to offshore site	70 NM
Sailing speed (loaded)	11 knots
Sailing duration (loaded)	Approx. 6.5 hours
Sailing speed (empty)	13 knots
Sailing duration (empty)	Approx. 5.5 hours
Time per cycle x #cycles	± 12 hours

6.1.8 Installation methodology


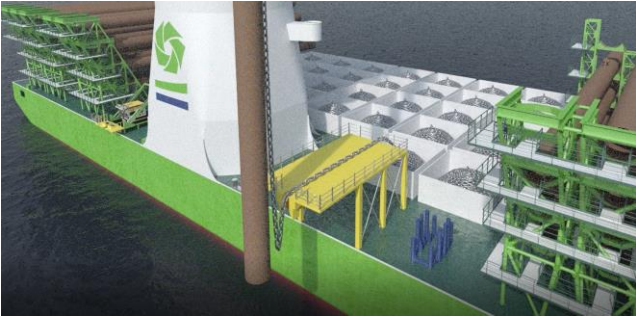

Two (2) different installation methodologies are described below. The first methodology describes the installation of subsea anchor piles by driving with a vibro-hammer and is a rather new state-of-the-art technology. The second installation methodology consists of driving piles with an impact hammer, which is commonly used in the offshore wind business. Both methodologies require different techniques and equipment and vary in installation cost and duration.

A conclusion on the most appropriate method for the *Space@Sea* project is described in chapter 7

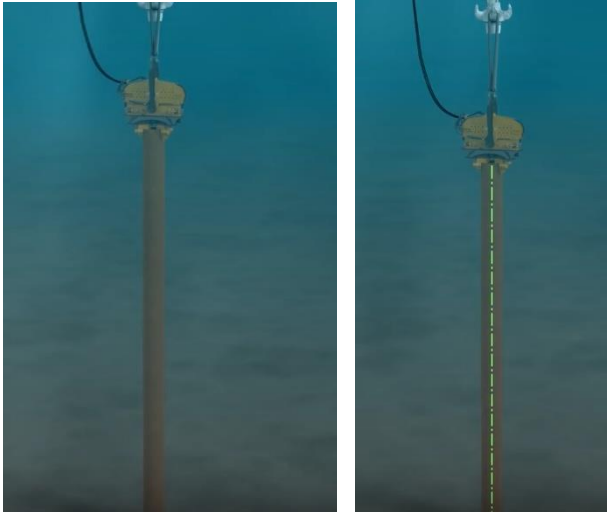

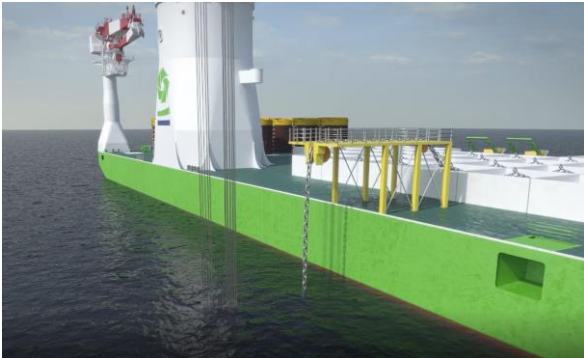
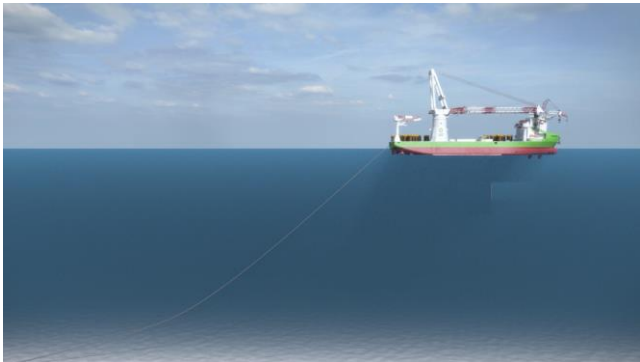
6.1.8.1 Installation methodology: driving piles with vibro-hammer



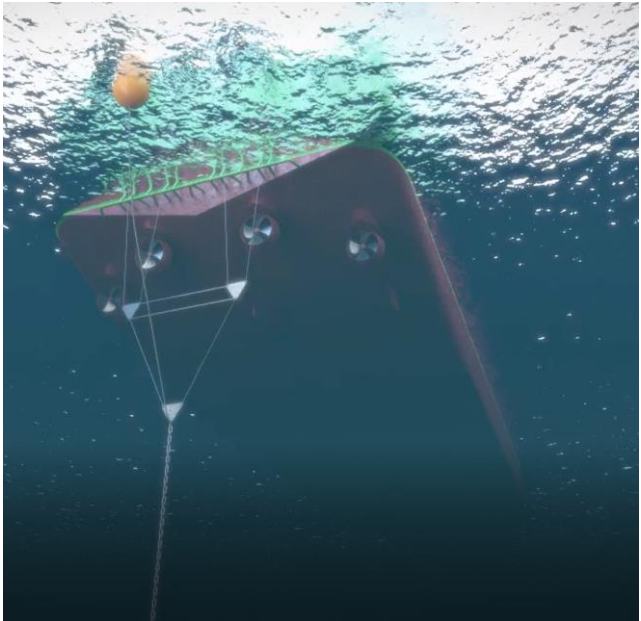

D5.1 T&I Manual*Figure 32 installation methodology - driving piles with Vibro-hammer (HLV Orion)*

1	HLV Orion leaves the marshalling port after loading foundations and mooring lines on deck and sails to offshore site	
2	Arriving at the offshore site, HLV Orion manoeuvres on dynamic positioning (DP3) to its first installation location. The main crane will be unseafastened and the deck is prepared for its first installation activity.	
3	The main crane will move the piles from horizontal position to vertical position by using the vibro-hammer, which consists of an internal lifting tool After upending, the pile will be moved sideward and lowered down to the seabed	
4	The pile will be lowered down by the vibro-hammer. Once the pile penetrates the seabed due to its own weight, the vibro-hammer will generate vibrations which drives the pile into the seabed. The vertical alignment will be managed by the vibro-hammer. Depending on the soil, this can be very quick operation.	

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5	<p>Once the piles penetrates the seabed due to its own weight, the vibro-hammer will generate vibrations which drives the pile into the seabed. The vertical alignment will be managed by the vibro-hammer. Piles can be easily retrieved by vibrating and pulling out the pile.</p> <p>Depending on the soil, this can be very quick operation.</p>	
6	<p>Pile will be driven below the seabed. The internal lifting tool of the vibro-hammer will release its grip and will be retrieved back on deck.</p>	
7	<p>The remaining part of the 750m long catenary line will be lowered down as preparation for procedure 8</p>	
8	<p>Once the full catenary line has been winched down in the water, HLV Orion will pull the catenary line with heavy force because the first part of the catenary (so called inverse catenary) is driven in the seabed.</p>	

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9	<p>At final position, 750m away from the anchor point, HLV Orion will lower down the catenary line on the seabed and installs a buoy system to mark its position for the connection with the floating modules.</p>	
10	<p>HLV Orion moves to the next location and starts again with procedure no. 1.</p>	

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The total amount of cycles and net duration of driving piles with a Vibro-hammer with HLV Orion are shown in below table. Reference is made to Annex 2: T&I schedule with HLV Orion for a complete T&I schedule.

Table 16 Cycle times HLV Orion with Vibro-hammering (good weather period)

HLV Orion with vibro-hammering – Start date: 01/04/20xx (Mediterranean Sea)		
Activity	Net duration (incl. 90% efficiency)	Repetitions
Enter the port	3.3 hours	1
Lifting 71 piles and mooring lines	37.8 hours	1
Sea fastening & leaving port	3.3 hours	1
Sailing to site	7.1 hours	1
Offshore execution works	7.5 hours	71
Sailing to port	6.0 hours	1
TOTAL	25.7 days (including 1 day learning curve)	
Weather down time Q50 (Figure 33)	+2.3 days	
Mobilization, transit, demobilization	+ 39 days (14+7.5+7.5+10 days)	
Total Project duration	Start project	01/04/20xx
	Mobilization and transit to offshore site	01/04/20xx – 24/04/20xx
	Offshore installation	24/04/20xx – 21/05/20xx
	Transit and demobilization	21/05/20xx – 06/06/20xx
	End project	06/06/20xx

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q25	81.58%	85.62%	85.84%	87.81%	95.35%	96.81%	97.31%	97.81%	94.96%	89.75%	80.66%	81.80%
Q50	74.97%	72.77%	81.58%	83.16%	91.92%	94.13%	95.02%	95.81%	91.94%	85.41%	73.82%	74.28%
Q75	67.05%	62.78%	73.10%	77.35%	85.47%	90.86%	91.42%	92.38%	87.67%	76.13%	68.76%	67.73%
Q90	61.09%	55.97%	67.76%	72.11%	75.48%	88.07%	87.46%	89.61%	83.40%	71.42%	60.41%	60.45%

Figure 33 monthly weather related workability

Applying an offshore construction vessel instead of a heavy lift vessel results in more net duration days due to more offshore handling, and more weather down time due to lower vessel limits. However, there is still adequate time for finishing the project before the bad weather starts. Introducing an offshore construction vessel for the offshore works results in extra **20 days**, finishing the driving operation in **26/06/20xx** (ref. Annex 3: T&I schedule with OCV)

Below section provides an alternative installation methodology, which is currently used in the offshore wind business. This method has not been taken as base case for this report as it is assumed that this new technology will evolve in the upcoming years, and it turns out that this technology decreases the installation time and accompanying costs drastically.

6.1.8.2 Installation methodology: driving piles with impact hammer

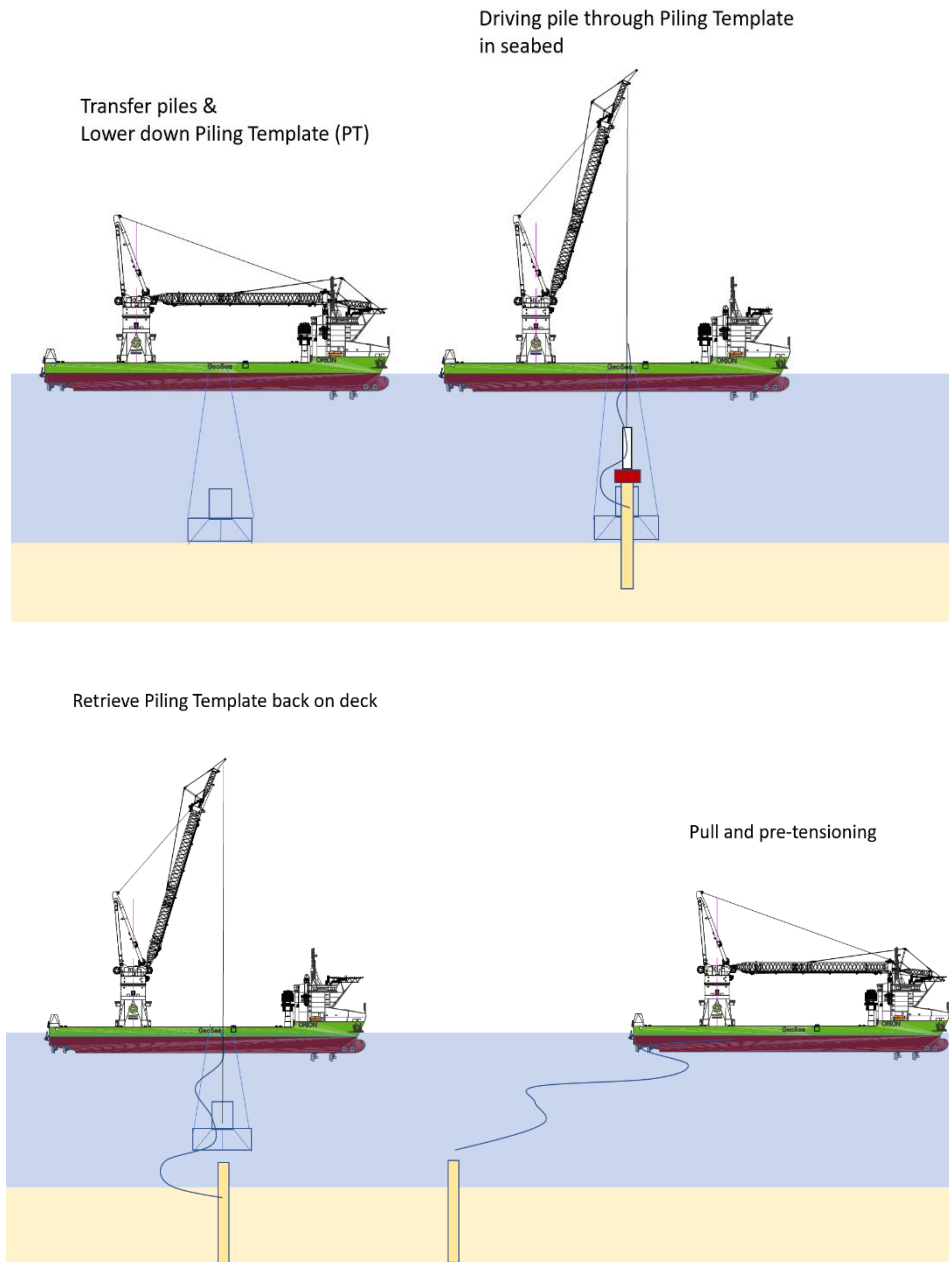


Figure 34 concept sketch installation methodology (1)

Driving piles with an impact hammer is currently used for the installation of windfarm foundations (e.g. monopiles). This methodology has not been taken as base case due to the following reasons;

- It requires a specific pile design made for impact. This results in more pile weight
- Driving piles with an impact hammer emits heavy noise which affects marine mammals. During this operation, it is required to provide a noise mitigation system which has an impact on the installation time and its accompanying cost.
- A piling template is required to grip the pile underwater during the change of installation tools (e.g. from internal lifting tool to impact hammer). This results in longer installation time and extra investment cost.

