Department of Mechanical and Aerospace Engineering

Alternative Installation Methods for Offshore Wind Substations

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Signed: Justo Aguiar Quintana Date: 27/08/2016

Abstract

The aim of this project is to investigate the feasibility of alternative installation methodologies for offshore substations in order to drive the cost of the offshore wind down.

Current installation methodologies rely on hiring expensive heavy lift vessels. For this project it has been proposed the following alternative installation methodologies which will not depend on a lifting operation as the float-over, Self-Elevating Unit, Self-Elevating Unit assisted by barge and a Semisubmersible.

For each methodology was carried out a technical assessment for the fabrication and installation stages. The fabrication assessment was based on special requirements of manufacturing facilities, cost steel, man hours and special equipment. Also, an installation assessment was performed based on weather restrictions, vessels required and complexity of the installation activities for each concept. A score matrix was used to obtain a preferable concept.

Furthermore, an economic analysis was carried out to contrast technical feasibility with economic feasibility. Afterwards the Float-over resulted on the most expensive concept while the semisubmersible was technically more reliable than any of the other concepts.

Acknowledgements

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1 INTRODUCTION

Most of the countries in Europe have set the goal of a reduction of 20% greenhouse gas emissions, 20% of energy coming from sustainable sources and 20% of improvement of the energy efficiency (1). It is known as the “European 20 – 20 – 20 Targets”. In this scenario, offshore wind energy has an important role to play in order to achieve such a target. However, still is a source of energy which is expensive and in many cases requires help of the governments, as an example in UK, through Contract of Difference (2). In spite of this, the offshore wind business has been growing for the last decade.

1.1 Offshore Wind Farms

An Offshore wind farm will be composed of wind turbines which will be mounted on floating solutions (TLP, Spar and Semisubmersible), steel jackets, monopiles or gravity bases, this different type of foundations will depend on the depth where the wind farm is located. The export of power from the individual turbines will take place via the inter-array cable to the offshore substation located within the wind farm. From the OSS one or two export cables, according to the capacity of the wind farm, will take the power to the onshore substation.

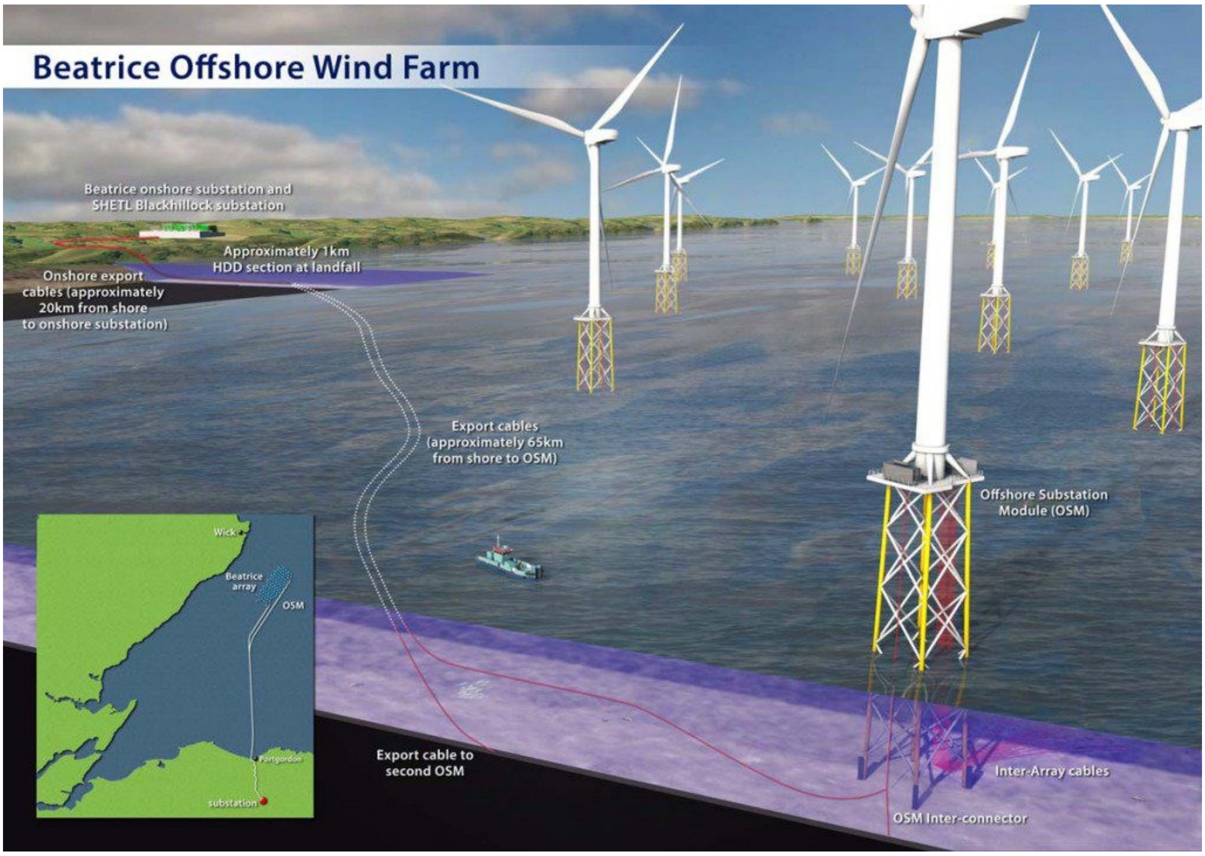

Figure 1: Beatrice Offshore Wind Farm (3)

1.2 Offshore Substation

An offshore substation is an offshore platform which collects the power from each wind turbine from the wind farm and take it to the onshore substation through the export cable as afore mentioned. Most of the offshore substations comprise topside and jacket.

- Topside: the structure of the topside will depend on the project. Most likely it will have four decks: cable deck, main deck, utility deck and roof deck (see figure 2). The main equipment of the topside is helipad, transformers, reactors, switchgear, pedestal crane, water tanks, cable supports, platform access, accommodation and control room.
- Jacket: the structure which supports the Topside. The jacket could have 3, 4 or 6 legs and their main components are transition piece which provide boat landing and access to the platform, legs, bracings, j-tubes, piles sleeves, piles and mud mat

Figure 2: Anholt Offshore Substation (4)

1.3 Purpose

The purpose of this project is to reduce the cost of the most usual installation method for Offshore Substations in the offshore wind which is based on lifting operations and the consequent heavy lift vessel bottle neck

Within the project, three main OSS installation methodologies have been proposed.

- Float Over: Topside installed by ballasting the transportation barge on a jacket which will be installed by launching avoiding any costly lifting operation (alternatives jacket installation methodologies are also described).
- Self-elevating Units: proposing two different installation methods. A method based on the concept of a traditional SEU and a second method, a SEU assisted by barge. Both concepts are designed with a submerged jackets/template as foundation reducing the weight of the foundation and reducing the lifting capacity needed for the lifting operations.

- Floating solutions: focusing in semisubmersible platforms.

1.4 Scope of Work

This project describes the technical and economical assessment performed to address the most suitable installation methodology, based on economic scenarios determined for this purpose.

For each of the installation concepts, the work performed in this report includes the following points:

- Description of fabrication, sea-deployment, transport and installation
- Risk assessment analysing the risk involves on the transportation and installation of each solution proposed
- Cost evaluation of fabrication, sea-deployment, transport and installation

For this project, there is not any design of an OSS. Therefore, this technical and economic study is just a preliminary analysis based on assumptions.

1.5 Dissertation structure

- Chapter 1: Introduction. Summarise the aim, scope and structure of the present project. Including a brief description of the items analysed in this project
- Chapter 2: Float-over. Describes the jacket and topside fabrication, sea deployment, transport and installation for this installation method. Including a description and brief analysis of alternative jacket installation methods
- Chapter 3: Self elevating unit. Describes the SEU fabrication, sea deployment, transport and installation for this installation method emphasising the possible differences with the alternative proposed for this concept, SEU assisted by barge.
- Chapter 4: Semisubmersible. Describes the Semisubmersible fabrication, sea deployment, transport and installation for this installation method
- Chapter 5: Installation methodologies analysis. Technical assessment of each of the installation methodologies

- Chapter 6: Risk Assessment. Risk analysis of each of the activities involve for the transportation and installation of the Float-Over.
- Chapter 7: Cost analysis. Economic study of each of the installation methodologies
- Chapter 8: Conclusion. Describes the conclusion obtained from the technical and economical assessment plus the risk analysis
- Chapter 9: Recommendations. Describes the suggestions for further work.
- Chapter 10: List of references. Bibliography and sources used in the literature review and research process of the project.
- Chapter 11: Appendix. Risk analysis of each of the activities involve for the transportation and installation of the rest of installation methodologies except floatover described in section 6

2 FLOAT-OVER

A float-over is an alternative methodology for the installation of the Topside of an OSS on its foundation, for this study a Jacket has been considered as a foundation. As a result of an increasing trend in the capacity, distance from shore and depth of the offshore wind farms, OSS are experimenting an increase in their weight which reduce the availability of Heavy Lift Vessels and increase cost.

The methodology of the float-over is based on a barge which is outfitted for the transportation and installation of the topside. Once on site, the barge is driven between the legs of the Jacket and by ballasting means the barge is brought down to performed the mating between Topside and Jacket. (5)

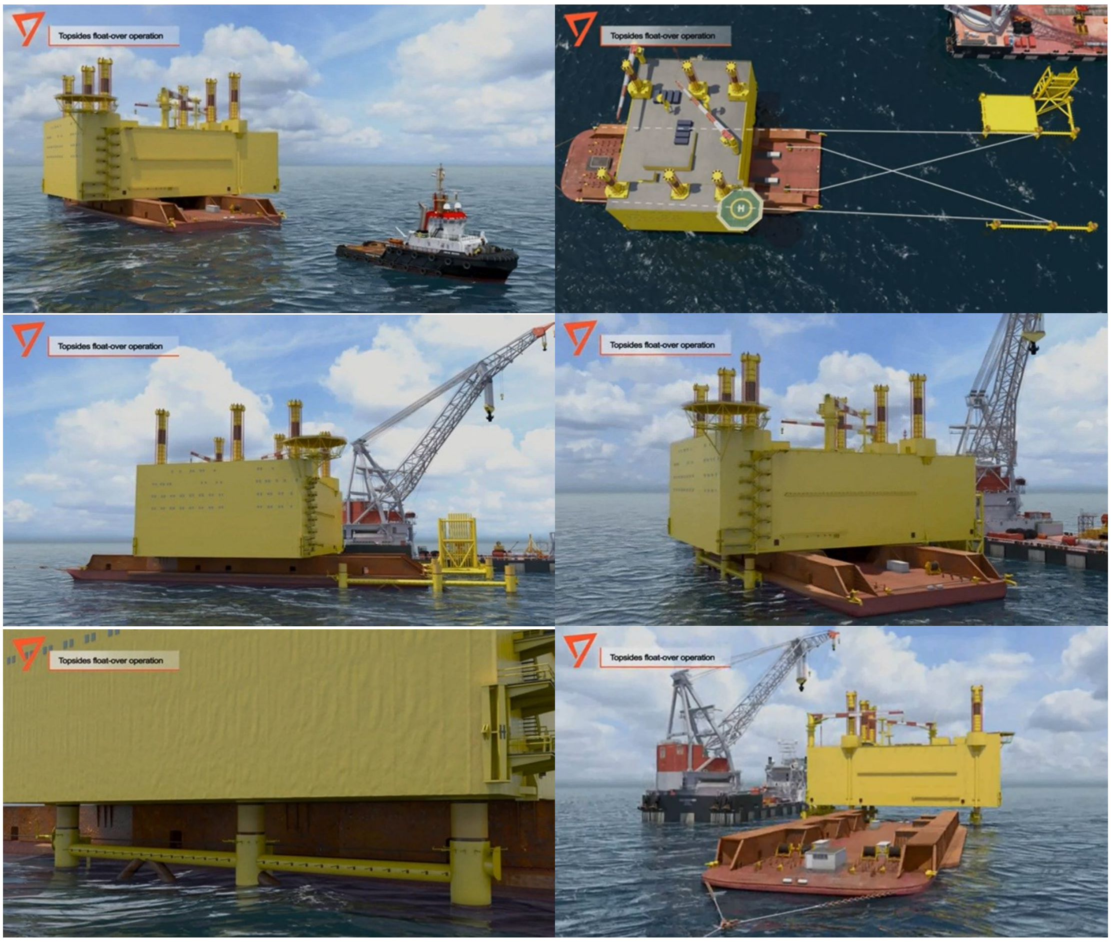

Figure 3: Sylwin Alpha, float-over installation sequence (6)

2.1 Fabrication

The construction of the Jacket is based on two main stages, fabrication and assembly. The methodology for the fabrication and assembly of the Jacket differs depending on the contractor as the construction company will fit its fabrication strategy to their capabilities considering different factors as lifting mean restrictions, available manufacturing area, tidal restrictions, and obstructions from the yard to open seawater, etc.

For this study a Jacket conceptual design is not available. However, as a base case scenario the following considerations have been taken into account:

- As result of the installation methodology, the distance between the stabbing cones must be wider in order to accommodate the installation barge between the legs of the Jacket
- Crossing bracings at the upper part of the Jacket shall be installed at a level that allows enough clearance between the bracing and the bottom of the barge during all the installation operation (5)

Once the Jacket is fully assembled, the steel structure shall be transported vertically or horizontally, depending on the Jacket installation methodology, nearby to the quayside in order to outfit the Jacket with the necessary means to proceed with the load-out.

As aforementioned for the Jacket design, for this study a Topside conceptual design is not available. In spite of that, for this particular installation methodology, it can be assumed an increase in the Topside weight due to structural modifications:

- The Topside is unable to be supported on the same configuration as it will be on the Jacket during the transportation. As a result of that, it is necessary to fabricate a special grillage, known as deck support units, to support the topside during the transportation. This will bring an extra cost due to the need to outfit the barge with this more complex grillage, see Figure 2.
- The increase of the distance between the stabbing cones will also affect negatively the total weight of the Topside (5)

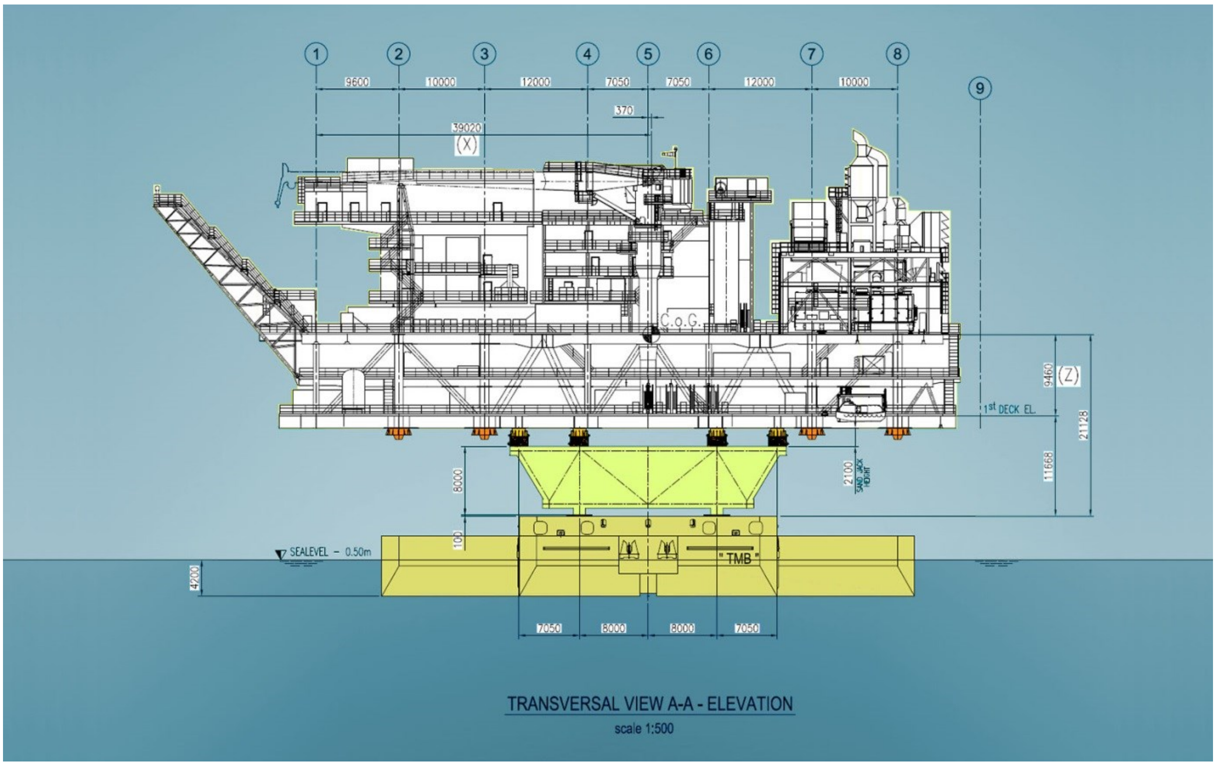

Figure 4: Filanovsky Topside, Caspian Sea (project undergoing) (7)

2.2 Sea Deployment

The topside will be fully fabricated and assembled onshore. Once it is ready for the load-out, the topside is transported from the fabrication shop or assembly area to the dockside in order to perform the load-out onto the installation barge.

Load-outs are usually performed by means of SPMTs. There are alternative methods like skid tracks or crane depending on their availability and final weight of the Topside.

The following parameters will affect the requirement for the load-out stage:

- Topside weight
- Tidal range
- Quayside dimensions
- Barge freeboard

This load-out does not differ from the load-out of any Topside installed by lifting, with the exception that the topside is loaded out onto the float over installation barge outfitted with a grillage and seafastening appropiate for the float-over (5)

Figure 5: Topside is skidded onto the HYSY229 launch barge (8)

2.3 Transport

For the transportation of the Jacket, tug vessels and a transportation barge, different to the installation barge used for the Topside, will be required with enough space on its the deck to accommodate the piles and Jacket. The transportation of the Jacket can be performed vertically or horizontally depending on the installation methodology, this would have an impact on the grillage and seafastening.

In the case of the Topside, for the transportation it will be required an installation barge with enough deck to accommodate the topside and outfitted with all the means to perform the installation. Prior to the sail away, as aforementioned, this seafastening and grillage is more complex than the seafastening required transporting a topside installed by lifting, as a result of the extra support needed for the topside during transportation. The stability of the vessel is a fundamental requirement for a float-over transportation.

The stability of the installation barge depends mainly on the beam and draft of the vessel. However, an increase in vessel width results in an increased jacket width requirement, this has unfavourable consequences for the jacket design, and an increase in stability results in, an increase on seafastening loads as a result of higher acceleration when the barge recovers its stability to quick.

Consequently, the best scenario for the transportation barge would by that one where the barge has the minimum beam and accomplish with the stability requirements (5).

Figure 6 Oil and Gas Float-over Topside transported on a Heerema Barge (9)

Figure 7 Jacket Horizontally Transported (10)

2.4 Installation

As it has been mentioned, the design of the jacket and the topside is affected by the float-over installation methodology. Transportation, installation and operating loads shall drive the structural design of the jacket and the topside. The main consequence of these implications is an increase on the structural weight that will have cost implications on the fabrication of both elements as more structural steel will be needed to reinforce the structure against the loads before mentioned. (5)

2.4.1 Jacket Installation

The size and weight of the jacket will determine the installation procedure to carry out as well as the pilling concept: pre-piled or post-piled. As the intention of this project is to not rely on heavy lift vessel, as a base case scenario the jacket would be installed by any of the alternatives jacket installation methods described below excluding single lift operations.

Furthermore, as future Offshore Wind Farms will be further away in deeper waters, the potential height and weight of the jacket would limit considerably the number of installation vessels capable to carry out such lifting vertically. Therefore, it is likely that other installation methodology might be used, like the double-hook, lift-float up-ending or launching, which would require the jacket to be transported horizontally. The following list represents the heavy lift vessels in the market with a lifting capacity suitable for the expected weight of the jacket that normally operate in Europe (there are other vessels with high lifting capacity, but the possibilities that they come to Europe for a single lifting operation is unlikely):

Name	Lifting Capacity (Ton)
Thialf	14200
Saipem 7000	14000
Svanen	8700
Hermond	8100
Balder	7200
Oleg Strashnov	5000
Oceanic 5000	4400
Kaizen 4000	4200
Rambiz 4000	4000
Rambiz	3300
Asian Hercules	3200

Table 1: Heavy Lift Vessels available in Europe (data available in the Technical Specification of each vessel)

For clarifying purposes, the following example has been provided based on the following assumptions:

- Hevay lift Vessel: Rambiz, lifting capacity 3.300 Tons
- 3 - 5 m clearance between Crane vessel and barge (DNV-OS-H205 Lifting Operations)
- Jacket Weight: 1.400 Tons (Nordsee 1)
- Jacket Height: 50 m + 2 m Grillage + 3 m (Freeboard + Rigging Configuration) = 55 m
- Installation barge: Standard 400 feet North Sea barge, 122 x 36.6 x 7.6
- Lifting Point at 23.3 m from the stern of the installation vessel (18.3 m Center of the Barge + 5 m Clearance) and 55 m height from the barge deck

As it can be seen in Figure 6, the size of the jacket is too high for the Rambiz crane. This kind of issues will narrow down the availability of crane vessels.

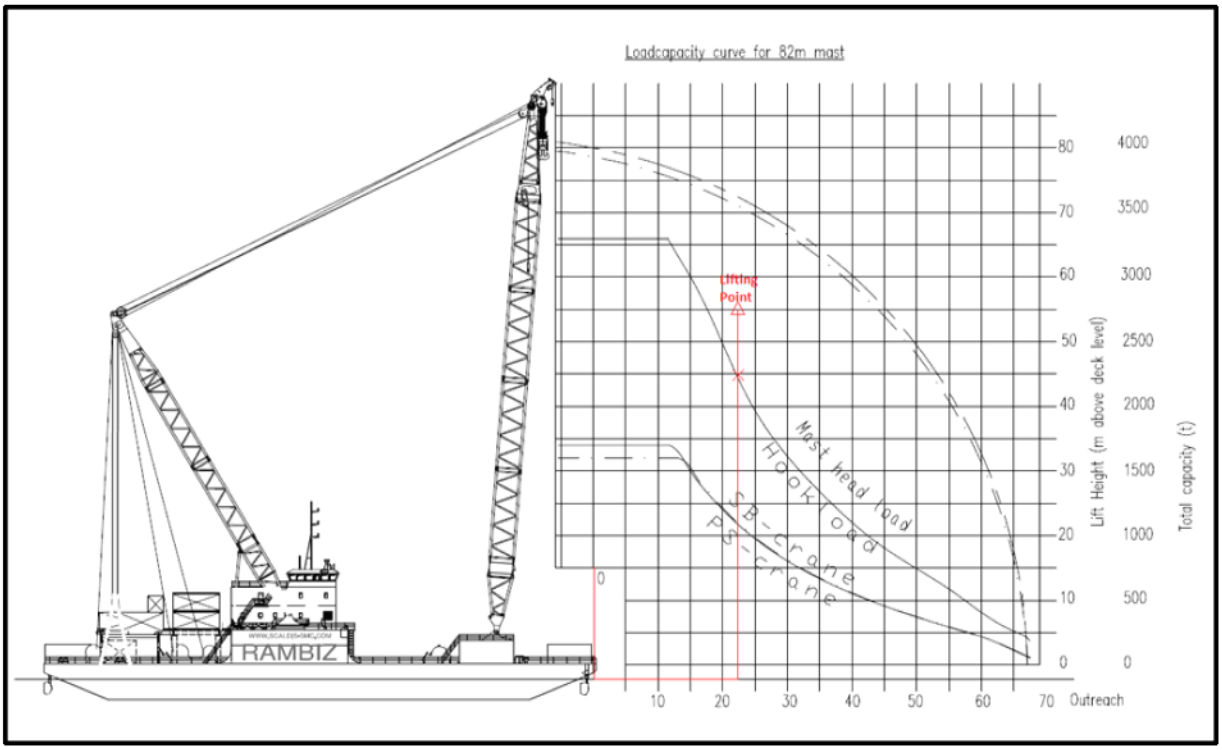

Figure 8: Rambiz lifting curve. Case Study

A) Lifting

This methodology is the most common in the offshore wind at this moment. The installation procedure is based on a single lift operation using the main hook of the heavy lift vessel. For this operation the jacket shall be loaded out vertically into the transportation barge. Once the load out has been performed the jacket and the piles must be seafastenned.

At the installation site, the jacket is release from the seafastening and grillage and lifted from the transportation barge. Before lowering the jacket down to the seabed, the orientation of the jacket must be checked and verified. Afterwards, the installation of the piles into the piles sleeves of the jacket and the hammering operations can begin.

This procedure is the most simple method as not many operation are required at the offshore site. Consequently, this method does not consume much time offshore which reduces the risk of possible weather downtime. (9)

Figure 9: Dantysk OSS lifting operation by SHL (11)

b) Double Hook

This methodology requires the jacket to be loaded out onto the transportation barge horizontally. The main crane will be used to lift the jacket from the transportation barge while the auxiliary crane is used for the upending of the jacket. Once the upending has been performed, and as in the lift method, before lowering the jacket down to the seabed, the orientation of the jacket must be checked and verified. Afterwards, the installation of the piles into the piles sleeves of the jacket and the hammering operations can begin.

Some requirements are necessary to performed a double hook lift as enough lifting capacity from the auxiliary hook, enough gap between the HLV and jacket as well as enough clearance between the seabed and jacket. In some cases, buoyancy means may be used in order to reduce the lifting capacity of the auxiliary hook.

As the lift operation this method is quite straightforward. Consequently, this method does not consume much time offshore which reduces the risk of possible weather downtime. However, it may require buoyancy and ballasting means on the jacket as well as hydraulic hoses to release the rigging from the bottom part of the jacket. By using this method the height of the jacket will not be a problem as it is horizontal and the lifting point is much lower than in the lift operation as it was explained on figure 6. However, this installation methodology would require crane vessels with the capabilities of a tandem lift or two crane vessels with a lower lifting capacity, or an auxiliary hook which accomplish with the load requirements. (9)

Figure 10: Double Hook Lifting Operation by Rambiz HVL (12)

c) Lift-Float Up-ending

This installation method would also require a horizontal transportation of the Jacket to the site. The jacket is transported to the site on a semisubmersible barge which once on site by ballasting means leaves the jacket afloat.

In this methodology, an auxiliary vessel will be required in order to keep the jacket on the right orientation during all the operation. The upending of the jacket will be carried out flooding tanks (or similar) located at the bottom of the jacket and with the assistance of the crane on the HLV which will performed the lifting of the jacket upper part.

Following this operation, and once the jacket is upended and completely vertical, its orientation and position must be verified previous to set down the jacket on the seabed. Piling operations can star as soon as the bottom of the jacket is fully ballasted. After the installation of the piles any stability means must be removed.

The most critical point of this methodology regarding to the engineering, construction and offshore installation is the jacket floating stability.

Special preparation by the manufacturer of the jacket will be required as especial means are required as the above mentioned flooding and ballasting means (valves, tanks, flooding lines), buoyancy tanks, hydraulic hoses to releases the rigging and four lifting points for the upending of the jacket. (13)

Figure 11: Lift float, Sylwin Alpha Jacket Installation (14)

d) Launching

This methodology is a real alternative for the installation of heavy jacket, as the lifting capacity requirement of the HLV involves in the installation operations is much lower. For this installation method, a special launching barge is required and tug vessel which will pull the jacket to the installation site.

As with the previous installation methodologies described, this procedure will also require the horizontal load-out and transportation of the jacket to site.

Barge and jacket will required a special preparation for the launching operation. The launching barge will need to be outfitted with the rigging system for the jacket upending, winches and the ballasting system.

Once on the proximities of the offshore site, the ballasting of the launching barge will bring the barge to the launching trim angle. The jacket will be release from the seafastenning once this angle is achieved. Afterwards, the winches above mentioned will pull the jacket towards the stern of the launching barge increasing the launching trim angle. At this point, the jacket will slide completely off the barge and dives into the sea.

The next step will be to bring the jacket into the reach of the HLV which will perform the jacket upending. The jacket will be upended following the same principle as the Lift-Float Up-ending method flooding the bottom tanks of the jacket and executing the upending with the crane on the HLV using the upending rigging.

Following this operation, and once the jacket is upended and completely vertical, its orientation and position must be verified previous to set down the jacket on the seabed. Piling operations can star as soon as the bottom of the jacket is fully ballasted. After the installation of the piles any stability means must be removed.

The detailed design of the jacket will rely on the capacity of the launching barge available. The forces which act on the jacket during the transportation and launching will result in a much heavier jacket.

Regarding to the special preparation required to the jacket, this methodology will need additional heavy launch trusses, flooding and ballasting means, buoyancy tanks, hydraulic hose to release the rigging, upending rigging, closure plates and diaphragms.