A detailed description on driving the piles with an impact hammer can be found in Annex 1: Installation manual HLV Orion with impact hammering

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Below table shows the durations for impact hammering with HLV Orion.

Table 17 Cycle times HLV Orion with Impact hammering (good weather period)

HLV Orion with impact hammering – Start date: 01/04/20xx (Mediterranean Sea)		
Activity	Net duration (incl. 90% efficiency)	Repetitions
Enter the port	3.3 hours	1
Lifting 71 piles and mooring lines	37.8 hours	1
Sea fastening & leaving port	3.3 hours	1
Sailing to site	7.1 hours	1
Offshore execution works	12.2 hours	71
Sailing to port	6.0 hours	1
TOTAL	39.6 days (including 1 day learning curve)	
Weather down time Q50 (Figure 35 monthly weather related workability)	+4.2 days	
Extra installation time compared to vibro-hammering	16 days extra	
	Start project	01/04/20xx
	Mobilization and transit to offshore site	01/04/20xx – 24/04/20xx
	Offshore installation	24/04/20xx – 06/06/20xx
	Transit and demobilization	06/06/20xx – 22/06/20xx
	End project	22/06/20xx

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q25	79.13%	82.65%	82.93%	84.85%	93.49%	95.23%	95.38%	96.09%	93.08%	87.67%	75.40%	77.69%
0	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Q50	72.56%	68.62%	76.86%	79.16%	89.63%	92.22%	92.87%	93.50%	89.54%	82.60%	69.90%	69.92%
Q75	63.65%	59.78%	69.60%	73.42%	82.68%	89.06%	87.80%	89.14%	84.55%	72.78%	65.76%	63.70%
Q90	57.47%	51.55%	64.43%	67.89%	71.09%	85.43%	84.22%	86.26%	80.13%	68.41%	54.85%	56.08%

Figure 35 monthly weather related workability

6.1.9 Transit back to marshalling port and demobilization

After executing the offshore works for the *Space@Sea* project, HLV Orion will sail back to mobilization port in the Netherlands and takes approx. 10 days for dismantling the vessel.

6.2 Transport of floating modules and offshore installation

6.2.1 Engineering and preparatory works

6.2.1.1 Engineering

The transport of the preassembled modules from Marshalling port to the offshore deployment site is conducted using one or multiple tugs, towing the floating bodies through the water. In order to plan this procedure, limiting environmental conditions are defined. The probability of weather windows with less severe conditions than the limiting state should be high enough to guarantee that the operation can be conducted within the assigned operation reference period.

Within the defined limiting environmental conditions, the tug or tugs should be able to compensate the towing resistance, composed by the drift forces induced by wind, waves and current, under all conditions. The scenario of zero forward velocity is typically referred to as “Bollard Pull” condition. The required bollard pull force, exerted by the tugs at this condition, depends on the responsiveness of the towed object to the acting environmental forces, consisting of wind and current induced drag as well as wave induced drift forces. First order wave response is not considered here since only an average force over 1min is considered.

6.2.1.2 Wave drift

Since towage of floating structures is a standard operation of marine engineering, DNVGL ruling provides an empirical formula to estimate wave induced drift forces for a given body and significant wave height (DNV, 2011):

$$F_{wd} = \frac{1}{8} \rho_w g R^2 B \cdot H_s^2.$$

In this formula, B refers to the breadth of the towed object, ρ_w to the density of sea water, g to the magnitude of gravitational acceleration and H_s to the significant wave height. R represents an empirically defined reflection coefficient. For square faced objects in tow, a reflection coefficient of $R=1$ is given in the literature.

6.2.1.3 Current drag

The devised installation site in the Mediterranean Sea shows only minor influences by tidal or other currents. As a conservative approximation, a value of 0.5m/s is assumed for the tow operation. The resulting drag force can be estimated based on:

$$F_D = \frac{1}{2} c_D v^2 A,$$

with v as the relative velocity of towed object and free stream, A as the lateral area of the object exposed to the current and c_D as the drag coefficient. Since the area A only refers to the submerged area, it is defined as the product of draft and breadth of the floater module. For rectangular structures such as the floaters investigated in this study, DNVGL guidelines provide empirical values for the drag coefficient, which may be taken with a value of 1, just as for the reflection coefficient above.

6.2.1.4 Wind

Wind forces may be approximated similar to the drag forces described in the paragraph above. The velocities to be applied here are based on the average wind velocities which may be expected during the tow and installation operation. While statistical data can be used for the general planning of the procedure, reliable weather forecasts have to be consulted before starting the operation. In this study, data from Argos has been taken. Other, free data repositories like the ERA5 data base established by ECMWF within the Copernicus program can be consulted for statistical data on environmental conditions within European waters.

6.2.1.5 Tow efficiency

In order to account for reduced efficiency of the tugs due to hydrodynamic interaction, age of equipment, marine growth and similar effects, the nominal bollard pull of the tugs is multiplied by a tow efficiency factor. An estimation of an efficiency factor may also be derived from DNVGL ruling, which provides an empirical formula:

$$T_{eff} = 80 - (1 - 0.0417 \cdot L_{OA} \cdot \sqrt{F_{BP} - 20}) \cdot (H_s - 1)$$

In this formula, F_{BP} refers to the static bollard pull of the tug. It should be noted, that this formula is only deemed applicable for tugs up to an overall length of $L_{OA}=45\text{m}$ and a static bollard pull between 20t and 100t.

In addition to the Bollard Pull requirement, the tug should be able to provide the desired service speed to complete the operation within the given time frame. A service speed of 5kn is assumed for the tow operation of a single floater and 3kn for the triple-floater configuration. The total resistance resulting at service speed can be modelled as a superposition of calm water resistance for the defined forward velocity and wave induced drift forces, also known as added wave resistance.

This simplification is only valid at very slow forward velocities, since the forward velocity of a partly-submerged body may have a significant influence on the added mass component of the inertia term in the equation of motion.

Resistance values for a single module with the properties of the accommodation hub developed in WP6 *Energyhub@Sea*, were computed for calm water conditions using the RANS CFD code StarCCM+. Velocities of 1kn to 5kn in steps of 2kn were tested. The resulting force in axial direction for the respective velocity is shown in Figure 36.

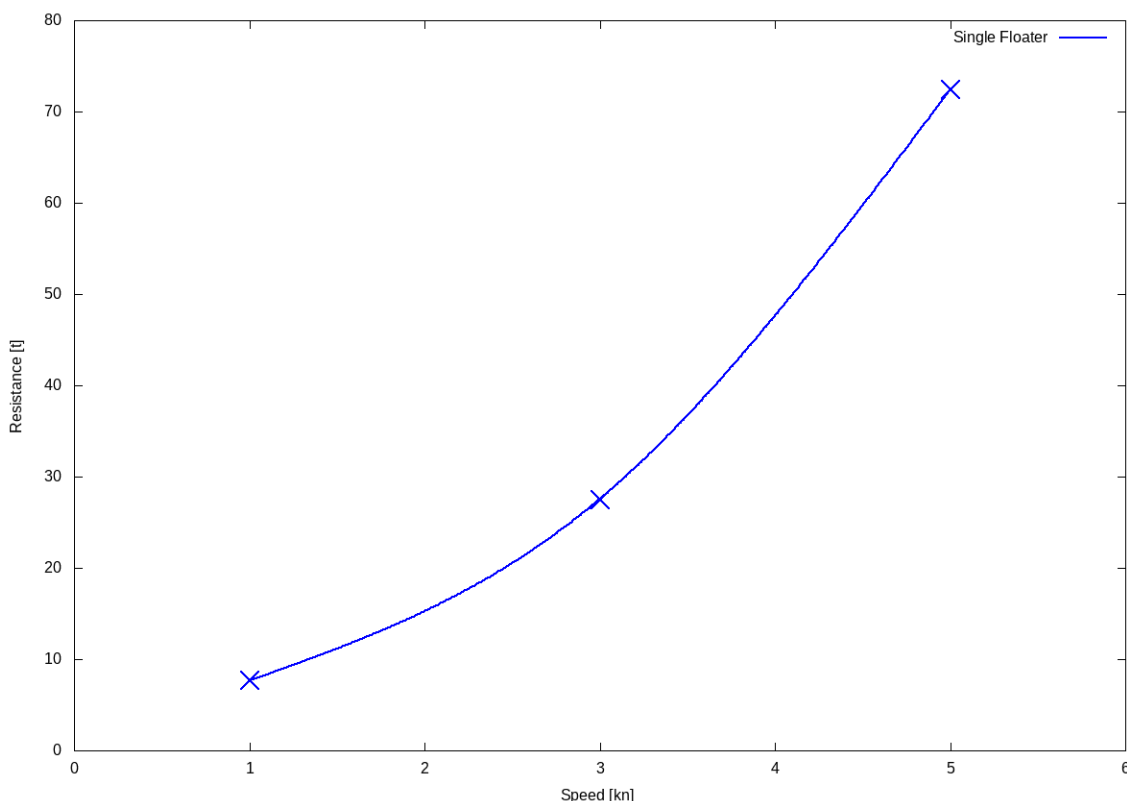


Figure 36: Tow Resistance of Single Module in [t] over Towing Speed, based on the WP6 accommodation hub

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Based on the results of the empirical formulae in combination with the calm water resistance of the bodies, the limiting environmental conditions can be defined based on the desired operability. Based on the wave scatter diagram and the average wind speeds, the following limiting conditions under consideration of the α -factor were defined:

Table 18 Design limiting values of environmental forces for tow operation

Environmental Load Component	Limiting Value
Wind Speed	15m/s
Current Speed	0.5m/s
Significant Wave Height	2m

Under the conditions listed in Table 18, 2 tugs of each 100 ton BP and an over length (LOA) of 45 meters or more, or a 200 ton BP tug (Figure 37) would be able to conduct the operation as planned. With regard to the Bollard Pull requirement as included in the DVNGL recommendations on tow operations, this tow configuration would be able to operate in conditions as listed in Table 19

Table 19: Maximum Limiting Bollard Pull Condition for Tow Operation using two 100t BP tugs or one 200t BP tug with LOA>45m

Environmental Impact	Limiting Value
Wind Speed	20m/s
Current Speed	0.5m/s
Significant Wave Height	4.5m

6.2.2 Marine equipment

As per above, two tugs of each 200 tons are required for towing the module from marshalling port to offshore site and one additional tug is needed for maneuvering purposes in the vicinity of the deployment site. During transit, the tug will be attached to the rear of the three-floater configuration to enhance maneuvering capabilities in case of emergency. For the single floater transport scenario, the tug may stay at the deployment site or may also assist during transit if the weather conditions require additional safety measures.