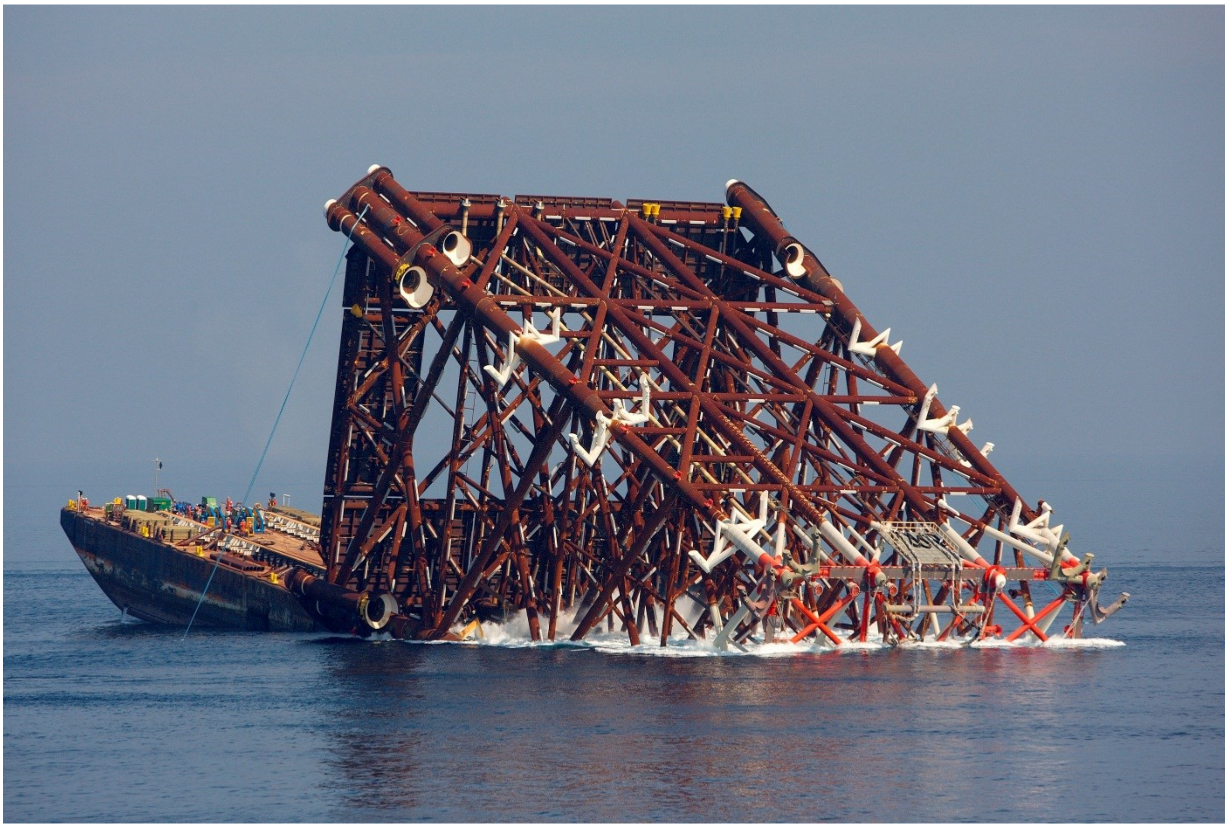

Figure 12: Launching Operation. North Field Alpha Project (Qatar) (15)

8.2.1.1 Jacket installation assessment

In this section, the different methods to install the jacket have been assessed; the target of the analysis is to rank them. It is a cualitative assesment, the jacket's designs are not available so a cuantitative assesment is imposible for this study. It has considered three scoring levels (from 1 to 3, being best level 3 and 1 the worst case) for the following aspects below described:

- **Influence on jacket design:** with the launching method the jacket would suffer more loads than in any of the other methods; it will result on heavier jackets. Furthermore, regarding to the lifting and the double hook method, the fact of having more lifting points on the double hook methods would have an impact on the design. Also, the engineering stages would be affected for those jackets which require floatability.
- **Additional accessories required:** double hook may require buoyancy and ballasting means on the jacket as well as hydraulic hoses to release the rigging from the bottom part of the jacket; lift float and launching must require jackets

with ballasting and flooding means plus buoyancy tanks. On the other hand, jacket installed by lifting would only require as considered special equipment, a rigging system as the rest of methods.

- **Transportation barge required:** for lifting and double hook methods standard transportation barge are used, lift float would require a semisubmersible barge to leave the jacket floating while launching requires launch barge with tilting beams, launch beams and launch equipment, wich have limitted availability and are rare and expensive.
- **Number of vessels:** Double hook and lifting require the same number of vessel. However, the lift float method requires one more tug vessel to keep the orientation of the jacket during the upend process. On the other hand, for the launching method, a heavy lift won't be needed, just tugs vessels and a launching barge.
- **Operational weather window:** Cranes methods have the smallest operational window weather for the fact of using a crane and all the limitations that it entails as limiting significant wave height, and, wind and current speed. The lift float and launching do not required complex lifting operations. Also, the concept of self-upending jackets (16) could be an option to reduce lifting capacity and risky lifting operations.
- **Offshore installation time:** lift method has fewer interfaces than any of the other methods. Double hook has the complexity of the upending which will require time. For the lift float upending the flooding or ballasting of the tanks to perform the upending would require even more time. Launching has a longer offshore operation than any of the other methods due to the need of towing the jacket to deeper waters to the launching site in order to avoid any impact with the seabed.
- **Dependency of lifting capacity:** launching method does not depend on HLV as the Lift-float methodology which neither require much lifting capacity, just to assist during the upending of the jacket. On the other hand, double hook up-ending requires less lifting capacity than the lift float because in the double hook the loads are distributed on two cranes but it will require more lifting

capacity than the lift-float as the jacket must be lifted from the transportation barge.

The following table summarises the classification criteria used to select the jacket installation method:

		Lifting	Double Hook	Lift float	Launching
Fabrication	Influence on Jacket design	3	2.5	2	1
	Additional accessories required	3	2.5	2	1
Transportation	Transportation barge required	3	3	2	1
	Number of vessels	2	2	2	2
Installation	Operational weather window	2	2	3	3
	Offshore installation on time	3	2.5	2	1
	Dependency of lifting capacity	1	2	3	3
Total		17	16.5	16	12

Figure 13: Jacket Installation Methodologies Assessment

The analysis of the scores obtained from the jacket installation methods assessment results on the lifting method as the most effective installation methodology considering the parameters mentioned above. The reason behind this is the simplicity of this installation method.

However, the best considered option for the installation of the jacket would be the lift float method as the intention of this project is to avoid the reliance on expensive HLV with high lifting capacity as much as possible, and the fabrication, transportation and installation are not as complex as the launching method.

2.4.2 Topside Installation

The installation of the topside will be done by means of an installation barge which will be outfitted with the neccesary equipment to carry with the float over operation.

The topside installation must accomplish the following steps:

- <u>Float-over preparation</u>

Once the transportation has been completed, the installation barge requires being prepared before starting the docking operation of the installation barge. This preparation works will be carried out on the proximities of the jacket. Below are listed the works which are required:

- Seafastenning need to be removed
- Mooring, docking and mating equipment must be prepared
- Electrical equipment to monitor the installation barge motions must be prepared
- Ballasting pumps must be checked

• <u>Installation barge docking</u>

At this stage, the barge is towed from the jacket proximities to the final installation location onto the jacket. Docking operation must accomplish with the requirements listed below:

- The orientation of the installation barge must allow a smooth entrance into the jacket.
- The forces on the jacket during the docking must not by higher than the expected impact loads for the design of the jacket.
- Any impact between the Topside stabbing points and the leg mating units must be avoided at all cost
- Any motion of the installation barge must be controlled specially the translational motions: surge, heave and sway.

• <u>Installation barge Premating</u>

After the docking operations has concluded, the topside stabbing points and the leg mating units need to be in the right position for a perfect married. As the installation barge is ballasted, the air gap between the topside stabbing points and the leg mating units will be decreased. During this stage the following parameters must be bear in mind:

- Sway motion of the barge must be controlled in order to guarantee the right orientation of the topside stabbing points and the leg mating units.

    - Forces acting on the Jacket resulting from lateral movements of the installation barge must not be higher than the expected impact loads for the design of the jacket.
    - Forces acting on the Jacket resulting from vertical movements of the installation barge must not be higher than the expected impact loads for the design of the jacket and its leg mating units design.

- Topside – Jacket Mating

  The mating of the topside with the jacket will be performed once all the weight of the topside is transferred from the installation barge to the jacket. This mating will be achieved by ballasting the installation barge, as afore mentioned. As an alternative to the ballasting procedure, the mating could be also accomplished through hydraulics system on the desk of the installation barge which will bring the Topside down until the mating with the jacket legs.

- Installation barge post mating position

  At this stage and after all the weight of the topside is transferred from the installation barge to the jacket, there is some risk of impacts between the topside and the float-over support frame or grillage. As a result of that, in order to increase the air gap the barge must be ballasted until the air gap between the topside and the float-over support frame or grillage has increased enough to undock the installation barge. During the ballasting operations is important to limit lateral and vertical impact loads, and lateral movements of the barge.

- Installation barge undocking

  Once, ballasting operations mentioned above has been carried out to increase the air-gap between the topside and grillage, the barge can be undocked from the jacket. At this stage is important to limit lateral and vertical impact loads, and control the movement of the barge.

Figure 14: Sylwin Alpha Floatover (17)

3 SELF ELEVATING UNIT

This installation concept works with the same principle as a jack up. In this case the topside is designed to operate rising the hull from the water line keeping a safety air gap between the hull and the water line. This concept will require topside with buoyancy and with the structural capability to attach the self-elevating unit legs to its hull. The legs will be attached to a submersible jacket previously installed. For this study it has been considered two different concepts, a traditional SEU and another concept that would not require a hull with buoyancy as the Topside would be assisted by a barge during transportation and installation. For both scenarios, the legs of the SEU will be welded or grouted to a submerged jacket.

Figure 15: Borwin Beta OSS 800 MW (18)

Figure 16: F3-FA Installation, SEU assisted by barge (19)

3.1 Fabrication

The fabrication procedure of the jacket for these solutions does not differ from the manufacturing of a standard jacket of a platform installed by lifting. However, its size shall be much smaller than the jacket described for the float-over, this fact would have an important impact on the final fabrication cost scenario.

In the case of the SEU, the topside will be manufactured on a shipyard where enough space can be dedicated for fabrication the topside following the pancake method, basically deck by deck (see figure 15), and enough space for the assembling of the legs. It must be mentioned that it is one the major challenge in the fabrication of the SEU. Most likely the legs will be manufactured horizontally, upended by lifting means and then lowered down into the legs sleeves attached to the corners of the SEU. For the fabrication of the hull, structural elements such as the outer shell, decks, bulkheads and girders shall be dimensioned according to environmental loads, permanent loads, accidental loads, deformation loads, fatigue loads as well as transportation and installation loads (16). The hull must provide positive stability during transport and installation, for this reason is expected more steel weight comparing with float-over. But, its steel cost shall be less than the semisubmersible as result of its smaller dimension.

On the other hand, in the case of the SEU assisted by barge, the modules would be assembled, like common topsides, at the fabrication yard prior to loading onto barge for transport to site. This solution would not require buoyancy, so it would be affected by different loads during the transportation and installation to the SEU with buoyancy. As a result of that, the design is less complex, because does not need structural elements to provide buoyancy and to deal with loads during transportation. Therefore, this lack of buoyancy would have a positive effect in the fabrication cost scenario in front of the semisubmersible and the SEU; still the float-over will be lighter, as a result of the SEU's legs as it has been explained below.

For both solutions, legs may be either shell type or truss type. More steel will be needed in the joints between the legs and the hull or main deck of the SEU as a result of the inertia forces on the legs.

Shell legs are hollow steel tubes with either rack teeth or holes in the shell in order to enable jacking of the hull up and down the legs:

- Advantages: Shell legs can operate on smaller decks. Also, its construction is much less complex to the construction of truss legs
- Disadvantages: difficulties to operate in water depths over 100 m. Shell legs require more steel than the truss type to provide the same resistance to environmental loads

Truss legs are latticed structures with nodes and bracings.

- Advantages: These kinds of structure are more cost effective as less steel is required for the same performance. Suitable to operate in water depths over 100 m.
- Disadvantages: it construction is more complex

Also, it must be taken into account that those concepts will require an extra amount of primary steel for its legs. The legs of self-elevating units shall be designed to resist the forces and bending moments resulting from the different loads mentioned below (20):

- Permanent Loads
- Environmental Loads
- Deformation Loads
- Accidental loads
- Fatigue loads

Figure 17: F3-FA SEU construction. Heerema facilities (15)

Figure 18: SEU with shell legs (left) (19). SEU with truss legs (right) (22)

3.2 Sea Deployment

Load out of the jacket would be performed by means of SPMTs. There are alternative methods like skid tracks or crane depending on their availability in the manufacturing yard.

In the case of the watertight SEU with buoyancy, the float-off is the most efficient way to deploy into the sea a Self-Elevating Unit. Float-offs can be performed either by Syncrolift, large elevator which raises and lowers vessels in and out of the water for dry-docking ashore, or by flooding dry-dock. For this last scenario, flooding a dry dock, a tug vessel will be required inside the dry dock area in order to assist during the towing operation of the platform and start with the transportation of the SEU, for this operation the tug vessel will have to be lifted and deployed into the dry-dock (see figure 17).

For the SEU assisted by barge is necessary a traditional load-out by SPMT, lifting or skid out.

Figure 19: Borwin Beta OSS assisted by tug vessel inside dry-dock (21)

3.3 Transport

The jacket will be transported vertically on the desk of a transportation barge and towed by a tug vessel following the same procedure as in the jacket transport for the float over.

Self-elevating units have hulls with sufficient buoyancy to safely transport the unit to the desired location, after which the hull is raised to a predetermined elevation above the sea surface on its legs. For ocean transit conditions, it may be necessary to reinforce or support the legs, or to remove sections of them. Therefore, towing arrangements are needed to perform the transportation of the SEU where it will just be necessary a tug vessel with enough bollard pull. It could have a positive impact on the transport and installation cost scenario because it is just necessary to hire a vessel. However, the time sailing to site is a problem for this solution as a result of a higher hydrodynamic resistance for its square shape.

Figure 20: Borwin Beta towed by tug vessels (23)

In the case of a SEU assisted by barge, the transport would be done on a barge where the SEU has to be loaded out. It would result on an extra cost hiring a barge and an anchor handling vessel. Also, it must be taken into account that the barge need to be outfitted before sailing out, this preparation has a negative effect on the transport and installation cost assessment. However, this solution would have the best condition for time sailing to site as a result of lighter topside than the other concepts, and the fact that the barge has better hydrodynamic resistance than SEU and Semisubmersible.

3.4 Installation

The jacket expected in the SEUs concepts shall be smaller than a standard one designed for topside installed by lifting, and therefore the number of vessels available in the market to carry out such lifting would increase. It would be positive from a cost scenario point of view and reduce vessel hiring cost.

In both cases, SEU and SEU assisted by barge, the installation in the site comprises a series of operations which serve to go from the “floating” state to “jacked-up” mode, case of the SEU, or from “resting on the desk of the barge” state to “jack-up” mode, in which the structure rests on the submerged jacket. The progress of these different operations largely depends on the weather conditions.

Also, either for the SEU or the SEU assisted by barge, it has ben assumed the assistance of 3 tugs plus the anchor handling vessel, that could be the one used for theto the transport, for station keeping. To complete this task is necessary high accuracy to match the legs with the sleeves at the top of the jacket. Due to a better station keeping of the barge than the SEU by itself, the installation time for the SEU unit assisted by barge is expected to be shorter than the SEU.

The installation includes the following successive phases:

- Positioning and mooring of the structure on arrival in site
- Lowering of the legs.
- Contact of the footings to the submerged jacket/template
- Raising of the hull slightly above the sea level for application of preloaded if is required by ballasting
- Removal of preloaded
- Elevation of the hull to the operational position.
- Welding/Grouting between SEU legs and jacket.

During the first three installation phases, the SEU undergoes combined movements of translation and rotation, due to wave action. When the legs are lowered, the movements are amplified at the bottom of the legs, with the risk of impact between the footing and the jacket (submerged).

While the hull is being raised, the SEU already rests on the jacket but the still submerged hull is subject to wave and current loads. In the case of the SEU assisted by barge, these loads would be faced by the barge which has a better seakeeping than the SEU by itself. As a result of this the insallation of the SEU has a higher risk than the SEU assisted by barge

Deploying legs could be done leg after leg or simultaneously, to reduce the time of the operation and to ensure the horizontally of the structure more easily, this procedure minimise the punch through risk.

The weather conditions impose limitations to the performance of SEU installation operations, as aforementioned:

- The movements of the structure when the legs contact the seabed
- The action of wave and current on the hull still into the water or on the barge
- Overloads resulting from de environment during preloading

A SEU is only really safe on completion of preloading and after the hull is raised to a safe level clear of extreme wave crests. Consequently, the operator must make sure of a favourable weather window, which is sufficiently long to allow completion of all installation phases in the best possible conditions, and possibly a backup plan to a strategic position prepared in advance. The allowable weather conditions in the installation phase ultimately depend on the behaviour of the SEU while afloat and on the structural strength available during preloading.

The maximum allowable conditions for performance the operations are not systematically dictated by the maximum allowable wave height, but also depend on its period. During the seabed or jacket approach phase, in which the SEU is still afloat, the limitation results from the real movements of the structure, this depends on the wave period (see figure 15). (20)

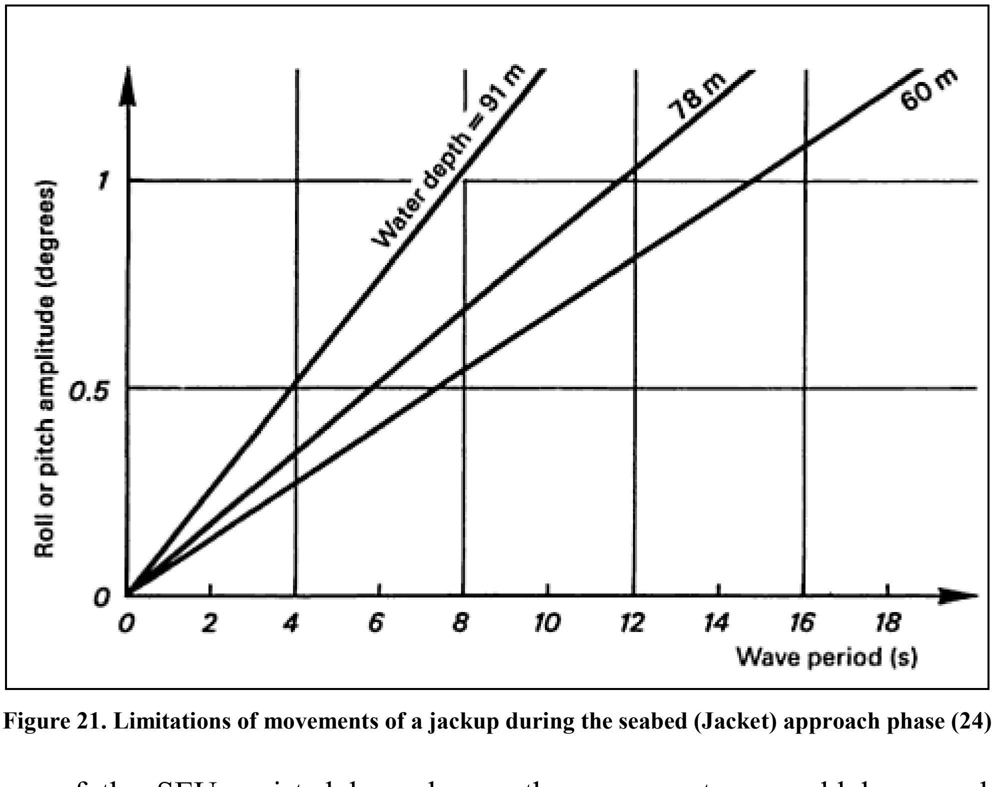

Figure 21. Limitations of movements of a jackup during the seabed (Jacket) approach phase (24)

In case of the SEU assisted by a barge, those parameters would be completely different; the weather window is expected to be better as a result of the much better seakeeping provided by the barge.

4 SEMISUBMERSIBLE

This concept would require a complete different design to the previous concepts. It would have the same principle as the semisubmersibles in the Oil and Gas, but adapted to the necessities of the offshore wind, with topside which is at enough high to avoid the exposure to the waves supported by buoyant pontoons which will be submerged during the life operation of the OSS. The Topside is connected to the pontoons through large columns which provide stability to the structure. This concept has been already used in the offshore wind with the OSS Dolwin Beta (see figure 22), in this case the OSS rest directly on the seabed, differently to the most common concept of the O&G where the Semisubmersibles use mooring lines, for the concept analyses in this project an OSS with mooring lines will be considered.

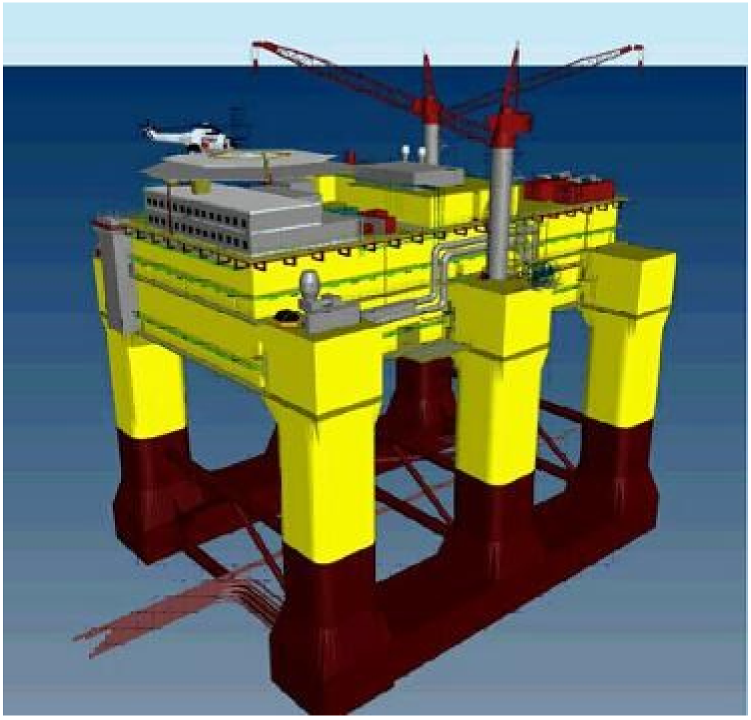

Figure 22: Dolwin Beta OSS (25)

4.1 Fabrication

The fabrication of this type of offshore substation concept would be divided in two stages which can be carried out in parallel in the same yard, or either the topside or the hull will be fabricated in another yard and then a mating operation would be performed. For this concept a yard with a large dry-dock and gantry cranes or crawler cranes with high lifting capacity will be required.

Firstly, **the hull** will be manufactured. Most commonly the hull is built with sub assembled components. A dry dock will be used for the fabrication of the lower part of the hull, which will involve bracings, columns and pontoons (26).

Figure 23: Fabrication of Dolwin beta bracings, columns and pontoons on drydock (27)

The **topside** for a semi-submersible consists of several assemblies, including skid-mounted packages and modules but the same principle as for the previous concepts will be follow (deck by deck).

If the different modules of the topside and the deck are built at a different site than the hull structure, the topside and the deck structure are usually constructed as a complete unit and then mated to the hull. To accomplish this, the hull is relocated to a suitable near shore location, moored in shelter water, and ballasted down to a mating draught. The topside and the deck structure are towed to the near shore location on a barge small enough to allow the structure to be floated between the columns of the hull. The hull is then de-ballasted with the deck structure positioned over the columns. Final alignment, mating preparation and welding precede final de-ballasting and removal of the barge. If the topside is built at the same site as the hull structure, the hull and the topside can be assembled in one shipyard with a large drydock facility. (26)

Figure 24: Dolwin Beta Fabrication Sequence (28)

4.2 Sea Deployment

Semisubmersible can be loaded out or floated out, depending if the construction is carried out in a yard or in a drydock. The float out in a drydock is a simple operation:

- The drydock is flooded
- The door is removed when water level at two sides of the door is the same
- The semisubmersible is deballasted and towed away.

The load out is an standardized operation and, roughly speaking, the only new aspect with respect to loading out of jackets and topsides is that the barge has to be submersible for carrying out a float off operation, release de semisubmersible and let it floating by itself.

4.3 Transport

A semisubmersible is not specifically designed for sailing and they are massive structures so is expected a large bollard pull and therefore will be necessary more powerful transportation vessels or a semisubmersible transportation barge

As about mentioned, two possible scenarios may be considered for the transportation, either a tug vessel or a semisubmersible transportation barge. This will depend on the distance from the fabrication yard to the site. From previous project experience as the Dolwin Beta project it can be seen how for long distances it was employed a semisubmersible barge, from the yard to the heaven port, while for shorter distance it was used tug vessels, from the heaven port to the offshore site.

Regarding to the sailing characteristics of the structure, the maximum available sea state will be high. It is a very stable structure with a large freeboard. But, it should be taken into account that the higher the waves are the larger forward resistance and higher bollard pull needed. Like the case with barge, the maximum available sea state will be theoretically high, but it is not practical to tow the semisubmersible at this limiting sea state, under this conditions the use of a semisubmersible barge could be an option but it would have an impact on the cost.

Figure 25: Dolwin Beta OSS transportted by Semisubmersible bar (above) and transported by AHV (below) (29)

4.4 Installation

Offshore installation of this concept of offshore substation starts with the preparation and installing the anchors or piles at the offshore site using anchor handling vessels and any other required support vessels. According to the conditions of the seabed at the offshore site, a remote-operated vehicle (ROV) will be used to precisely place drag anchors on the seabed, or a crane with enough crane capacity for the pile lifting operation is employed to install steel anchor piles or suction anchors.

Survey vessels perform pre-installation surveys to confirm that installation areas and mooring line laydown corridors are free and suitable for installation.

Generally, Semi-submersibles require from 9 to 12 mooring lines. The mooring lines are designed to hold the platform on site.

The installation of the mooring lines will start once an operational weather window is available. Mooring line bottom segments must be pre-attached to the anchor or piles before its installation, any other configuration would require the use of ROV or drivers.

Once the anchor or pile is at the site, and before lowering it to the final positioning, a survey must confirm its position. When the anchor reaches the seabed its position must be confirmed too. During tensioning of the mooring lines, lengths and tensions must constantly be monitored, until the vessel confirms that the anchor is set.

The monitoring of the procedure must include the following measurements: penetration depth, applied pressure, penetration rate, plugs heave, tilt and orientation. It shall be necessary to confirm the anchor position and verify that the mooring line elements are not twisted beyond the allowance criteria and that no mechanical damage has occurred. After that the tension must be equalised in the several anchor legs. (26)

At this stage, the bottom mooring lines are laid on the seabed and must be marked with pennant buoys to the surface, to proceed with the installation of the Offshore Substation.

When the mooring lines have been installed, the Semi-submersible locates to the installation site, while buoys are deployed. Anchor handling vessels are employed to retrieve the temporary pendant buoys and recover the mooring pendants. ROVs are employed to secure wire leads to the chain moorings, and the chains are then recovered through mooring hawser pipes located in the vertical legs of the semi-submersible. (30)

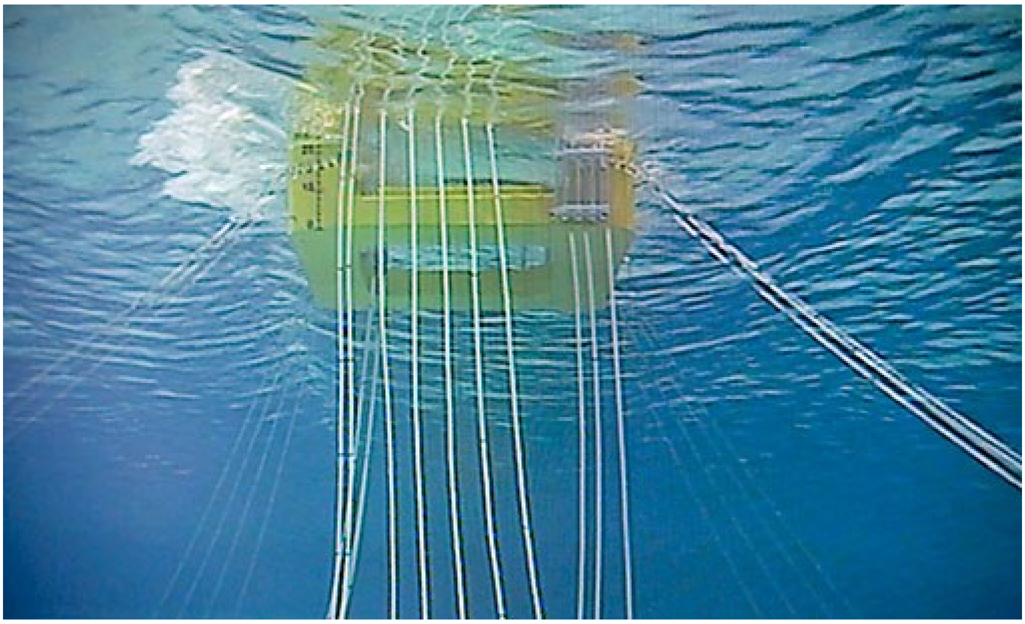

Figure 26: Mooring lines in a Sumersible OSS

5 INSTALLATION METHODOLOGIES ANALYSIS

The objective of the concept analysis is to rank the potential installation concepts described in this project based on various cost and risk indicators relating to the fabrication, transport and installation of the different proposed solutions. For this task the previous sections where the different concepts were described have been taken as a reference.