Figure 37 Example of a 200t BP tug boat

As can be determined from the statistical weather data for the installation site, the conditions listed in Table 18 are only exceeded during less than 20% of the year. Nevertheless, in order to further increase the safety margin of the operation, the size of tugs can be increased to 120t BP. In the following calculations, this larger tug size was used to assess the cost associated with the respective tow configuration options. The tow operations are assuming a tow of pre-assembled modules from the harbor presented in section 3 to the installation site.

During installation, an additional Offshore Construction Vessel is required for supporting the connection with the mooring lines and/or pre-installed floating modules. Edda Freya from Deepocean has been selected due to its high capacity crane (400/600 mT) to ensure it can lift up the mooring line from the sea-bed and deliver it to the floaters. This is done using messenger lines, small lines that are easily manageable, connected to the mooring chain. While the messenger line is hauled in using adequate equipment on the floaters, the weight of the mooring line, which will later keep the island in position, has to be compensated by the OCV. In the subsequent step, this procedure has to be repeated for the opposite side of the floaters, in order to establish an equilibrium of mooring forces, before the tugs can disconnect from the island. Therefore, at least four vessels are needed on site for the installation procedure.



Figure 38 Example of OCV with sufficient crane capacity (Edda Freya Deepocean)

6.2.3 Mobilization

Possible solutions for the tow operation would be the tugs Eraclea and Kamarina, both based in the port of Catania, Sicily. With a nominal bollard pull of respectively 120t and 123t, these vessels would be able to cope with the environmental conditions encountered on the route.



Figure 39 Tugs Eraclea and Kamarina (indicative)

6.2.4 Transit

The tug and empty will sail from the port of Catania to the marshalling port (ref. 3) where the barges will be prepared for towing operations. With a sailing speed of approx. 10 knots (empty), the vessel will reach the marshalling port in approx. 8.5 days.

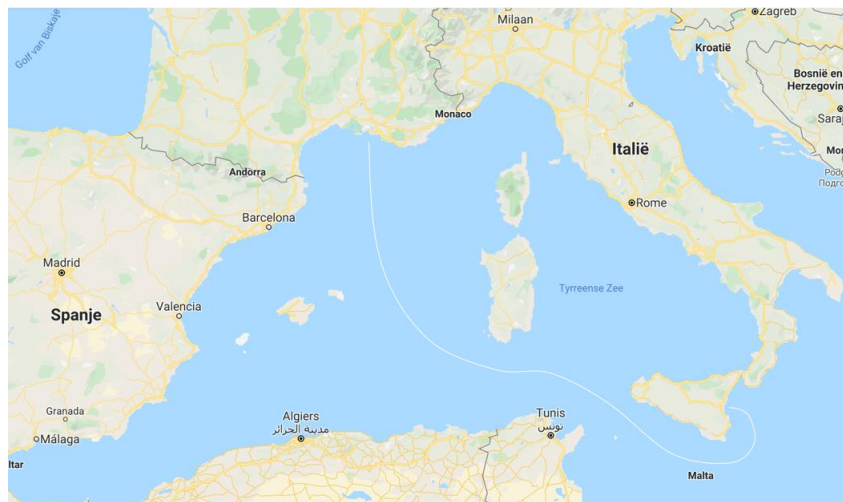


Figure 40 vessel transit from Italy to Port of Marseille

6.2.5 Installation methodology

Below procedure and figure shows the offshore installation sequence of the floating modules to the pre-installed mooring lines. This report considers only the outside of the island configuration consisting of the *Energyhub@Sea* and *Logistics@Sea* floating modules. The full installation procedure can be found in section 8.

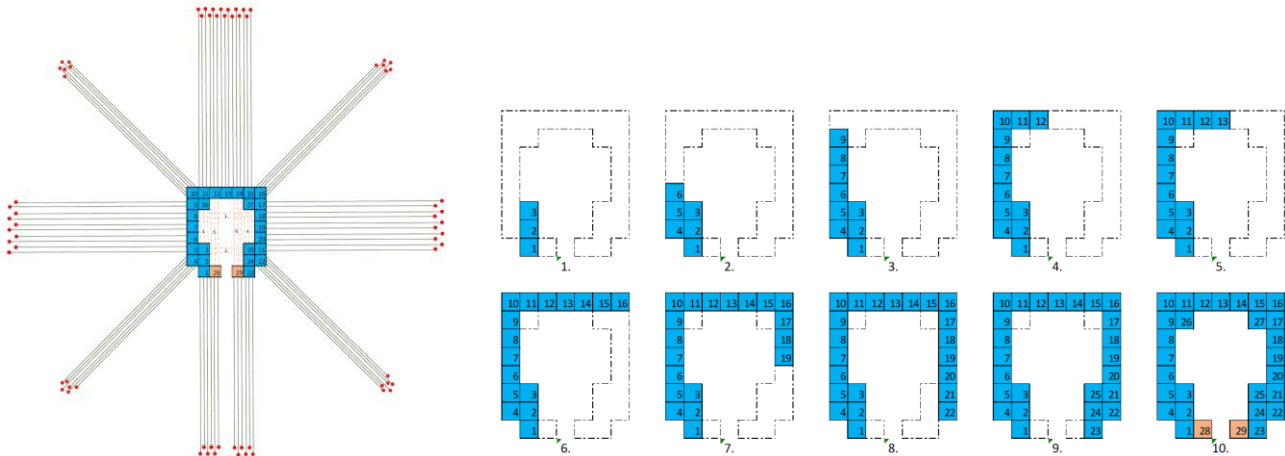


Figure 41 Overview floating modules, permanent mooring lines (black) and temporary mooring lines (orange)

It has been decided to mainly opt for a triple body towage which means that three (3) floating modules will be pre-connected in the marshalling port before towage. Figure 41 shows mainly triple towage and if needed some single towages. Below figure shows the three (3) connected floating modules at marshalling port.

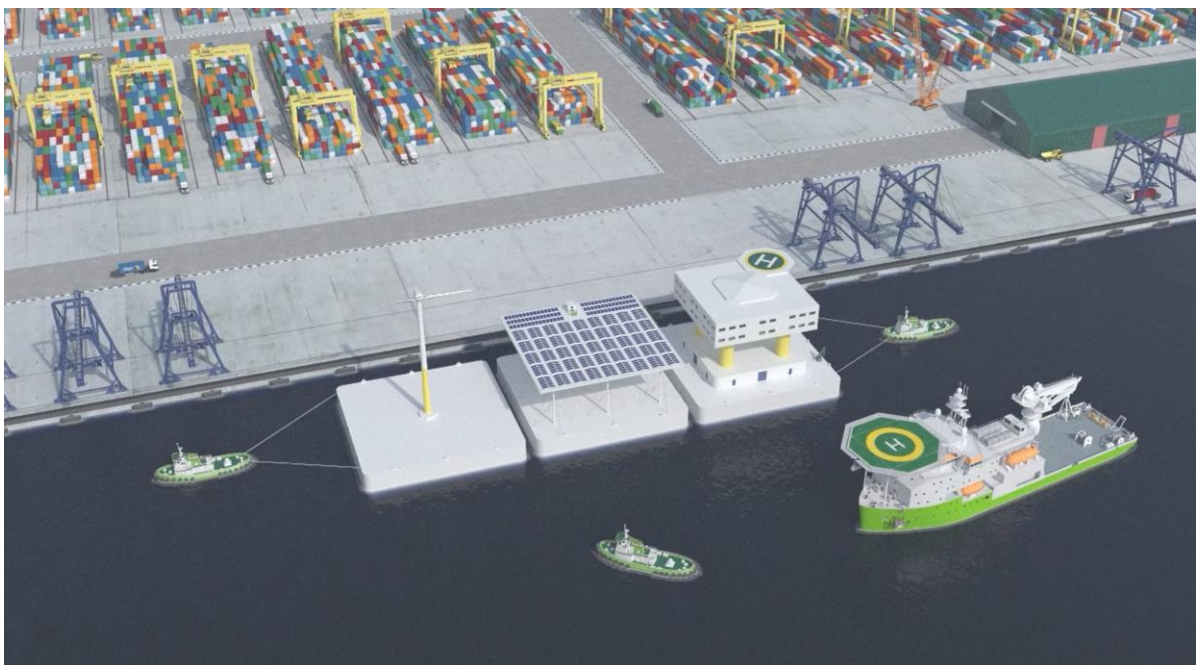


Figure 42 Triple towage (pre-connected at Marshalling Port)

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Two (2) tug boats and an additional support tug will tow the triple body from marshalling port to offshore site with a speed of only five (5) knots. The supporting tug and CSV keep an eye on the connectors and will intervene if something goes wrong.



Figure 43 triple body towage to offshore site

When arriving at the offshore site, the three (3) tugs will manoeuvre the three floating modules to its first location ready to be connected to the pre-installed mooring lines.

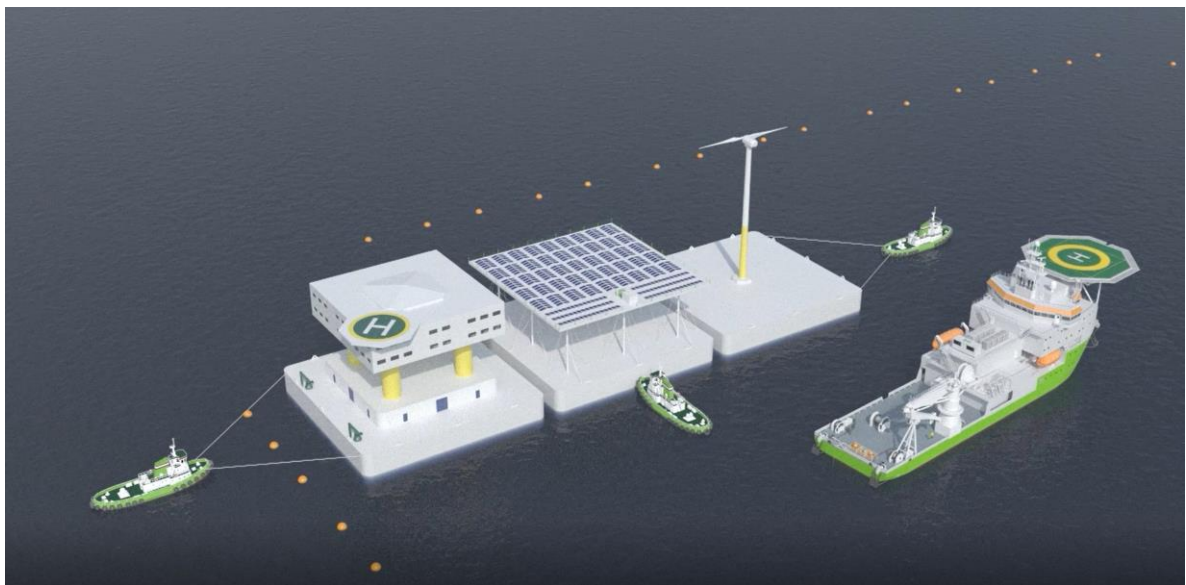


Figure 44 Arriving at offshore site

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The first location with three (3) floating modules will be connected with three (3) mooring lines. In order to keep the modules stable and in place during the installation period, it is required to install auxiliary mooring lines to the module. This is shown in below figure where the black lines represent the mooring lines and the orange lines the preliminary auxiliary lines. These auxiliary lines are steel wires.

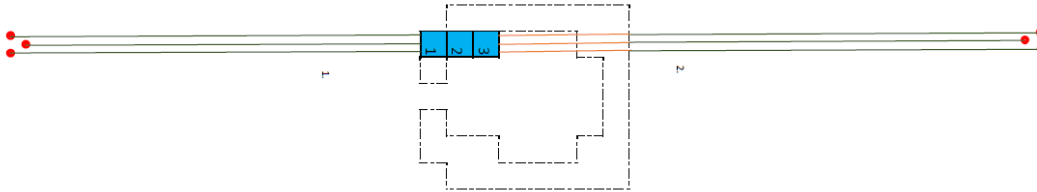


Figure 45 mooring line and auxiliary lines

The CSV will sail to the first buoy in order to pick up the mooring line from the seabed. This buoy was previously installed by HLV Orion during the driving operation of the anchor piles. The steel wire will be connected to the mooring line and pulled towards the floating modules. After the connection of the floating modules with the auxiliary lines, the connection of the pre-installed mooring lines with the floating modules will be executed. The three (3) tugs will sail back to marshalling port to pick up the second triple body.

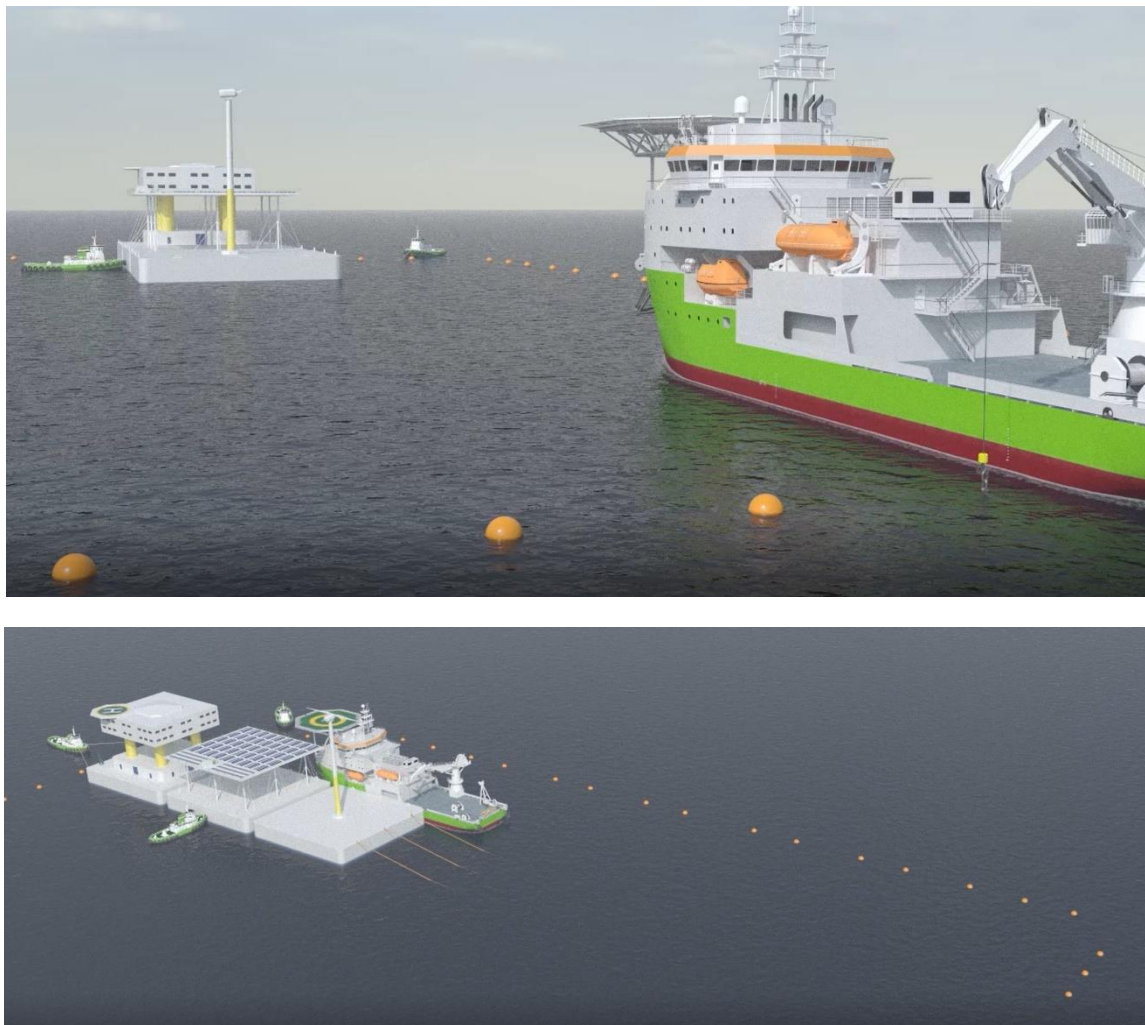


Figure 46 offshore connection of auxiliary line with floating module

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When the second triple body arrives at offshore site, next to the first module, the six (6) floating modules will be connected to each other with the rigid connectors. This report considers the rigid connection (designed by WP 9) as base case for the connection between the floating modules. The offshore assembly of the rigid connection will be done in the following steps;

1. Positioning the modules to be coupled with the help of tugs
2. Temporary mooring between modules using a removable winch and bollards fitted on deck
3. Folding the arms of each connector in the fitting position starting with the lowest one towards the highest one
4. Introduction of the guide bolts into the eyes of the bearings
5. Pulling the bolt with a manual and removable lifting device
6. Locking the bolt through the end plates

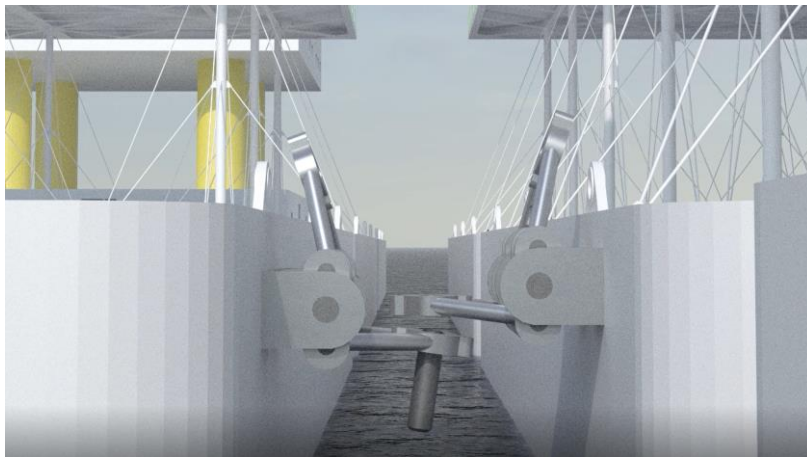
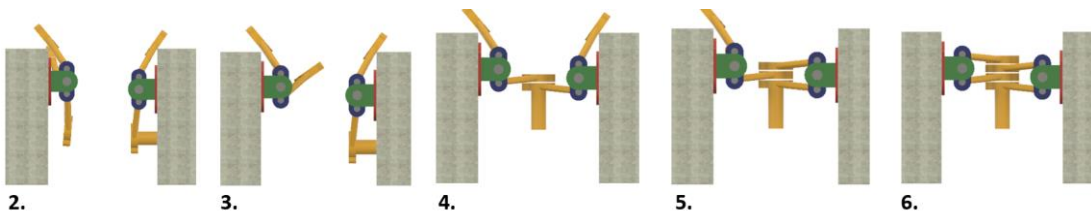
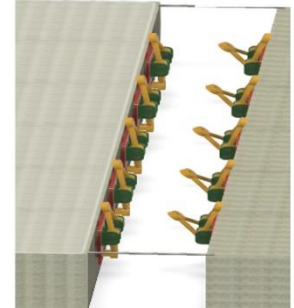
1.

Figure 47 rigid connection between floating modules (WP 9)

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The above procedure is highly sensitive to relative motion of the modules and can therefore only be conducted in small significant wave heights or for short wave periods. An acceptable motion range of neighbouring floating modules than are to be connected should not exceed the size of the bearings.

As can be seen in Figure 48, even for small significant wave heights, combined pitch and roll motion are likely to prevent a safe connection operation for most of the investigated $H_S - T_P$ combinations. However, for wave spectra with peak periods smaller than 6s, a significant reduction in maximum significant response amplitude can be observed. In these sea states, most wave components are shorter than the module dimensions and thus result in less severe motion excitation. For the Mediterranean Sea deployment site, sea states with peak periods of 5s and shorter occur during approximately 50% of the year, as is shown in Table 12. Therefore, while being forced to operate significant wave heights of 0.5m or less for wave periods longer than 6s, a good level of workability may nevertheless be reached as shorter wave periods enable work in significantly higher significant wave heights. This specifically applied to the summer months, when the probability of calm weather is higher and the weather windows during which these conditions are maintained are correspondingly longer.

In case of the triple body installation, a reduction of response may occur due to the increased overall mass of the structure. The effective response will however depend on the relative direction of incoming wave and axis of pre-installed connections. In case of 90° relative angle, the motion will be almost identical to the single body cases, since gap effects have been shown to be of minor importance for small waves. As the orientation of the assembled floaters cannot be adjusted based on the instantaneous wave direction but has to be set according to the installation design and the pre-installed mooring lines, an optimization of encounter angle cannot be guaranteed and the same body response as for single bodies is assumed, as this represents a conservative approach.

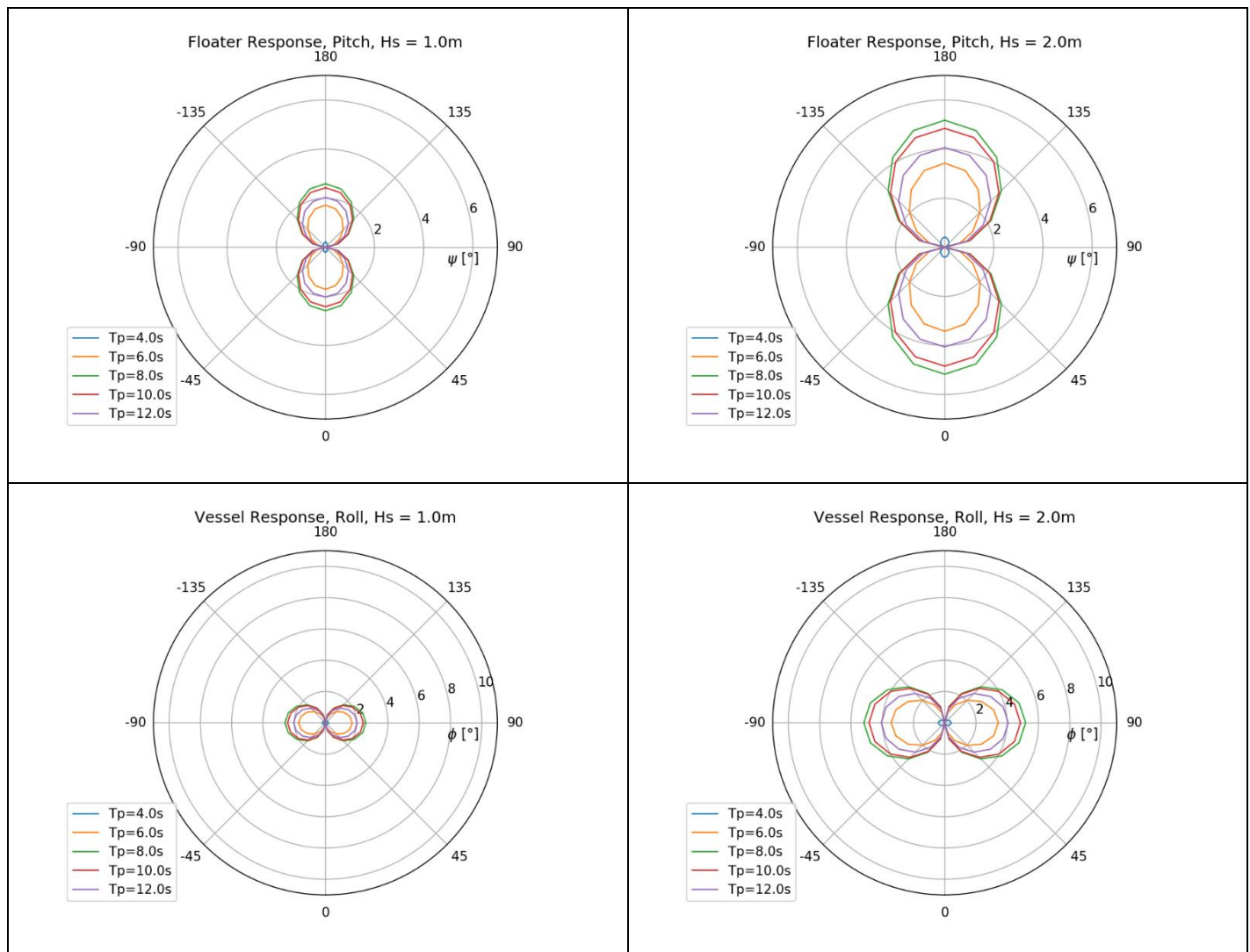


Figure 48: 99.99 Percentile maximum response for Pitch and Roll in two different significant wave heights for a single Space@Sea floater module (WP6 – Accommodation Hub)

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Eventually, two (2) triple floating bodies have been transported and installed offshore. The transport from marshalling port to offshore site, the connection with the pre-installed mooring lines, the installation and connection of auxiliary wires and the rigid connection with the floating modules forms the basis of the towage and offshore installation section.