Evaluation of the different concepts is based on fabrication, transportation and installation criteria, used to score each concept. It has considered four scoring levels (from 1 to 4, being best level 4 and 1 the worst case). Some criteria have been considered more important than other, so different weightings are applied to different criteria. For this study, a conceptual design of the proposed solutions is not available, as a result of that, it is just possible to make a qualitative analysis from the proposed solutions.

5.1 Classification Criteria

The following section summarises the classification criteria used to assess the different installation methodologies, with their individual weights in square brackets [X%].

Although manufacturing cost is much higher than the T&I costs, it has been considered an overall weighting of the fabrication issues of 40% and consequently the overall weighting of T&I matters is 60%. This assumption has been considered mainly because one of the targets of the project is to develop alternative installation methodologies for offshore wind and also due to the high risk associated with the installation activities.

5.1.1 Fabrication Criteria

The following factors have been considered in relation to manufacturing criteria for each concept:

- **Special requirements of manufacturing facilities** [12.5%]: Any of the solutions under study have their own construction procedure which is very dependent of factors like: type of facilities, dry-docks availability, lifting capabilities, available machinery, manpower experience etc. It is difficult to find a perfect manufacturing yard with all the necessary capabilities for constructing any kind of structure. Also, regarding to the fabrication process all the solutions are quite similar, despite of the bigger dimensions of some solutions, that would limit the number of yards able to manufacture such big structures.

  - **Float Over:** Score 4. It has been considered the maximum score for this concept as basically the facilities for the topside and jacket of a float over would by the same as for classic OSS for a lifting installation method. The only concern could be the bearing capacity of the load-out quay but as many of the yards around Europe have experience in the O&G this should not be a major concern.
  - **SEU + Jacket:** Score 2. For this concept it has been considered a 2 as the topside would be watertight and requires to be built in a dry-dock
  - **SEU assisted by barge + Jacket.** Score 3. The reason behind this is that none special facilities will be required for this concepts. However, it would be required crawler cranes with enough lifting capacity for the assembly of the SEU legs.
  - **Semisubmersible:** Score 1. The minimum score was considered for this concept as the same issues as with the SEU + Jacket are present while in this scenario because of the size of this concept the dry-dock required would be much higher. This issue will narrow down the number of yards capable to built this concept

- **Adaptable to modular construction** [12.5%]: considering if any of the solutions are adaptable to a modular onshore construction in order to carry out multiple manufacturing activities at the same time and possible impacts on the fabrication schedule.
  - **Float Over:** Score 2. Most likely for this concept jacket and topside will be built in parallel, and the topside for this concept accommodates modular construction but there is not any additional advantage on this. For this reason it has been given the lowest score to this concept

- **SEU + Jacket:** Score 3. In this scenario most likely the legs of the SEU would be fabricated in other yard, in order to not have any impact on the schedule of the jacket and topside construction. This concept will have the advantage of accomodate a shorter programme as the manufacture of the jacket will need less time because of the smaller size. Topside for this concept is also adaptable for modular construction

- **SEU assisted by barge + Jacket:** Score 3. Same principle as SEU + Jacket

- **Semisubmersible:** Score 4. The highest score was given to this concept as it will also accommodate modular construction where the hull, pontoons and bracings of the semisubmersible will be manufactured at the same time but in a different location to the Topside. This concept should requires less time than any of the other concepts as a jacket is not required and the construction of truss structures is not required.

- **Deck integration** [12.5%]: it depend on if the main components of the structure are built together and how are the mating operations of topsides with platforms.

  - **Float Over:** Score 3. This concept has the highest scored as the concept does not have any disadvantage for the integration of the different decks to complete the fabrication of the Topside.

  - **SEU + Jacket:** Score 2. It has been considered a worse score than the floatover as this concept would require the integration of the SEU legs besides the integration of the different decks.

  - **SEU assisted by barge + Jacket:** Score 2. Same principle as SEU + Jacket

  - **Semisubmersible:** Score 1. This concept has the lowest scored because of the complex operation for the mating between the topside and the semisubmersible hull.

- **Cost variation due to steel weight** [25%]: some of the solution would require much more steel than others.
    - **Float Over:** Score 3. This concept would have the highest score among the different solutions as it does not required a water tight topside and SEU legs
    - **SEU + Jacket:** Score 2. This concept will require more steel than the float over and the SEU assisted by barge as it requires a water tight topside.
    - **SEU assisted by barge + Jacket:** Score 3. For this concept it has been given the same score as the float over, in spite of requiring SEU legs, but this concepts does not require a structural reinforce of the topside neither a complex sea-fastening and grillage.
    - **Semisubmersible:** Score 1. The semisubmersible would require the highest amount of steel because of the size of the OSS as a result of the manufacture of semisubmersible hull, pontoons and bracings.
- **Cost variation due to man-hours** [25%]: solutions where a jacket is involved will require more man hours as the manufacturing of the jacket is not a mechanised process.
    - **Float Over:** Score 1. The lowest scored was given to this concept as the jacket size of this concept is the biggest one among the different solutions proposed.
    - **SEU + Jacket:** Score 2. This concept will require more man hour than the semisubmersible as the fabrication of jacket is involved plus the fabrication and assembly of the SEU legs
    - **SEU assisted by barge + Jacket:** Score 2. Same principle as SEU + Jacket
    - **Semisubmersible:** Score 3. This concept would require less man hours as a jacket is not involved and the complex welding activities for the truss structure are not required.

- **Cost variation due to special equipment** [12.5%]: some of the solutions would require special equipment as the self-elevating units where a jacking system will be required
  - **Float Over:** Score 3. This concept would require a transportation barge outfitted with a hydraulic system for the mating operation between the topside and jacket.
  - **SEU + Jacket:** Score 2. The SEU concept has been given the lowest score as for this solution it would be required a jacking system for the deployment of the SEU legs.
  - **SEU assisted by barge + Jacket:** Score 2. Same principle as SEU + Jacket
  - **Semisubmersible:** Score 4. The highest score has been given to this concept as not special equipment is required. For this concept would be only require the usual ballast system.

The weighting of the different activities being assessed respond to the impact that each activity by itself will have in the final cost. **Special requirements of manufacturing facilities**, **Adaptable to modular construction**, **Deck integration** and **Cost variation due to special equipment** were considered to have a weight of 12.5% as these activities would not have as much impact on the final cost as the **Cost variation due to steel weight** and **Cost variation due to man-hours** whose activities have a weight of 25%. The reason behind this is that the procurement of steel and the manufacturing costs have a higher impact on the costs than the fabrication methodology, special equipment required for each concept, or the use of certain type of facilities as dry docks for instance.

5.1.2 Transportation and Installation Criteria

The following factors have been considered in relation to Transport and Installation activities for each concept:

- **Weather Restrictions** [20%]; during the transport and installation activities, as some the concepts may experience longer periods of weather downtime than others.

- **Float Over:** Score 3. It has been considered to give a higher score to this concept than the scored given to the SEU concepts because it has been assumed that the installation for this concept is less complex as the activities involved in the installation will be above the sea level and the mating between the topside and the jacket will have a wider weather window.
- **SEU + Jacket:** Score 1. This concept has the lowest score because of the lack of hydrodynamic features of the water tight Topside design. Also, the installation procedure would require a calm state of the sea because of the complexity of the activities carried out under water for the mating between the bottom of the SEU legs and the submerged jacket.
- **SEU assisted by barge + Jacket:** Score 2. In this case it has been given a higher score than the SEU + Jacket as the transportation will be less restricted because of the employed of a transportation barge
- **Semisubmersible:** Score 4. This concept has received the highest scored as for the transportation of the semisubmersible the maximum wave high will be higher than in any of the different concepts as the robust structure of the semisubmersible and the absence of any sea-fastening and grillage as the topside is not exposed to the same transportation loads as any of the other concepts. Furthermore, it installation does not require risk operations therefore a wider weather window is expected

- **Vessels Required for Transportation** [10%]; considering the bollard pull requirements and also the number and kind of vessels involved during the transportation.
    - **Float Over:** Score 2. Vessels required for the transportation of this installation concept are transportation barges for the transportation of the topside and jacket plus the tugs vessels for the towing of the transportation barges.

- **SEU + Jacket:** Score 3. For this concept only one transportation barge will be required which will be used for the installation of the jacket. Tugs vessels will be needed it for the towing of the jacket transportation barge and one or two tug vessels, as a higher bollard pull will be needed, for the towing of the watertight topside. It has been given a higher score than the float over and the SEU assisted by barge as only one transportation barge will be required.
- **SEU assisted by barge + Jacket:** Score 2. Vessels required for the transportation of this installation concept are transportation barges for the transportation of the SEU and jacket plus the tugs vessels for the towing of the transportation barges.
- **Semisubmersible:** Score 4. This concept has the highest score as only tugs vessels will be required. In a possible scenario where the yard for the fabrication of the semisubmersible is far from the installation site, a semisubmersible transportation barge may be required.

- **Time sailing** [10%]; considering the time spent from the yard to the side taking into account the hydrodynamic characteristics of each solution, weight, bollard pull, etc.
  - **Float Over:** Score 4. It has been considered to give the highest score to this concept because this concept requires the use of a transportation barges which have higher hydrodynamics properties than the SEU and the Semisubmersible.
  - **SEU + Jacket:** Score 1. This concept would require the longest weather window and will spend more time sailing than any of the other concepts because from a hydrodynamic point of view this concept is very poor because of the shape of the topside.
  - **SEU assisted by barge + Jacket:** Score 4. As for the float over, this concept has been considered to give the highest score because this concept requires the use of a transportation barges which have higher hydrodynamics properties than the SEU and the Semisubmersible.

- **Semisubmersible:** Score 2. The transportation for this concept will require more time than the concepts which have a transportation barge because of the dimensions of the OSS. However, it hydrodynamics are acceptable and there is a large experience on this concept from the O&G.

- **Vessels Required for Installation** [30%]; considering the number and kind of vessels involved during the installation as well as their availability.
  - **Float Over:** Score 1. For this concept it would be required a heavy lift vessels with a higher lifting capacity than any of the other concepts for the installation of the jacket plus 2 or 3 tugs vessel for the complex operation of the mating between the topside and the jacket. For these reasons this concept has the poorest score. Furthermore a transportation barge equipped with all the requirements to proceed with the float over installation will be required
  - **SEU + Jacket:** Score 3. This concept will also require a heavy lift vessel but with less lifting capacity than the float over as the jacket size and weight will be lower. Also, it will be required 2 or 3 tugs vessels for the mating between the SEU legs and the top of the jacket.
  - **SEU assisted by barge + Jacket:** Score 2. As the all the concepts which involved a jacket this concept will also require a Heavy lift vessel. Same lifting capacity will be required as the SEU concept. Also, ocean tugs will be required for the mating between the SEU legs and the top of the jacket. However, it must be mentioned the complexity of the grillage and sea-fastening on the transportation barge that is why it has been given a worse score than the SEU + Jacket.
  - **Semisubmersible:** Score 4. This concept has the highest score as only tug vessels and anchor holding vessels would be required for the installation of this concept.

- **Offshore activities** [30%]; considering the number and complexity of offshore operations, and the potential cost/risk impacts

- **Float Over:** Score 3. For this concept there is a lifting operation, which always has a risk involved, for the installation of the substation. Also, there is a lot risk involved in the mating operation between the topside an the jacket. However, it has been considered to be less risky than the SEU mating operations as these operations for the floatover are performed above the sea level differently to the scenario of the SEUs concepts.
- **SEU + Jacket:** Score 1. This concept has the worst score because of the complex operations for the mating between the legs of the SEU and the top of the jacket, plus the accuracy of the seakeeping which in this scenario is worse because of the lack of hydrodynamics properties of the floating topside
- **SEU assisted by barge + Jacket:** Score 2. This SEU concept has been given slightly better score than the SEU + jacket because of the assistance of the transportation barge will reduce the risk of the mating between the legs of the SEU and the jacket.
- **Semisubmersible:** Score 4. This concept has the highest score as there is not any lifting operation involved in the installation of the semisubmersible.

Same principle as for the fabrication has been followed for the transportation and installation. The weighting of the different activities being assessed respond to the impact that each activity by itself will have in the final cost. For the activities involved in the transportation and installation it has been considered a weight of 10% for the **Vessels required for transportation** and **Time sailing** as the cost of this factors is much lower than the **Vessels required for installation** and **offshore activities** where it has been considered a 30%. The reason behind this is that installation vessels are much more expensive than transportation vessels and the risks of the offshore activities during the installation of the OSS are much higher than any other activity involved in this study.

5.2 Summary Installation Methodologies Analysis

The following table summarises the classification criteria used to assess the proposed installation concepts:

		Score					Weighted Score			
		Float Over	SEU + Jacket	SEU assisted by barge + Jacket	Semisubmersible	Weight (%)	Float Over	SEU + Jacket	SEU assisted by barge + Jacket	Semisubmersible
Fabrication 40%	Special requirements of manufacturing facilities	4	2	3	1	12.5	0.5	0.25	0.375	0.125
	Adaptable to modular construction	2	3	3	4	12.5	0.25	0.375	0.375	0.5
	Deck Integration	3	2	2	1	12.5	0.375	0.25	0.25	0.125
	Cost variation due to steel weight	3	2	3	1	25	0.75	0.5	0.75	0.25
	Cost variation due to man hours	1	2	2	3	25	0.25	0.5	0.5	0.75
	Cost variation due to special equipment	3	2	2	4	12.5	0.375	0.25	0.25	0.5
						Total Weighted	2.5	2.125	2.5	2.25
Transportation & Installation 60%	Weather Restrictions Transport nad installation: Wave, Wind, Current. AWW	3	1	2	4	20	0.6	0.2	0.4	0.8
	Vessel required for transportation	2	3	2	4	10	0.2	0.3	0.2	0.4
	Time sailing	4	2	4	3	10	0.4	0.2	0.4	0.3
	Vessel required for installation	1	3	2	4	30	0.3	0.9	0.6	1.2
	Offshore Activities	3	1	2	4	30	0.9	0.3	0.6	1.2
						Total Weighted	2.4	1.9	2.2	3.9
						Total Weighted	2.44	1.99	2.32	3.24

6 INSTALLATION METHODOLOGIES – RISK ASSESSMENT

The transportation and installation of the different OSS installation methodologies and their foundation involves several activities which introduces hazards and risks. These risks must be managed in order to be mitigated.