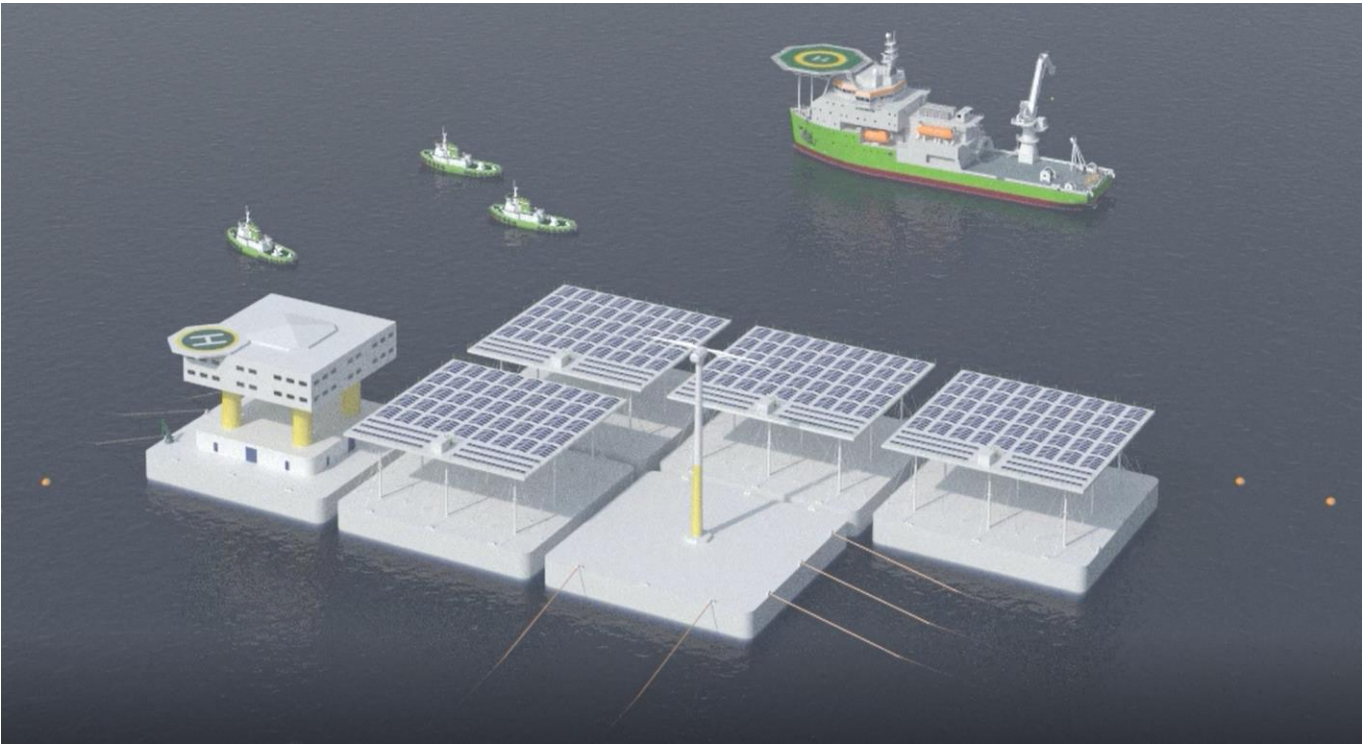


Figure 49 completed connection of floating modules

The total amount of cycles and net duration of towage and offshore installation of the floating modules of the *Energyhub@Sea* and *Logistics@Sea* are provided in below table. Reference is made to Annex 2: T&I schedule with HLV Orion for a complete T&I schedule.

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Table 20 Cycle times of towage and offshore installation of floating modules

Towage and offshore installation – Start date: 07/06/20xx (Mediterranean Sea)		
Activity	Net duration (incl. 90% efficiency)	Repetitions
Towage	311 hours	1
Offshore connection with pre-installed floaters	216 hours	1
Offshore handling with mooring lines	312 hours	1
Deinstallation of auxiliary lines	48 hours	1
Learning curve	24 hours	1
TOTAL	38 days	
Weather down time Q50	+40.5 days minimum*	
Mobilization, transit, demobilization	+39 days	
Project duration Pile installation	01/04/20xx – 06/06/20xx	
Project duration T&I floaters	Start project	15/05/20xx
	Mobilization and transit	15/05/20xx – 06/06/20xx
	Preparation floating modules	07/06/20xx – 13/06/20xx
	Towage and offshore installation	14/06/20xx – 31/08/20xx
	Transit and demobilization	31/08/20xx – 18/09/20xx
	End project	18/09/20xx

*minimum has been taken as it is considered to be more. The above calculation is only based on maximum weather windows of 40 hours as it turns out that work abilities are 0% for longer weather windows. The following installation limit have been taken into account

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q25	33.56%	33.06%	35.04%	31.60%	51.02%	54.65%	56.27%	68.02%	64.07%	44.12%	26.23%	25.67%
0	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Q50	22.13%	20.04%	21.34%	24.93%	37.11%	44.17%	43.00%	56.32%	43.36%	31.35%	0.00%	0.00%
Q75	0.00%	0.00%	0.00%	0.00%	24.04%	32.63%	33.17%	42.71%	28.67%	0.00%	0.00%	0.00%
Q90	0.00%	0.00%	0.00%	0.00%	0.00%	25.79%	6.50%	23.68%	0.00%	0.00%	0.00%	0.00%

Figure 50 Weather down times during towage and offshore installation

Activity	Max. transport & installation limits
Towage	2m Hs wave height and 15m/s wind speed
Offshore connection with pre-installed floaters	Only 0.5m Hs wave height (based on input WP9)
Offshore handling of mooring lines, auxiliary lines	1.5m Hs wave height and 15m/s wind speed

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Below table shows detailed information on the towing and offshore installation procedure;

Table 21 detailed overview on towing and offshore installation

	Details offshore connection with pre-installed floaters / mooring lines		
Floater	Activity	Net duration	Island setup
#1 - #3	Towage 1 st set of floaters	24 hours	<i>Energyhub@Sea</i>
#1 - #3	Positioning 1 st set of floaters	24 hours	<i>Energyhub@Sea</i>
#1 - #3	Handling of 6 mooring lines (and 3 auxiliary lines) with 1 st set of floaters	27 hours	<i>Energyhub@Sea</i>
#1 - #3	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+82 hours	
#4 - #6	Towage 2 nd set of floaters	24 hours	<i>Energyhub@Sea</i>
#4 - #6	connection 2 nd set of floaters to pre-installed floaters (1 st set)	24 hours	<i>Energyhub@Sea</i>
#4 - #6	Handling of 12 mooring lines (and 2 auxiliary lines) with 2 nd set of floaters	42 hours	<i>Energyhub@Sea</i>
#4 - #6	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+97 hours	
#7 - #9	Towage 3 rd set of floaters	24 hours	<i>Energyhub@Sea</i>
#7 - #9	connection 3 rd set of floaters to pre-installed floaters (2 nd set)	12 hours	<i>Energyhub@Sea</i>
#7 - #9	Handling of 8 mooring lines (and 2 auxiliary lines) with 3 rd set of floaters	30 hours	<i>Energyhub@Sea</i>
#7 - #9	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+73 hours	
#10 - #12	Towage 4 th set of floaters	24 hours	<i>Energyhub@Sea</i>
#10 - #12	connection 4 th set of floaters to pre-installed floaters (3 rd set)	12 hours	<i>Energyhub@Sea</i>
#10 - #12	Handling of 9 mooring lines (and 3 auxiliary lines) with 4 th set of floaters	36 hours	<i>Energyhub@Sea</i>
#10 - #12	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+79 hours	
#13	Towage 5 th set of floater: single floater	14 hours	<i>Energyhub@Sea</i>
#13	connection 5 th set of floaters to pre-installed floaters (4 th set)	12 hours	<i>Energyhub@Sea</i>
#13	Handling of 0 mooring lines (and 0 auxiliary lines) with 5 th set of floaters	0 hours	<i>Energyhub@Sea</i>
#13	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+33 hours	
#14 - #16	Towage 6 th set of floaters	24 hours	<i>Energyhub@Sea</i>

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#14 - #16	connection 6 th set of floaters to pre-installed floaters (5 th set)	12 hours	<i>Energyhub@Sea</i>
#14 - #16	Handling of 18 mooring lines (and 3 auxiliary lines) with 6 th set of floaters	63 hours	<i>Energyhub@Sea</i>
#14 - #16	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+106 hours	
#17 - #19	Towage 7 th set of floaters	24 hours	<i>Energyhub@Sea</i>
#17 - #19	connection 7 th set of floaters to pre-installed floaters (6 th set)	12 hours	<i>Energyhub@Sea</i>
#17 - #19	Handling of 4 mooring lines (and 2 auxiliary lines) with 7 th set of floaters	18 hours	<i>Energyhub@Sea</i>
#17 - #19	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+61 hours	
#20 - #22	Towage 8 th set of floaters	24 hours	<i>Energyhub@Sea</i>
#20 - #22	connection 8 th set of floaters to pre-installed floaters (7 th set)	12 hours	<i>Energyhub@Sea</i>
#20 - #22	Handling of 8 mooring lines (and 2 auxiliary lines) with 8 th set of floaters	30 hours	<i>Energyhub@Sea</i>
#20 - #22	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+73 hours	
#23 - #25	Towage 9 th set of floaters	24 hours	<i>Energyhub@Sea</i>
#23 - #25	connection 9 th set of floaters to pre-installed floaters (8 th set)	24 hours	<i>Energyhub@Sea</i>
#23 - #25	Handling of 0 mooring lines (and 4 auxiliary lines) with 9 th set of floaters	12 hours	<i>Energyhub@Sea</i>
#23 - #25	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+67 hours	
#26	Towage 10 th set of floaters	14 hours	<i>Energyhub@Sea</i>
#26	connection 10 th set of floaters to pre-installed floaters (3 rd and 4 th sets)	24 hours	<i>Energyhub@Sea</i>
#26	Handling of 0 mooring lines (and 3 auxiliary lines) with 10 th set of floaters	9 hours	<i>Energyhub@Sea</i>
#26	Towage empty to marshalling port	7 hours	<i>Energyhub@Sea</i>
		+54 hours	
#27	Towage 11 th set of floaters (SIMOP with #26)	(14 hours)	<i>Energyhub@Sea</i>
#27	connection 11 th set of floaters to pre-installed floaters (6 th and 7 th sets)	24 hours	<i>Energyhub@Sea</i>
#27	Handling of 0 mooring lines (and 3 auxiliary lines) with 11 th set of floaters	9 hours	<i>Energyhub@Sea</i>
#27	Towage empty to marshalling port (SIMOP with #26)	(7 hours)	<i>Energyhub@Sea</i>
		+33 hours	
#28	Towage 12 th set of floaters	14 hours	<i>Logistics@Sea</i>

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#28	connection 12 th set of floaters to pre-installed floaters (1 st set)	12 hours	<i>Logistics@Sea</i>
#28	Handling of 3 mooring lines (and 3 auxiliary lines) with 12 th set of floaters	18 hours	<i>Logistics@Sea</i>
#28	Towage empty to marshalling port	7 hours	<i>Logistics@Sea</i>
		+51 hours	
#29	Towage 13 th set of floaters (SIMOP with #28)	(14 hours)	<i>Logistics@Sea</i>
#29	connection 13 th set of floaters to pre-installed floaters (9 th set)	12 hours	<i>Logistics@Sea</i>
#29	Handling of 3 mooring lines (and 3 auxiliary lines) with 13 th set of floaters	18 hours	<i>Logistics@Sea</i>
#29	Towage empty to marshalling port (SIMOP with #28)	(7 hours)	<i>Logistics@Sea</i>
		+30 hours	
	SUBTOTAL	839 hours	35.0 days
Rest	De-installation of auxiliary lines	+48 hours	
Rest	Learning curve	+24 hours	
	TOTAL	911 hours	38 days