Transport and installation tasks must have a risk assessment; these must be subject to a review of each of the activities and equipment which are involved in the overall installation process.

The purpose of this analysis is to assess which are the risks involve on the transportation and installation of the methods proposed in order to be able to obtain a better understanding of which solution would be the most convenient.

During this preliminary risk assessment the following matrix will be used to define the various levels of risk as it is explained below:

CONSEQUENCE→ PROBABILITY↓	(1) MINOR	(2) SEVERE	(3) MAJOR	(4) CATASTROPHIC
(1) VERY LOW	1	2	3	4
(2) LOW	2	4	6	8
(3) MEDIUM	3	6	9	12
(4) HIGH	4	8	12	16

LOW RISK
MEDIUM RISK
HIGH RISK

Table 2: Risk Matrix

CONSEQUENCE	
Minor (1)	
Personal Illnes /Injury	Minor or non-lost time injury
Equipment losses	Slight-easily repairable
Production losses	System reparable within 1 hour
Environmnet	No traceable impact on the environment
Severe (2)	
Personal Illnes /Injury	Lost time injuries less than 3 days disability
Equipment losses	Damage to system or areas, repairable with the onsite sources
Production losses	Less than 2 equivalent days of full production
Environmnet	Short term damage of limited parts of environmental sensitive areas
	Minor damage to short areas
Major (3)	
Personal Illnes /Injury	Lost time injuries to 2 or more personnel of over 3 days
Equipment losses	Serious damage to vessel or worksite - no danger life
Production losses	2-9 equivalent days of full production
Environmnet	Temporary damage to environmental sensitive areas
	Pollution of shore areas
	Restoration time less than 2 years
Catastrophic (4)	
Personal Illnes /Injury	Fatality/Severe multiple injuries
Equipment losses	Serious damage to vessel or worksite - danger life
Production losses	10 days or more production loss
Environmnet	Permanent damage to environmental sensitive areas
	Severe pollution of shore areas
	Restoration exceeds 2 years
PROBABILITY	
Very Low (1)	Not expected to occur during the execution of the project
Low(2)	Expected to occur once during the execution of the project
Medium (3)	Expected to occur more than once during the execution of the project
High (7-16)	Expect to occur on several projects
RISK	
Low (1-3)	No additional measurements required
Medium (4-6)	Preventive measurements required, operation may proceed
High (7-16)	Works may not continue without preventive measures

Table 3: Risk Matrix Explanation

6.1 Float-over

To complete the float over risk assessment proposed in this study, the following activities have been considered, jacket and topside transportation and installation.

6.1.1 Jacket Transport

Barge Transport					
Task	**Hazard**	**Risk**	**Consequence**	**Probability**	**Risk**
Departure/Arrival	Unsuitable tug & barge	Tow cannot proceed	3	2	6
	Adverse Weather	Damage to quay/vessels	1	3	3
	Barge grounded	Damage to barge	4	2	8
	Tug grounded	Damage to tug	4	2	8
Connect/Disconnect Moorings	Breaking Rope	Personal Injury	4	2	8
	Unsafe access mooring points	Personal Injury	4	2	8
Transport	Adverse weather	Damage to barge/jacket	3	3	9
	Adverse Weather	Lost control over tow	4	2	8
	Barge instability	Damage to barge/jacket	4	2	8
	Collision	Damage to the tug, barge or/jacket	4	2	8
Tug break down	Lost control over tow	Damage to tug or barge	3	2	6
Towing line break	Lost control over tow	Damage to barge	3	3	9
	Uncontrolled movement of towing wire	Personnel injury	4	2	8
Shifting load	Damage to the load and barge	Loss of asset	3	2	6

Table 4: Jacket Transportation - Risk Assessment

6.1.2 Jacket Installation

Jacket Installation					
Task	**Hazard**	**Risk**	**Consequence**	**Probability**	**Risk**
Preparation rigging	Entangling rigging	Damage to rigging	2	2	4
	Dropped rigging items	Personnel Injury	3	2	6
	Sweeping rigging	Damage to Jacket & Personnel Injury	2	3	6
Connect rigging to Jacket	Crash rigging with different items	Damage to items	2	3	6
	Working on height	Personnel falling	4	2	8
	Unsafe access to rigging points	Persons falling	4	2	8
	Dropped objects	Personnel injury	3	2	6
Sling Tensioning	Rigging connections	Damage to rigging or Jacket	3	2	6
Disconnect/cut seafastenings	Hot work	Personnel injury & Damage to materials	3	2	6
	Dropped Objects	Personnel injury & Damage to materials	2	3	6
	Incomplete disconection	Damage to objects	3	2	6
	Difficult access	Personnel injury	3	3	9

Lift Jacket	Dropped objects	Personnel injury & Damage to materials	3	3	9
	Rigging failure	Loss of Jacket	4	2	8
	HLV crane failure	Loss of power	3	2	6
	Failure of lift point	Loss of Jacket	4	2	8
	Unstable Jacket	Overload rigging	3	2	6
	Unexpected movement of Jacket	Personnel injury & Damage to materials	2	3	6
	Incorrect ballasting of cargo barge	Stability problems	4	2	8
Positioning of object	Non fit	Delay operations	4	2	8
	Uncontrolled set down	Damage to Jacket	4	2	8
Disconnection of rigging	Crash rigging with different items	Damage to Jacket	2	2	4
	Shackle pin dropping or uncontrolled move of shackle	Personnel injury	3	2	6
	Difficult access	Personnel injury	4	2	8

Table 5: Jacket Installation - Risk Assessment

6.1.3 Topside Transport

Barge Transport					
Task	Hazard	Risk	Consequence	Probability	Risk
Departure/Arrival	Unsuitable tug & barge	Tow cannot proceed	3	2	6
	Adverse Weather	Damage to quay/vessels	1	3	3
	Barge grounded	Damage to barge	4	2	8
	Tug grounded	Damage to tug	4	2	8
Connect/Disconnect Moorings	Breaking Rope	Personal Injury	4	2	8
	Unsafe access mooring points	Personal Injury	4	2	8
Transport	Adverse weather	Damage to barge/OSS	3	3	9
	Adverse Weather	Lost control over tow	4	2	8
	Barge instability	Damage to barge/OSS	4	2	8
	Collision	Damage to the tug, barge or/OSS	4	2	8
Tug break down	Lost control over tow	Damage to tug or barge	3	2	6
Towing line break	Lost control over tow	Damage to barge	3	3	9
	Uncontrolled movement of towing wire	Personnel injury	4	2	8
Shifting load	Damage to the load and barge	Loss of asset	3	2	6

Table 6: Topside Transport - Risk Assessment

6.1.4 Topside Installation

OSS Installation					
Task	Hazard	Risk	Consequence	Probability	Risk
Preparation Towing system	Entangling towing arrangement	Damage to towing system	2	2	4
Connect towing system to Installation barge	Unsafe access to towing points	Persons falling	4	2	8
	Dropped objects	Personnel injury	3	2	6
Towing system tensioning	Towing connections	Damage to towing or Jacket	3	2	6
Docking	Collision between jacket and installation barge	Damage to jacket/barge or OSS	3	2	6
	Unsafe access mooring points	Personal Injury	4	2	8
Disconnect/cut seafastenings	Hot work	Personnel injury & Damage to materials	3	2	6
	Dropped Objects	Personnel injury & Damage to materials	2	3	6
	Incomplete disconection	Damage to objects	3	2	6
	Difficult access	Personnel injury	3	3	9
Transfering loads	Towing system failure	Loss of Barge	4	2	8
	Ballasting or hydraulic system failure	Loss of power	3	2	6
	Unstable OSS	Shifting Load	3	2	6
	Unexpected movement of OSS	Personnel injury & Damage to materials	2	3	6
	Non fit	Delay operations	4	2	8
	Uncontrolled set down	Damage to Jacket ans OSS	4	2	8

Undocking	Collision between jacket and installation barge	Damage to jacket/barge or OSS	3	2	6
	Unsafe access mooring points	Personal Injury	4	2	8

Table 7: Topside Installation - Risk Assessment

Note: For Risk assessment of each of the other different intallation methodologies proposed, please refer to Appendix A

7 COST ANALYSIS

7.1 Cost assumptions

7.1.1 Fabrication cost assumptions

The costs can be estimated by multiplying the material quantities by suitable rates. Steel prices vary with changing market conditions and depend on strength, shape, and quantity ordered. For the jacket, unit rates have been estimated taking into account internet sources and papers. Rates for leg mating units and fenders in the float over case are missing, to get approximate prices and a rough idea it would be necessary to contact different companies from the sector, for example Trelleborg with a wide experience in float over installation. Jacket weight has been considered 3.100 Tons with 1250 Tons piles. For the SEU concept it has been considered 1.550 Tons for the Jacket weight with 625 Tons piles.

Sub-Item	Rated	
	Unit	Jacket
Steel	€/t	2,550.00
Piles	€/t	630.00
Seafastening and Grillage	€/t	630.00
Loadout by SPMT	€/day	3,000.00

Table 14: Jacket fabrication cost assumptions (31) (32)

On the other hand, for the fabrication costs analysis it has been considered as a base case a topside of 3.800 tonnes (500 MW), a steel rate of 800 €/ton with a manufacturing complexity factor of 300%, resulting on a final steel rate of 2400 €/ton, based on the prices of an offshore steel supplier (31) (33), an estimation for the cost of the High and low voltage equipment as Transformers, Shunt reactors and GIS of 27 mill € (36) and the following assumptions.

Topside Base Case (ton)	Float over	SEU	SEU assisted by barge	Semisubmersible
	Extra weight (ton)	Extra weight (ton)	Extra weight (ton)	Extra weight (ton)
3800	200	800	500	6.200
Total Topside weight	4.000	4.600	4.300	10.000
Seafastening estimation	200	N/A	150	N/A

Table 15: Topside fabrication assumptions

The reasons of these assumptions are as follows:

The Crown State third round 500 MW Offshore Substation. According to crown state sources there is not exist a prototype project for the third round. However, in their studies the crown state has considered as an example a 500 MW offshore substation which is 50 miles from shore (34) and a depth between 40 – 50 m. Also, it has been considered a Topside weight of 3.800 Tons and a Jacket weight of 3.100 Tons taking as an example Hohe See offshore substation which has capacity of 497 MW. (35)

- Float over: Topside will have to be reinforced for its double configuration as it has to be dimensioned for a configuration during the transportation and another configuration once the topside is sitting on the jacket. For this reason it has been considered for this concept an extra weight of 200 Tons.
- SEU: For this concept it has been considered to have a higher extra weight than the float over and the SEU assisted by barge as the topside has to be water tight. This condition will increase the amount of steel. Furthermore, for this concept are required 4 heavy legs which will also increase the steel required, resulting in an assumption of a total extra weight of 800 Tons.
- SEU assisted by barge: This concept will have the lightest topside. However, it has been considered to have a higher weight than the float over because of the required 4 legs, resulting in an extra weight of 500 Tons.
- Semisubmersible: this concept would have the highest assumption regarding to the extra weight because of the obvious bigger size of its structure. It has been taken as a reference the weight of the project OSS Dolwin beta which was 20.000 tonnes and a capacity of 900 MW. For this study as mentioned before it has been considered a OSS with a capacity of 500 MW, therefore it has been assumed a 50% of the Dolwin beta weight

It must be taken into account that the weight provided in this analysis belong to a theoretical basic design. Therefore, it has been considered to apply a contingency factor for each scenario based on estimating inaccuracy, design growth contingency and a contingency factor for each of the installation methodologies based on the analysis carried out in section 6.

For each scenario it has been assumed the same values for the estimating inaccuracy and design growth contingency for each installation methodology, as follows:

- Conceptual design – Estimating inaccuracy: 5% Base weight increase
- Conceptual design – Design Growth contingency: 5% Base weight increase

Once a detail design is on place these contingency factors would be lower. At this stage most likely there will be to possible scenarios, a first detail design which the fabricator would use for the steel purchase order and a design As For Construction. Finally, it shall be added construction weighed factor. The following values are not used for this study but for a better understanding they have been added.

- Detail design (Material Order) – Estimating inaccuracy: 2.5% Base weight increase
- Detail design (Material Order) – Design Growth contingency: 2.5% Base weight increase
- Detail design (AFC) – Estimating inaccuracy: 5% Base weight increase
- Detail design (AFC) – Design Growth contingency: 5% Base weight increase
- Construction weighed – Estimating inaccuracy: 5% Base weight increase
- Construction weighed – Design Growth contingency: 5% Base weight increase

For each installation methodology it has been consider a particular contingency factor.

- Floatover: 4 %. This concept will have a high contingency factor as a result of the reinforcement of the topside, the double configuration design of the topside (transportation and operational) the loads during the transportation and the wider gap at the top of the jacket for the entrance of the jacket which will require extra contingency factor
- SEU: 5 %. This concept has the higher contingency risk as a result of its water tight topside, its lack of hydrodynamic properties, risk of capsize plus the required reinforce of the topside at the joints between the topside and the SEU legs.

- SEU assisted by barge: 3 %. This concept has a lower factor than the float-over it has a less complex transportation configuration and the jacket design does not required to be modified

- Semisubmersible: 1 %. It has been considered only 1 percent as a result of its solid design and for the robustness structure of the semisubmersible and the absence of any sea-fastening and grillage as the topside is not exposed to the same transportation loads as any of the other concepts. Furthermore, it installation does not require risk operations

Summarising, it will be considered and overall contingency factor for each solution as followew:

- Float-over: 14 % overall contingency factor
- SEU: 15 % overall contingency factor
- SEU assisted by barge: 13 % overall contingency factor
- Semisubersible: 11 % overall contingency factor

This contingency factor would affect the fabrication costs and they will be only applied to the manufacturing items: Topside steel, jacket steel and piles steel. It would have a higher impact on the semisubmersible as a result of the amount of steel required for this concept, followed by the float-over as a result of it bigger jacket and reinforced topside and the SEU which will required extra steel for its water tight topside. The less affected concept would be the SEU assisted by barge concept.

7.1.2 Transport and installation assumptions

The costs have been estimated by multiplying the day rate of the vessels involve in the transportation and installation operations by the time sailing to site and installation time, an extra time due to weather delay has been applied in both cases. As an example it has been considered an installation weather window of two weeks for the jacket in the float over scenario, considering a likelihood of 7 operational days to perform the installation of the Jacket. Also, the rates considered for the analysis belong to the installation season in northern Europe which has been considered between mid-June to mid-September. As result of that those rates would be the most expensive rates along the year and in winter the cheapest one. An example has been added for a Jack up Vessel.

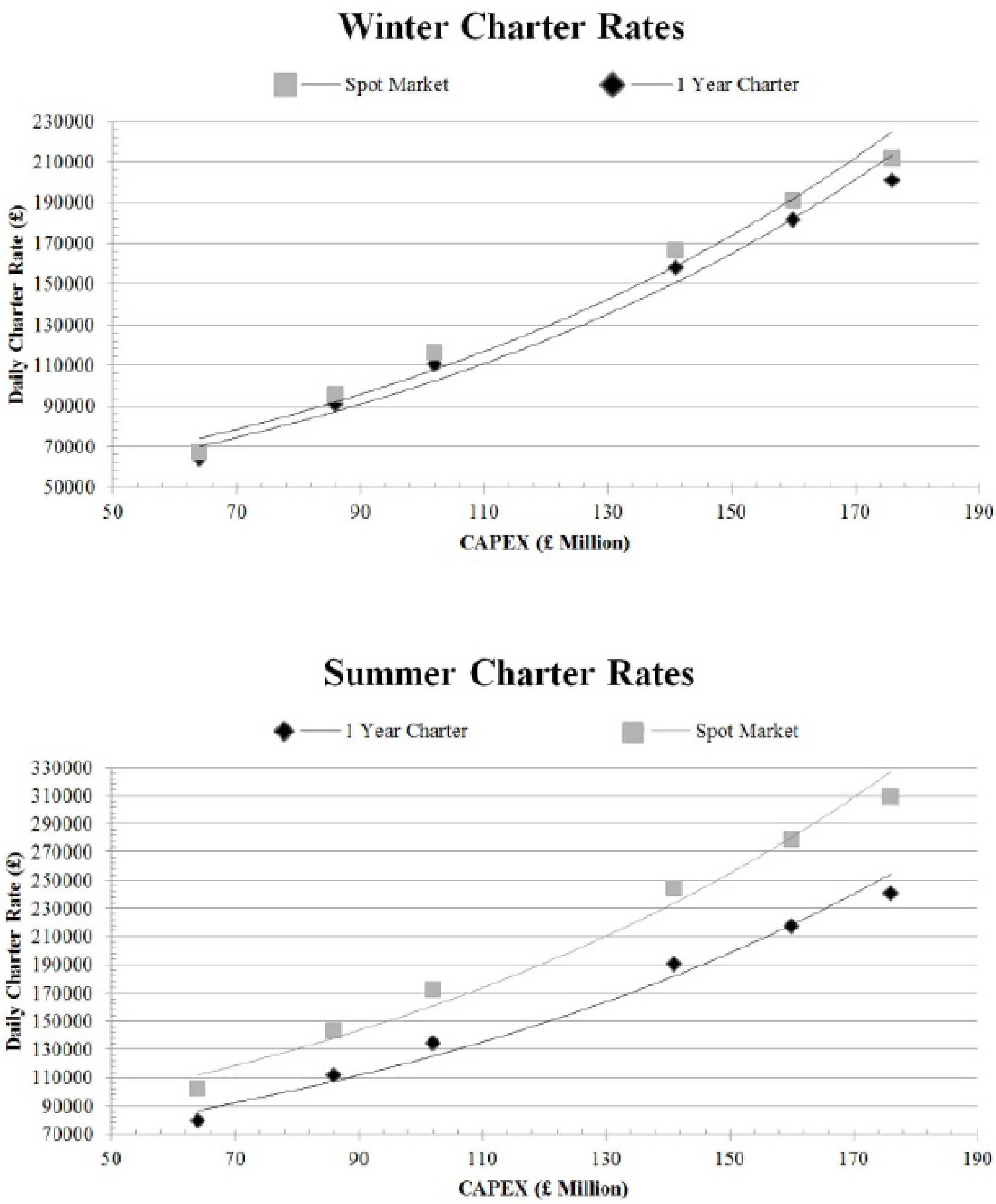

Figure 27: Seasonality influence for wind turbine jack-up vessels

In addition, the day rate of special equipment required during the installation as grouting, jacking, pilling hammer, WROV, etc. have been added. All the information with regard to the day rate of the special equipment has been founded in internet, for those values which were not found it on internet it has been given a value within an order of magnitude.

Vessel required	Rate	
	Mob/Demob (€)	Hire price (€/day)
Barge	200,000	15,000
Heavy lift vessel (lift capacity < 4000 ton)	1,000,000	270,000
Tug	N/A	10,000
Heavy lift vessel (lift capacity > 4000 ton)	1,000,000	400,000
Anchor handling Vessel	N/A	50,000
Offshore supply vessel	N/A	4,500

Table 16: Day rate estimation for the vessel required

Special equipment required	Rate	
	Mob/Demob (€)	Hire price (€/day)
Grouting equipment	250,000	50,000
Piling hammer	800,000	25,000
WROV	40,000	4,000
ROV	35,000	3,500
Mooring system	Cost (€)	
Mooring lines	1,698,000	N/A
Anchors	4,170,000.00	N/A

Table 17: Day rate estimation for the special equipment required

7.2 Cost Scenarios

For the analysis of these theoretical scenarios, it will be taken the conditions afore mentioned:

- Distance of 50 miles from the shore to the site.
- Depth of 40 - 50 m at the site

7.2.1 Float over

a) Jacket Float over

The jacket serves sleeves at the end of each leg through which the piles will be driven. Therefore, the template is not required. Instead of a template, a mud mat would be required to prevent the jacket from sinking into the soil.

The main activities to perform are sequenced below:

- Manufacturing of piles and jacket at the appointed yard
- Transport by SPMTs or similar to the quayside
- Load-out on the deck of the barge or installation vessel.
- Transport of jacket and piles to installation site
- Lowering of jacket onto the seabed and levelling
- Driving of piles
- Survey of piles to check of compliance to pile installation tolerances according to method statements, and perform pile cutting works accordingly, if required
- Grouting procedure and testing

The mobilisation for the transport and installation is the following:

- Barge
- Heavy lift vessel with grouting equipment, piling hammer and ROV
- Anchor handling vessel

The operations performed by each of the vessels addressed and reported above are assumed, for the cost scenario suggested, that would require the following net days to complete the tasks assigned, including mob/demob, outfitting, transportation, logistic delay and weather down time:

Vessels	Net days
Barge	50
Heavy Lift Vessel	15
Anchor Handling Vessel	35

Table 18: T&I vessels required- Jacket Floatover

Jacket Floatover							
Fabrication	**Item**	**Sub-Item**	**Comments**	**Rate**		**Weight (ton)**	**Manufacturing Cost (€)**
				Unit			
Manufacturing	Jacket			€/t	2,550.00	3,100.00	7,905,000.00 €
	Piles			€/t	630.00	1,250.00	787,500.00 €
Load Out	Seafastening and Grillage			€/t	630.00	100.00	63,000.00 €
	Jacket & Piles Load-out		Loadout by SPMT	€/day	3,000.00	21.00	63,000.00 €
Total							8,818,500.00 €

Transport & Instalation	**Item**	**Sub-Item**	**Comments**	**Rate**		**Net days**	**T&I Cost (€)**
				Unit	Hire price (€)		
	Barge	Mob/Demob		€	200,000.00	-	200,000.00
		Activity		€/day	15,000.00	50	750,000.00
	Heavy Lift Vessel	Mob/Demob		€	1,000,000.00	-	1,000,000.00
		Activity		€/day	400,000.00	15	6,000,000.00
	Anchor Handling Vessel			€/day	50,000.00	35	1,750,000.00
Total							9,700,000.00

TOTAL	18,518,500.00 €

Table 19: Cost Estimation – Jacket Float-over

b) Topside float over

The main activities to perform are sequenced below:

- Manufacturing of the topside at the yard
- Load out on the barge
- Transport of the Topside to Installation Site by anchor handling vessels
- Float-Over Stand-off
- Docking of Installation Vessel
- Pre-mating position of the installation vessel
- Mating of integrated deck to jacket
- Post mating of installation vessel
- Un-docking of Installation Vessel

The mobilisation for the transport and installation is the following:

- Barge with Deck Support Units, ballast system, jacking system and welding equipment
- Anchor handling vessel

The assumptions made to estimate the cost of the operations performed by each of the vessels addressed and reported above result in the following net days including mob/demob, outfitting, transportation, logistic delay and weather down time:

It has been estimated an excess of weight in the topside of 200 ton to adapt it to the float over operation requirements in respect to a topside installed by lifting.

Vessels	Net days
Barge	70
Anchor Handling Vessel	35
Tug	15

Table 20: Installation vessels required - Topside Float over

Topside Floatover							
Fabrication	**Item**	**Sub-Item**	**Comments**	Rate		**Weight (ton)**	**Manufacturing Cost (€)**
				Unit			
Equipment	Transformers, Shunt Reactors, GIS, HVAC System			€	27,000,000.00	-	27,000,000.00 €
Manufacturing	Steel			€/t	2,400.00	4000	9,600,000.00 €
	Seafastening and Grillage			€/t	630.00	200	126,000.00 €
Load Out	Topside		Loadout by SPMT	€/day	3,000.00	21	63,000.00 €
Total							36,789,000.00 €

Transport & Installation	**Item**	**Sub-Item**	**Comments**	Rate		**Net days**	**T&I Cost (€)**
				Unit	Hire price (€)		
	Barge	Mob/Demob		€	200,000	-	200,000.00
		Activity		€/day	15,000.00	70	1,050,000.00
	Anchor Handling Vessel			€/day	50,000.00	35	7,000,000.00
	Tug		3 Tugs are required	€/day	10,000.00	15	450,000.00
Total							8,700,000.00

TOTAL	45,489,000.00 €

Table 21: Cost Estimation - Topside Float over

Total cost assessment Float over installation method - Jacket FAB/Installation cost + Topside FAB/Installation cost: 18,518,500 € + 45,489,000 €

Total Cost – 64,007,500 € // ***Total Cost Contingency weight*** – 64,007,500 + 1,216,950 + 1,344,000 = 66,568,450 €

7.2.2 Self-Elevating Unit

a) Jacket SEU

The main activities to perform are sequenced below:

- Manufacturing of piles and jacket/template at the appointed yard
- Transport by SPMTs or similar to the quayside
- Load-out on the deck of the barge.
- Transport of jacket/template and piles to Installation Site
- Jacking-up at Site or mooring the installation vessel
- Lowering of jacket/template onto the seabed and levelling
- Piling of piles
- Survey of piles to check of compliance to pile installation tolerances according to method statements, and perform pile cutting works accordingly, if required
- Grouting procedure and testing

The mobilisation for the transport and installation is the following:

- Barge
- Heavy lift vessel or Jack-up with grouting equipment, piling hammer and ROV
- Anchor handling vessel

The assumptions made to estimate the cost of the operations performed by each of the vessels addressed and reported above result in the following net days including mob/demob, outfitting, transportation, logistic delay and weather down time:

Vessels	Net days
Barge	50
Heavy Lift Vessel	15
Anchor Handling Vessel	35

Table 22: T&I vessels required- Jacket SEU

Jacket SEU							
Fabrication	**Item**	**Sub-Item**	**Comments**	Rate		**Weight (ton)**	**Manufacturing Cost (€)**
				Unit			
Manufacturing	Jacket			€/t	2,550.00	1,550.00	3,952,500.00 €
	Piles			€/t	630.00	625.00	393,750.00 €
Load Out	Seafastening and Grillage			€/t	630.00	100.00	63,000.00 €
	Jacket & Piles Load-out		Loadout by SPMT	€/day	3,000.00	21.00	63,000.00 €
Total							4,472,250.00 €

Transport & Instalation	**Item**	**Sub-Item**	**Comments**	Rate		**Net days**	**T&I Cost (€)**
				Unit	Hire price (€)		
	Barge	Mob/Demob		€	200,000.00	-	200,000.00
		Activity		€/day	15,000.00	50	750,000.00
	Heavy Lift Vessel	Mob/Demob		€	1,000,000.00	-	1,000,000.00
		Activity		€/day	270,000.00	15	4,050,000.00
	Anchor Handling Vessel			€/day	50,000.00	35	1,750,000.00
Total							7,750,000.00

TOTAL	12,222,250.00 €

Table 23: Cost Estimation: Jacket SEU

b) Topside SEU

The main activities to perform are sequenced below:

- Manufacturing of the topside and legs at the yard
- Float Off
- Transport of the platform to Installation Site
- Positioning of the unit
- Station keeping
- Jacking down
- Welding/Grouting legs to the jacket

The mobilisation for the transport and installation is the following:

- Offshore supply vessel with grouting equipment and ROV
- Anchor handling vessel

The assumptions made to estimate the cost of the operations performed by each of the vessels addressed and reported above result in the following net days including mob/demob, outfitting, transportation, logistic delay and weatherdown time:

It has been estimated an excess of weight in the topside of 800 tn in respect to a topside installed by lifting.

Vessels	Net days
Anchor Handling Vessel	55
Offshore supply vessel	23
Tug	15

Table 24: Installation vessels required - Topside Float over

SEU

Fabrication	Item	Sub-Item	Comments	Rate		Weight (ton)	Manufacturing Price (€)
				Unit			
Equipment	Transformers, Shunt Reactors, GIS, HVAC System			€	27,000,000.00	-	27,000,000.00 €
Manufacturing	Steel			€/t	2,400.00	4600	11,040,000.00 €
Float off	Drydock	Undocking		€	25,000.00	-	25,000.00 €
Total							38,065,000.00 €

Transport & Installation	Item	Sub-Item	Comments	Rate		Net days	Installation Price (€)
				Unit			
	Offshore suply vessel			€/day	4,500.00	23	103,500.00 €
	Grouting Equipment	Mob/Demob		€	250,000	-	250,000.00 €
		Activity		€/day	50,000.00	23	1,150,000.00 €
	ROV	Mob/Demob		€	35,000.00	-	35,000.00 €
		Activity		€/day	3,500.00	23	80,500.00 €
	Anchor Handling Vessel			€/day	50,000.00	55	2,750,000.00 €
	Tug		3 Tugs are required, station keeping	€/day	10,000.00	17	510,000.00 €
Total							4,879,000.00 €

TOTAL	42,944,000.00 €

Table 25: Cost Estimation - SEU Topside

Total cost assessment SEU installation method - Jacket FAB/Installation cost + Topside FAB/Installation cost: 12,222,250 € + 42,944,000 €

Total Cost – 55,166,250 € // ***Total Cost Contingency weight*** – 55,166,250 + 565,012.50 + 1,656,000 = 57,387,262.50 €

c) SEU assisted by barge

The main activities to perform are sequenced below:

- Manufacturing of the topside and legs at the yard
- Load out
- Transport of the topside to Installation Site
- Positioning of the unit
- Station keeping
- Jacking down
- Welding/Grouting legs to the jacket

The mobilisation for the transport and installation is the following:

- Barge
- Offshore supply vessel with grouting equipment and ROV
- Anchor handling vessel

The assumptions made to estimate the cost of the operations performed by each of the vessels addressed and reported above result in the following net days including mob/demob, outfitting, transportation, logistic delay and weatherdown time:

It has been estimated an excess of weight in the topside of 500 tn in respect to a topside installed by lifting.