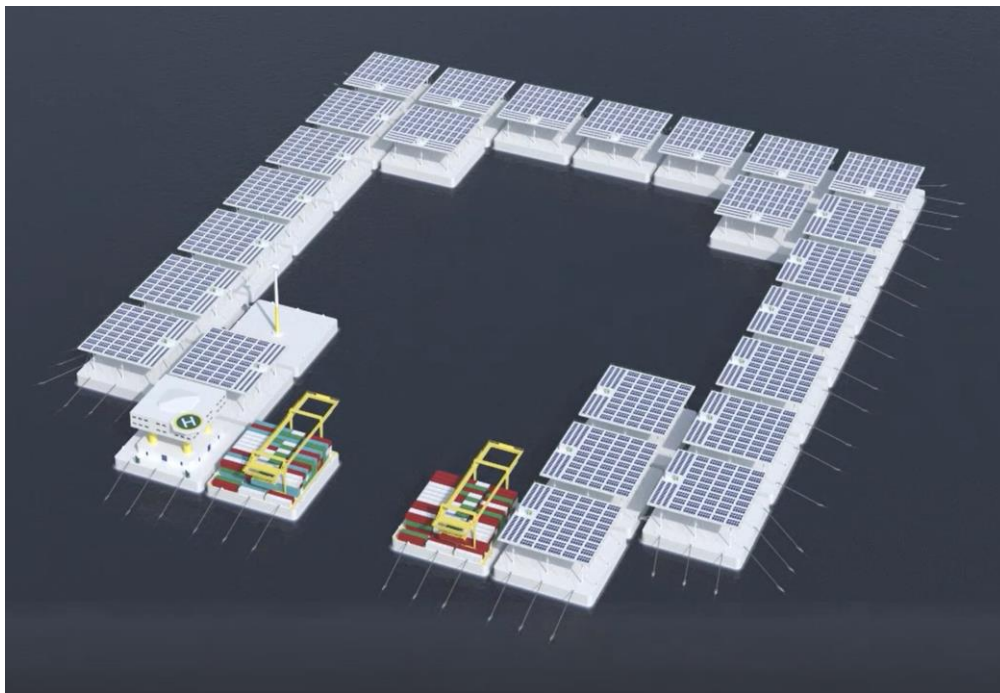


Figure 51 *Energyhub@Sea* and *Logistics@Sea*

Conclusion: It takes around **3 months** for transporting and installing the floating modules of the *Energyhub@Sea* and *Logistics@Sea* at the offshore site of the Mediterranean Sea. Based on the data of the rigid connection from Work Package 9, it is assumed that the floating modules can only be installed during a suitable sea state of 0.5m wave height and calm weather. However, such a low wave height does not exist for long time windows, resulting in extreme low work abilities. Therefore, it is suggested by the authors of this report that the offshore installation limits of the rigid connection should be revised and optimized to higher sea levels.

6.3 High level (T&I) manual – *Space@Sea* Mediterranean Sea configuration

The above sections concludes that it takes around **2 months** for installing the anchor piles and an additional **2.5 months** for transporting and installing 29 floating modules, consisting of 27 modules of *Energyhub@Sea* and 2 additional modules of *Logistics@Sea*. The installation of these two (2) island setups can be combined with the piling operation as the total project time matches the good weather window. However, it is highly recommended to install the rest of the island setups (*Living@Sea*, *Farming@Sea*, *WEC*) during the good weather period of the next year 20xx+1 (ref.5.2.1, scenario I) to reduce the amount of weather delays drastically. Below Figure 52 shows the installation procedure in year 20xx (focus islands) and Figure 53 shows the installation procedure of 20xx+1 for the other islands.

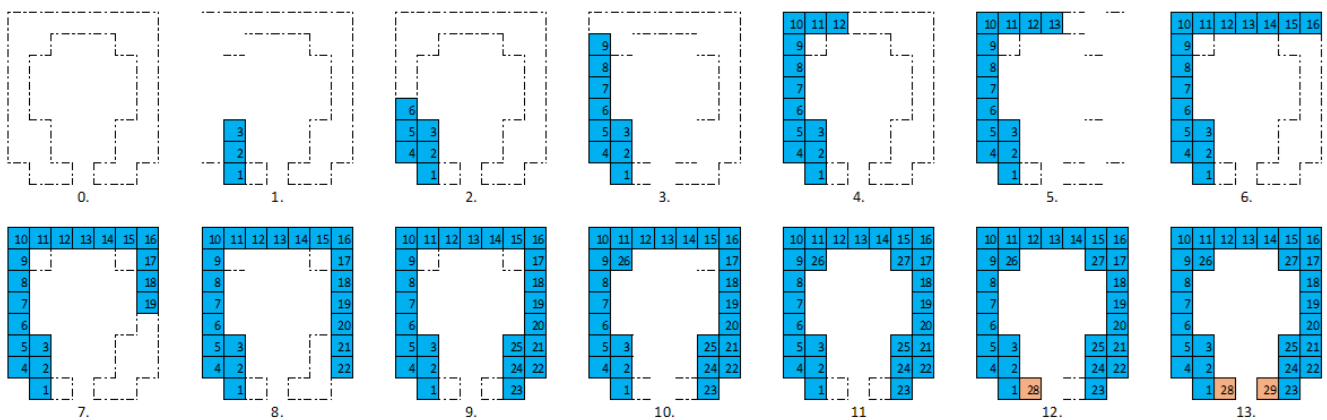


Figure 52 Installation setup *Energyhub@Sea* (blue) and *Logistics@Sea* (orange)

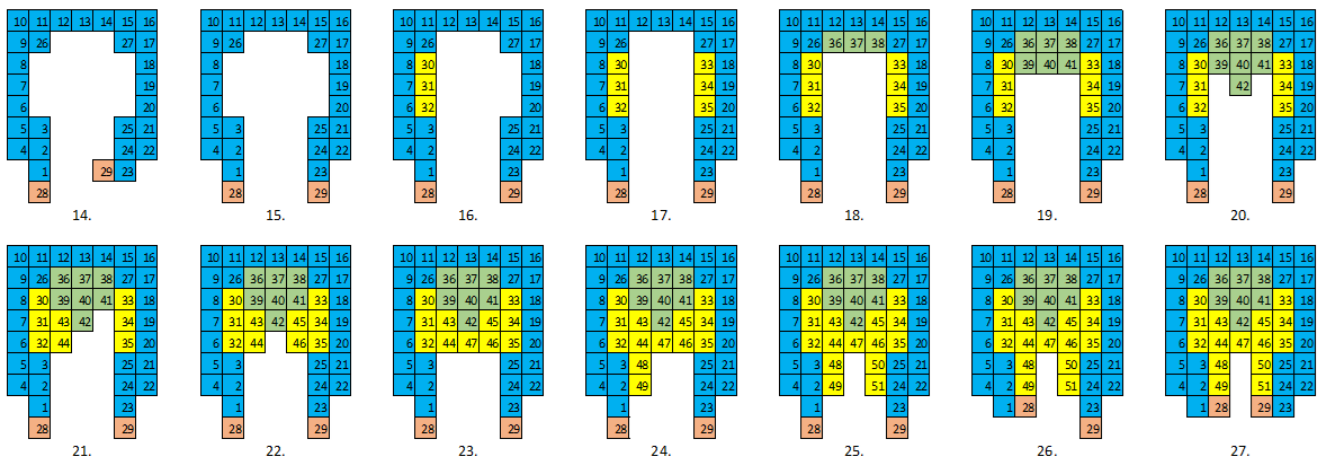


Figure 53 Installation setup other setups *Living@Sea* (green) and *Farming@Sea* (yellow)

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After installation of all floating setups, the project will be finalized with the installation of the Wave Energy Converters (WEC) around the outside of the island and is shown in below figure.

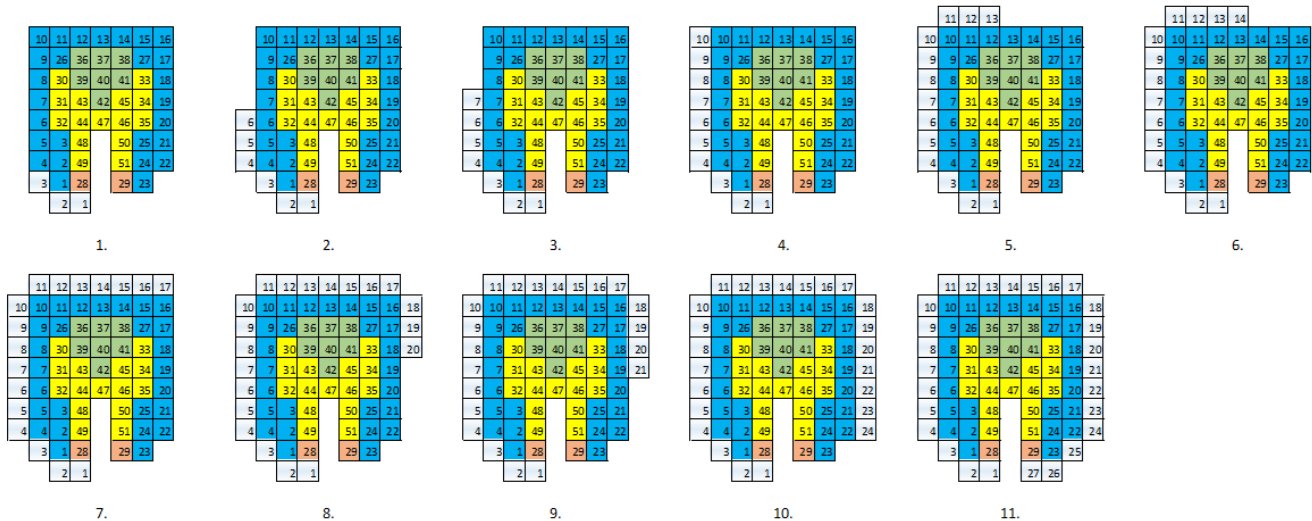


Figure 54 installation of the WEC

Below table shows an overview on the total durations of the installation of the full island configurations of the Mediterranean Sea. This table does not include the durations for mobilization and demobilizations of vessels.

Table 22 offshore operations project durations

Offshore operation	Start date	End date	Project duration
Driving operation (71 piles)	01/04/20xx	06/06/20xx	± 2 months
Towage and offshore installation <ul style="list-style-type: none"> - <i>Energyhub@Sea</i> (27) - <i>Logistics@Sea</i> (2) 	07/06/20xx	31/08/20xx	± 3 months
Towage and offshore installation <ul style="list-style-type: none"> - <i>Living@Sea</i> (7) - <i>Farming@Sea</i> (15) 	01/04/20xx+1	31/05/20xx+1	± 2 months
Towage and offshore installation <ul style="list-style-type: none"> - <i>WEC</i> (27) 	01/06/20xx+1	01/08/20xx+1	± 2 months
TOTAL transport & installation time			± 9 months

The towage and offshore installation in 20xx+1 requires an extra offshore activity by removing one (1) *Logistics@Sea* module in order to create space for entering the site. This means that floating module nr. 28 will be disconnected from floating module 1 and tentatively connected to the other side of module 1 (from east to south). Subsequently, module nr. 29 will be tentatively moved and connected to module nr. 23 (from west to south). Due to its modularity of the floating island, this extra procedure should not form any problem.

6.4 High level (T&I) Manual – North Sea

6.4.1 Marine equipment

Due to the shallow waters in the North Sea, a Jack Up Vessel (JUV) can be used for the installation of the anchor points. DEME's Jack up Vessel "Innovation" is suitable to perform the offshore works due its high crane capacity (1500 mT) and large deck space. The technical leaflet is provided in Annex 4: Technical leaflet JUV Innovation DEME



Figure 55 Jack Up Vessel Innovation (DEME)

6.4.2 Mobilization and transit

Like with HLV Orion, also JUV Innovation will be mobilized from the port of Vlissingen, the Netherlands. All required installation equipment will be installed on deck of the vessel. In general, it takes around two (2) weeks to make the vessel ready for execution. The same installation equipment is required as the Mediterranean sea configuration. Due to the fact that the mobilization port is very close to the marshalling port (ref. 3) the transit days are neglectable.

6.4.3 Load out at marshalling port and transit to offshore site

Reference is made to section 3.4 where the Port of Antwerp has been selected as marshalling port. JUV Innovation will enter the port, jack up and load out all the required structures and leaves the port. It has been assumed that the vessel is able to enter, jack up and leave this selected port. The time for loading out the piles on board of the vessel has been included in the cycle time calculations. The start of the load out procedure indicates the start of the entire installation period.

6.4.4 Installation methodology

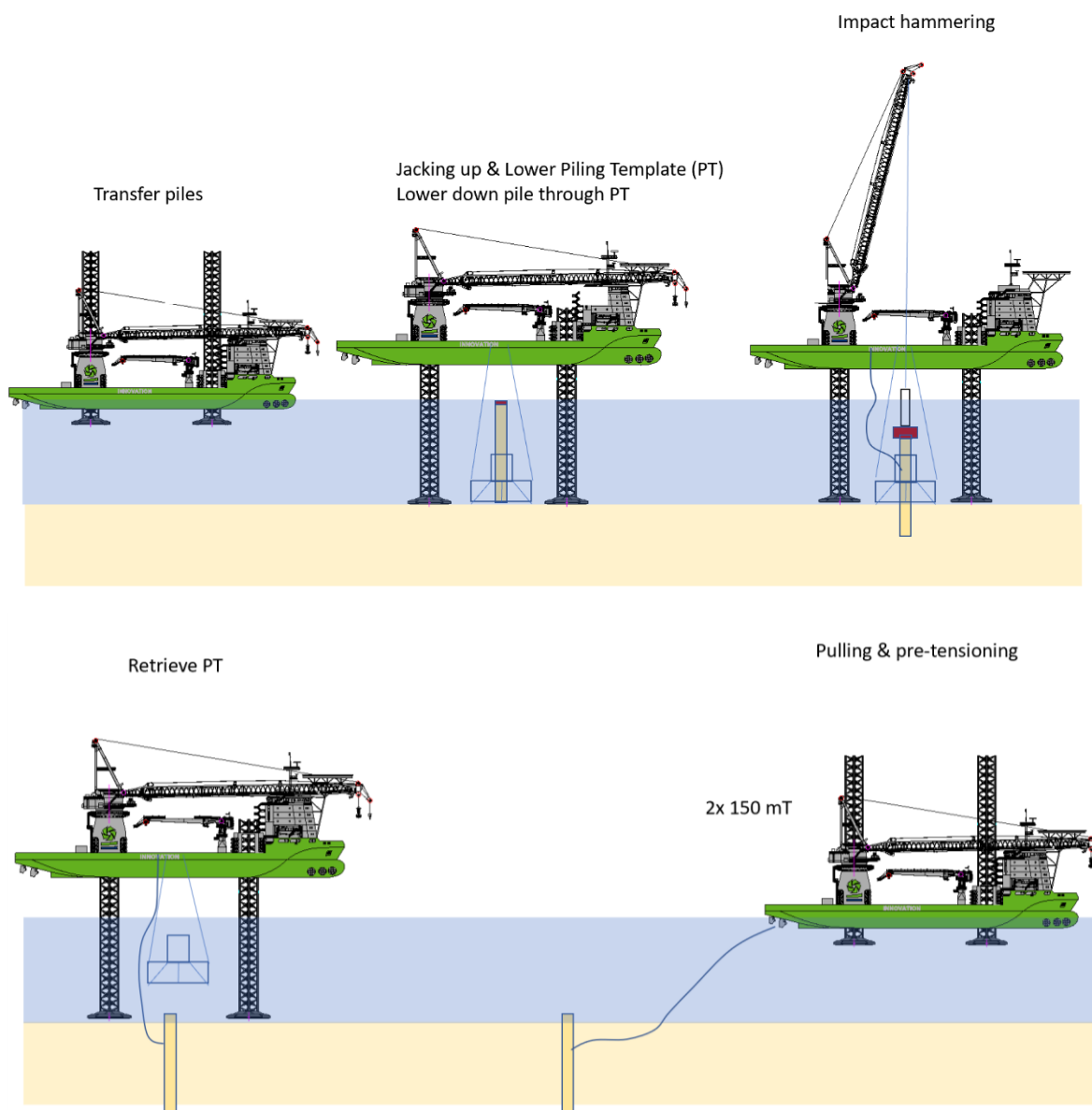


Figure 56 installation methodology with a jack up vessel

D5.1 T&I Manual*Table 23 cycle times JUV Innovation with impact hammering*

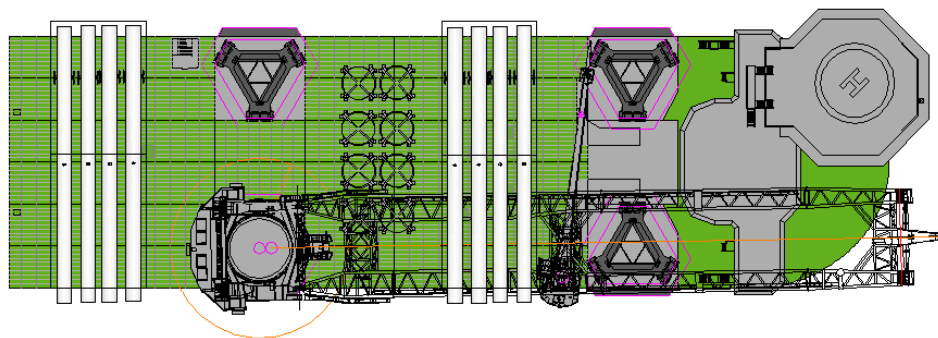
JUV Innovation with Impact hammering – Start date: 01/05/20xx (North Sea)		
Activity	Net duration (incl. 90% efficiency)	Repetitions
Enter the port	5.6 hours	9
Lifting 8 piles and mooring lines	5 hours	9
Sea fastening & leaving port	5.3 hours	9
Sailing to site	7.1 hours	9
Offshore execution works	16.4 hours	71
Sailing to port	6.5 hours	9
TOTAL	60.5 days (including 1 day learning curve)	
Weather down time Q50 (Figure 33)	+5 days	
Mobilization, transit, demobilization	+ 24 days (no transit)	
Total Project duration	01/05/20xx – 01/08/20xx	
Δ with floating installation and vibro-hammering	± 35 days more	

Amount of vessels required

- 1x Jack Up Vessel Innovation
- 1x Bubble Curtain Vessels (Noise mitigation during impact hammering)

Extra required installation equipment compared to HLV Orion

- Impact Hammer
- Piling Template (custom made)

*Figure 57 high level deck lay out JUV Innovation (indicative)*



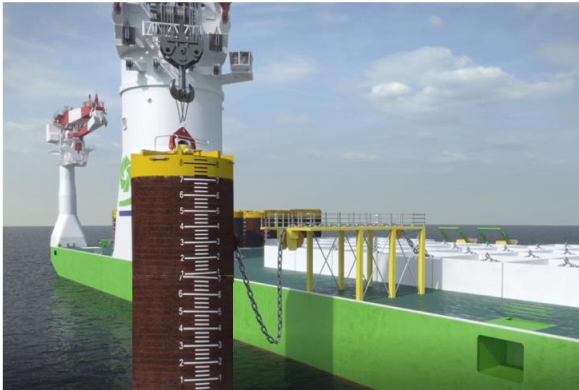
7. Conclusions

The following techno-economical conclusions and recommendations have been made based on the above provided data and calculations.




1. The new driving technology “**vibro-piling**” has been selected as the most appropriate installation technique. This state-of-the-art technology minimizes the amount of offshore handling which results in faster installation time and reduces the amount of installation equipment, resulting in less investments. The **difference in project duration is approximately two (2) weeks**.
2. A **Heavy Lift Vessel (HLV)** has been selected as the most appropriate vessel for driving the anchor piles in the seabed of the Mediterranean Sea. This type of vessel has a faster installation time and minimizes the amount of vessel in the field to only one (1). Compared to an Offshore Construction Vessel, this vessel type is approx. **20 days faster in installation**. The total cost for both approaches is similar in favor of HLV.
3. For **towage and offshore installation**, it has been concluded that three anchor handling (3) tugs and one (1) offshore construction vessel is required. It takes around **3 months** for towing and installing the floating modules of *Energyhub@Sea* and *Logistics@Sea*. The long duration for offshore installation is caused by the very low work abilities by connection the floaters to each other. The towage and offshore installation of the full configuration is approx. **7 months**.
4. Applying the **rigid connection** between the floaters generates a large amount of weather delays due to its limited sea state limit. It is recommended to WP9 to re-consider the offshore installation limit of 0.5m wave height. A more flexible connection will reduce the amount of weather delays significantly and reduces the total cost of installation.
5. Based on conclusion nr.4 it has been decided to perform as much as possible **triple towage**, which means that three (3) floating modules will be connected to each other at the marshalling port. This improves the installation time and reduces the weather delays and its associated costs.
6. The transport and installation of the **full island configuration of the Mediterranean Sea**, consisting of the pile & mooring line installation and towage & offshore installation of the floating module, takes approximately 11 months including the mobilization and demobilization. Due to this long period of transport & installation, it is highly appreciated to consider planning scenario I, which divides the offshore works over two (2) years during the good weather windows.
7. The transport and installation of the **North Sea configuration** implies a Jack up Vessel due to its shallow waters and impact hammering due to its rougher soil type. This will result in longer installation times and more cost. **It takes 35 days more** for installing the anchor piles compared to HLV Orion with vibro-hammering.
8. It is recommended to use the 45 by 45m configurations in order to keep the island modular. Applying the 90 by 90m configurations require larger vessels and limits the amount of (nearby) marshalling ports which makes the project less flexible during T&I and O&M.

8. Annex


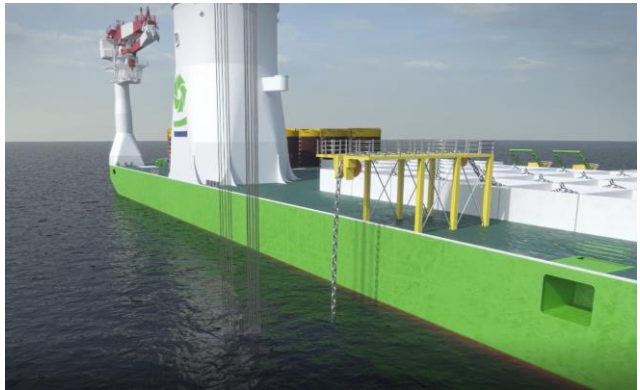
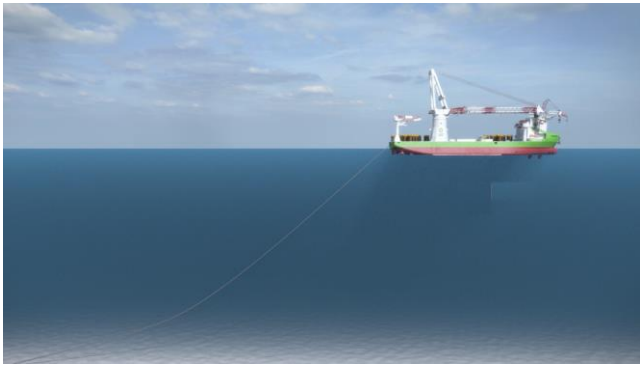
Annex 1: Installation manual HLV Orion with impact hammering

1	HLV Orion leaves the marshalling port after loading foundations on deck and sails to offshore site	
2	Arriving at the offshore site, HLV Orion manoeuvres on dynamic positioning to its first installation location. The main crane will be unseafastened and the deck is prepared for its first installation activity.	
3	<p>The main crane of the HLV lifts off the Piling Template (PT) and lowers it down on the seabed. ROV's will assist this operation by providing real-time video.</p> <p>Depending on the condition of the seabed, the template will level itself out in order to be stable and to ensure the verticality of the driven pile.</p>	
4	<p>The main crane will upend the piles from its horizontal position by using an internal lifting tool and upending cradle.</p> <p>After upending, the pile will be moved sideward and lowered down to the seabed</p>	

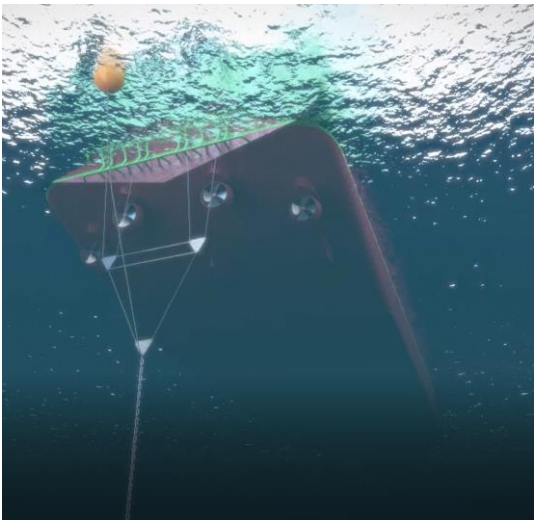

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5	<p>The foundation pile will be lowered down through the sleeve of the PT until it touches the seabed.</p> <p>The pile will softly penetrate the seabed a few meters due its own weight.</p> <p>The PT sleeve will clamp the pile to ensure it remains at place during procedure 6. The PT can adjust the inclination of the pile if needed.</p>	
6	<p>The internal lifting tool will release its grip and will be retrieved by the main crane on deck. The tool will be disconnected and the impact hammer will be connected.</p> <p>The hammer will be lowered down to the pile</p>	
7	<p>The impact hammer will connect with the top part of the pile and starts its driving operation.</p> <p>Once the impact hammer reaches the PT, the sleeve will open automatically to ensure the pile can be driven to final depth without the PT blocking the operation.</p> <p>The piles will be driven below the seabed. No pile stick up is required.</p>	

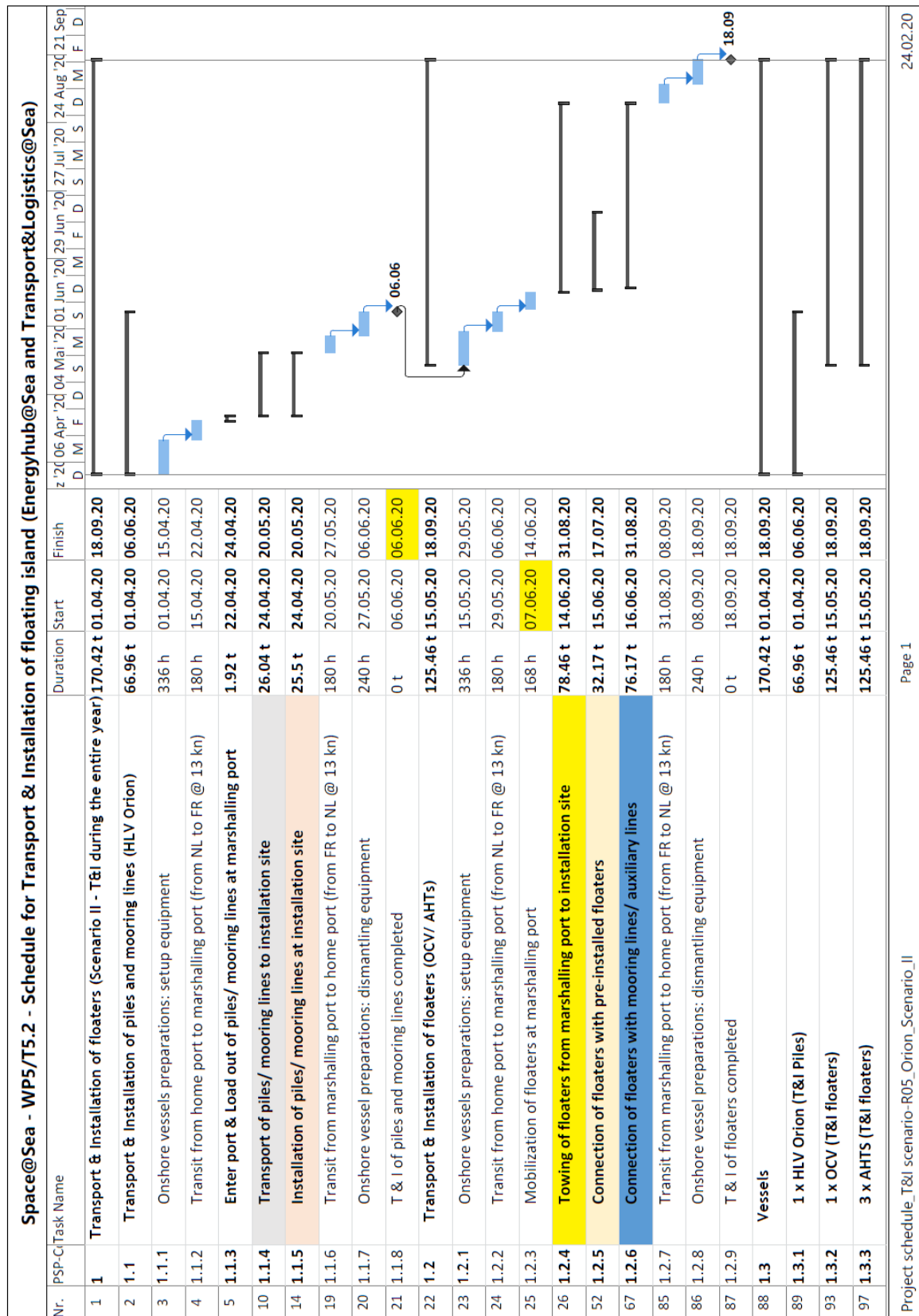
D5.1 T&I Manual

8	<p>Once the pile is driven into the seabed, the impact hammer will be disconnected and retrieved back on deck</p> <p>The piling template will be retrieved back on deck.</p>	
9	<p>After retrieving the PT, the remaining part of the 750m long catenary line will be lowered down as preparation for procedure 10.</p>	
10	<p>Once the full catenary line has been winched down in the water, HLV Orion will pull the catenary line with heavy force because the first part of the catenary (so called inverse catenary) is driven in the seabed.</p>	

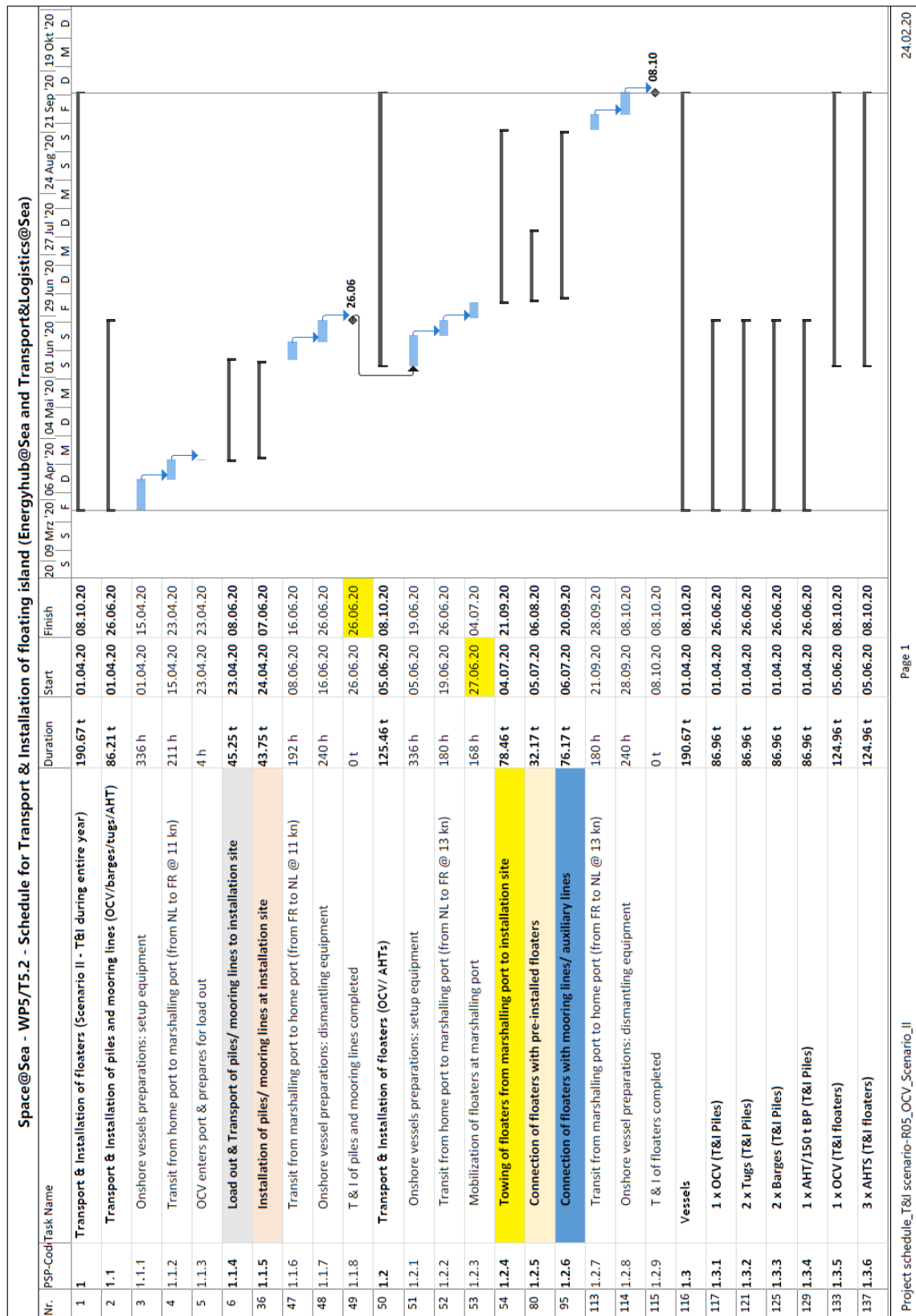
D5.1 T&I Manual

11	<p>At final position, 750m away from the anchor point, HLV Orion will lower down the catenary line on the seabed and installs a buoy system to mark its position for the connection with the floating modules.</p>	
12	<p>HLV Orion moves to the next location and starts again with procedure nr. 1.</p>	

Annex 2: T&I schedule with HLV Orion



Annex 3: T&I schedule with OCV



Annex 4: Technical leaflet JUV Innovation DEME

Innovation
OFFSHORE HEAVY LIFT DP2 JACK-UP VESSEL

CONSTRUCTION YEAR	2012
TYPE	Offshore Heavy Lift DP2 Jack-Up Vessel
CLASSIFICATION	Germanischer Lloyd



www.deme-group.com

MAIN DIMENSIONS	length breadth depth	147.50 m 42.00 m 11.00 m
JACKING SYSTEM	type capacity pre load speed leg length	Electrical Rack & Pinion 31,440 ton 4 x 18,180 ton 1.0 m/min 89.00 m
CRANE	capacity	1,500 ton
POWER & PROPULSION	dynamic positioning propulsion installed power	L3 DP2 4 x 3,500 kW Azimuth Thrusters 4 x 2,800 kW Tunnel Thrusters 28,620 kW
OPERATIONAL CONDITIONS	pay load (max) free deck area operating draft (max)	8,000 ton 3,400 m² 7.30 m
OTHER	accommodation helideck moonpools auxiliary crane	100 persons installed optional 40 ton, manriding

Annex 5: Technical leaflet HLV Orion DEME

Orion
OFFSHORE HEAVY LIFT DP3 INSTALLATION VESSEL

CONSTRUCTION YEAR	Under construction
TYPE	Offshore Heavy Lift DP3 Installation Vessel
CLASSIFICATION	Det Norske Veritas & Germanischer Lloyd



www.deme-group.com



MAIN DIMENSIONS	length breadth depth	216.50 m 49.00 m 16.80 m
CRANE	capacity	3,000 ton at 57 m 5,000 ton at 35 m
POWER & PROPULSION	dynamic positioning propulsion installed power	DP3 4 x 4,500 kW Azimuth Thrusters 2 x 4,200 kW Retractable Thrusters 2 x 2,500 kW Tunnel Thrusters 44,180 kW (Dual Fuel)
OPERATIONAL CONDITIONS	pay load (max) free deck area operating draft (max)	30,000 ton 8,000 m ² 11.00 m
OTHER	accommodation helideck moonpools auxiliary crane other	131 persons (extendable to 239 persons) installed space claim for 19,6 m x 10,5 m 2 x 100 ton, knuckle boom, manriding 8 points mooring system