Vessels	Net days
Barge	60
Offshore suply vessel	23
Anchor Handling Vessel	35
Tug	15

Table 26: T&I vessels required- Topside SEU assisted by barge

SEU Assisted by Barge

Fabrication	Item	Sub-Item	Comments	Rate		Weight (ton)	Manufacturing Price (€)
				Unit			
Equipment	Transformers, Shunt Reactors, GIS, HVAC System			€	27,000,000.00	-	27,000,000.00 €
Manufacturing	Steel			€/t	2,400.00	4300	10,320,000.00 €
Load Out	Seafastening and Grillage			€/t	630.00	150	94,500.00 €
	Topside		Loadout by SPMT	€/day	3,000	21	63,000.00 €
Total							37,477,500.00 €

Transport & Installation	Item	Sub-Item	Comments	Rate		Net days	Transport Price (€)
				Unit			
	Barge	Mob/Demob		€	200,000	-	200,000.00 €
		Activity		€/day	15,000.00	60	900,000.00 €
	Offshore suply vessel			€/day	4,500.00	23	103,500.00 €
	Grouting Equipment	Mob/Demob		€	250,000	-	250,000.00 €
		Activity		€/day	50,000.00	23	1,150,000.00 €
	ROV	Mob/Demob		€	35,000.00	-	35,000.00 €
		Activity		€/day	3,500.00	23	80,500.00 €
	Anchor Handling Vessel			€/day	50,000.00	35	1,750,000.00 €
	Tug		3 Tugs are required, station keeping	€/day	10,000.00	15	450,000.00 €
Total							4,919,000.00 €

TOTAL	42,396,500.00 €

Table 27: Cost Estimation - Topside SEU assisted by barge

Total cost assessment SEU-Barge installation method - Jacket FAB/Installation cost + Topside FAB/Installation cost: 12,222,250 € + 42,396,500 €

Total Cost – 54,618,750 € // ***Total Cost Contingency weight –*** 54,618,750 + 565,012.50 + 1,341,600 = 56,525,362.50 €

7.2.3 Semisubmersible

The main activities to perform are sequenced below:

- Manufacturing of the Pontoons, columns and hull at the yard
- Manufacturing of the Topside at the yard
- Load out or Float off
- Transport of the unit to the Installation Site
- Installation of the anchors
- Ballasting the tanks up to operation mode
- Attachment of the mooring lines to the platform

The mobilisation for the transport and installation is the following:

- Anchor handling vessel with WROV

The assumptions made to estimate the cost of the operations performed by each of the vessels addressed and reported above result in the following net days:

It has been estimated an excess of weight in the topside of 6.200 tn respect to a topside installed by lifting

Vessels	Net days
Anchor Handling Vessel	35

Table 28: T&I vessels required- Semisubmersible

Semisubmersible							
Fabrication	Item	Sub-Item	Comments	Rate		Weight (ton)	Manufacturing Price (€)
				Unit			
Equipment	Transformers, Shunt Reactors, GIS, HVAC System			€	27,000,000.00	-	27,000,000.00 €
Manufacturing	Steel			€/t	2,400.00	10000	24,000,000.00 €
Float off	Drydock	Undocking		€	25,000	NA	25,000.00 €
Total							51,025,000.00 €

Transport & Installation	Item	Sub-Item	Comments	Rate		Net days	Installation Price (€)
				Unit			
	Anchor Handling Vessel			€/day	50,000.00	35	1,750,000.00 €
		Mooring lines		€	1,698,000.00	-	1,698,000.00 €
		Anchor	9 - 12 anchors required	€	4,170,000.00	-	4,170,000.00 €
	WROV	Mob/Demob		€	40,000.00	-	40,000.00 €
				€/day	4,000.00	15	60,000.00 €
	Tugs		2 Tugs are required, station keepir	€/day	10,000.00	15	300,000.00 €
Total							8,018,000.00 €

TOTAL	59,043,000.00 €

Table 29: Cost Estimation Semisubmersible

Total cost assessment Semisubmersible installation method - Topside FAB/Installation cost: 59,043,000 €

Total Cost – 59,043,000 € // ***Total Cost Contingency weight*** – 59,043,000 + 2,640,000 = 61,683,000 €

8 CONCLUSION

This document is just a preliminary approach of a technical and economic evaluation based on a fabrication, transport and installation cost estimation for each of the installation methods aforementioned.

This costing methodology follows the main milestones in an offshore substation project (missing the engineering stage) fabrication, load out, transportation and installation of a topside and jacket, except for the submersible scenario. Firstly, the intention of this methodology was to obtain a base scenario in order to have as a benchmark a theoretical offshore substation conceptual design in terms of power capacity, weight and characteristics of the site, depth and distance to shore. As mentioned in section 8, for this goal it was considered an offshore substation from a The Crown of State case study.

The fabrication cost considered is only based on the cost of steel, special equipment required in each case for the different activities involved at the yard and the cost of the electric equipment's within the substation. As all these cost where the result of an internet research and in some cases some of the items were not available on internet a contingency factor was applied in order to obtain a more realistic figure. These fabrication costs were applied to each of the cost scenarios described in chapter 8. The most influence factor was the amount of steel required for each installation concept and their final manufacturing price.

For the installation of the substation the analysis was based on the equipment, vessels, sailing time and installation weather window required to perform the installation of the substation.

After the cost analysis of the different installation methods, the following cost estimations have been obtained (with contingency factor):

- Total cost estimation Float over installation method: Jacket installation cost + Topside installation cost = 66,568,450 €
- Total cost estimation SEU installation method: Jacket/template installation cost by HLV + Topside installation cost = 57,387,262.50 €

- Total cost estimation SEU assisted by barge method: Jacket/template installation cost by HLV + Topside installation cost = 56,525,362.50 €
- Total cost estimation Semisubmersible method: 61,683,000 €

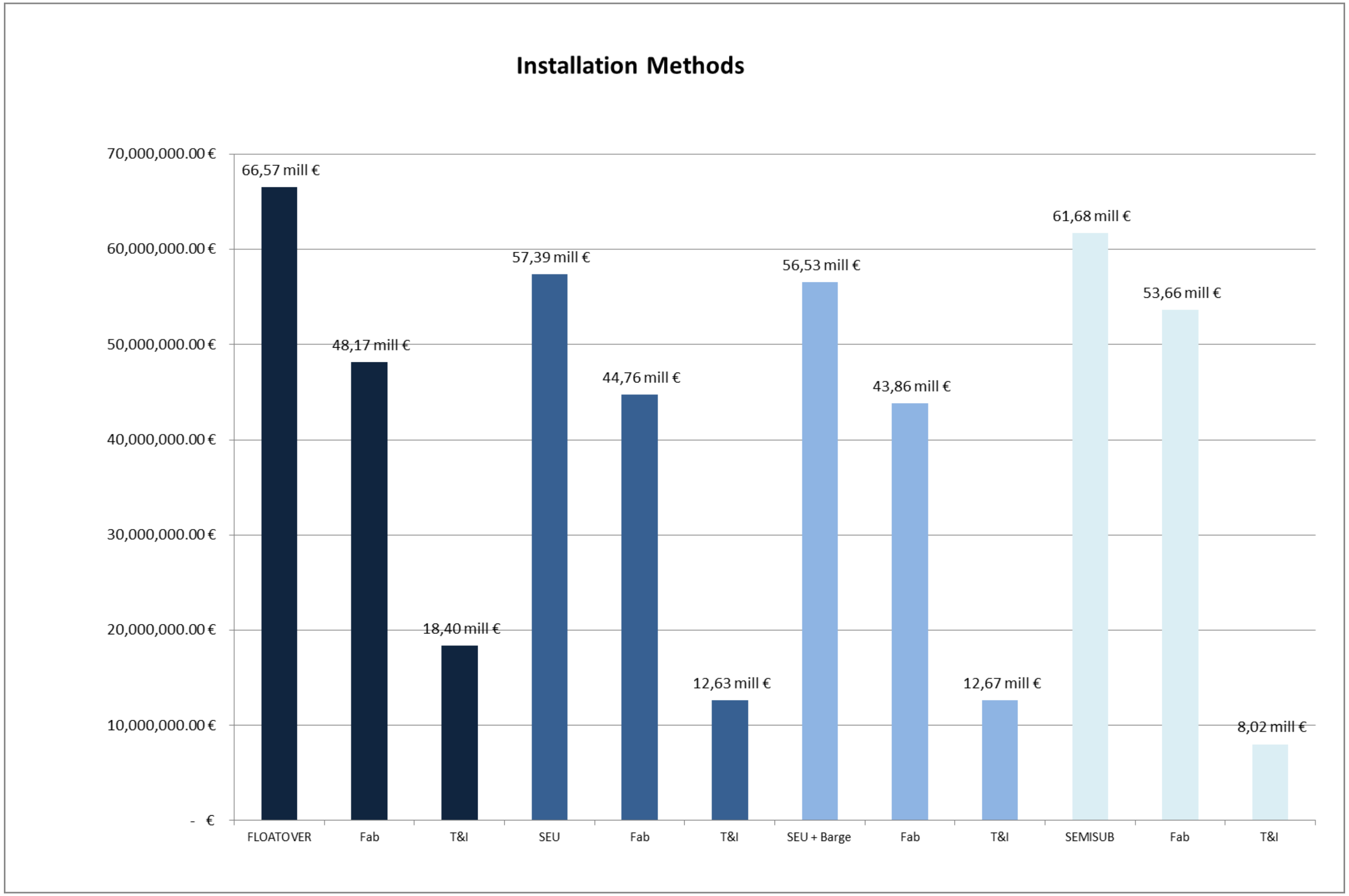

Table 30: Installation Methods - Cost Estimation Comparison

These values from the cost estimation chart must be taken carefully, as explained before; the manufacturing costs are just illustrative because for this study a conceptual design of each solution is missed. However, a conclusion has been obtained.

Firstly, it can be appreciated on the chart that the highest cost is the float-over cost, as a result of the size of the jacket which doubles in size the jacket of the SEUs methods. As it could have been expected, the fabrication cost of the Semisubmersible ends up as the most expensive one among all the solution due to the obvious bigger size of this concept, in spite of not having a jacket. Also, it can be seen how the SEU fabrication cost is less than one million more expensive than the SEU assisted by barge. On the other hand, focusing on the T&I cost, the diagram says that the semisubmersible solution has the cheapest T&I cost, it was expected as a result of the simple installation method of this solution which just consist in the installation of mooring lines with an anchor handling vessel, a kind of vessel much cheaper than any of the other vessels required for the installation in the other solutions. The float over also represents the most expensive solution for its T&I and jacket. It is because the needs to hire a HLV with a higher capacity than the HLV required to install the jacket for the SEUs and the necessity to mobilise the barge longer to be outfitted for the float-over requirements. In the case of the SEUs, the SEU assisted by barge was more expensive because the extra barge needed for the transportation. Nevertheless, technically, the installation of the SEU has a higher risk and a shorter available weather window as a consequence of its worse seakeeping.

With this preliminary cost estimation based just in illustrative cost, it is difficult to have a conclusion of which installation method could be the most reliable option. However analysing the technical criteria and the risk assessment it can be seen how the installation methodology which involve less risky offshore operations during the transportation and installation is the semisubmersible method. Furthermore, because of the simplicity of its installation this method ended up with the highest score in the technical assessment carried out.

Therefore, the semisubmersible installation method would be appointed as the most reliable installation method taking into account the balance between the technical-economic assessment and the risk matrix. It must be mentioned that this method presents important disadvantageous which have been mentioned along this study being the most important one the final size of the OSS and the available yards for its manufactured.

9 RECOMMENDATIONS

As it has been emphasised along this project, there has not been a conceptual design of the offshore substation.

For a more accurate economic study it would be necessary to have at least a conceptual design of the topside and jacket, where applies, for each of the installation methodologies proposed. Once a conceptual design is on place, both fabrication and T&I contractors could be approach to request quotations for many items which has been missed in this study. From the possible contractor it could be obtained prices which will help to support the assumptions made in this project to identify which solution is the most feasible from an economic perspective.

Furthermore, hydrodynamic and structural studies must be carried out to validate some of the technical assumptions that have been made along this project.

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11 APPENDIX A

11.1 SEU

To perform the SEU risk assessment proposed in this study, it have been considered the following activities jacket transportation and installation, which it has been considered the same as the risk assessment described for the jacket in the float over case, and topside transportation and installation based on the SEU concept.

11.1.1 SEU Transport

SEU Transport					
Task	Hazard	Risk	Consequence	Probability	Risk
Departure/Arrival	Unsuitable tug & SEU	Tow cannot proceed	3	2	6
	Adverse Weather	Damage to quay/vessels	1	3	3
	SEU grounded	Damage to SEU	4	2	8
	Tug grounded	Damage to tug	4	2	8
Connect/Disconnect Moorings	Breaking Rope	Personal Injury	4	2	8
	Unsafe access mooring points	Personal Injury	4	2	8
Transport	Adverse weather	Damage to SEU	3	3	9
	Adverse Weather	Lost control over tow	4	2	8
	SEU instability	Damage to SEU	4	2	8
	Collision	Damage to the tug, SEU	4	2	8
Tug break down	Lost control over tow	Damage to tug or SEU	3	2	6
Towing line break	Lost control over tow	Damage to SEU	3	3	9
	Uncontrolled movement of towing wire	Personnel injury	4	2	8

Table 8: SEU Transport - Risk Assessment

11.1.2 SEU Installation

SEU Installation					
Task	Hazard	Risk	Consequence	Probability	Risk
Positioning	Leg-footing collision with jacket	Damage to jacket and jack-up legs	3	2	6
	Anchors/moorings contacts with pipelines or cables	Damage to pipalines or cables and jack-up legs	2	2	4
Jacking and Preloading (If need it)	Leg impact on jacket	Damage to jack-up legs and loss of jacking capability	2	3	6
	Jacking system mechanical or power failure	Cannot elevate above the wave crests and cannot raise legs and move to shelter	4	2	8
	Punch-through	Damage to jacket and jack-up legs	4	2	8
Elevating Operations	Storm overload	Loss of airgap, structural failure and overturning	1	3	3
	Jacking system or leg structural failure	Leg structural damage, loss of jacking capability, difficul recovery operation and collapse	4	2	8
	Collision/impact by other vessel under way	Leg structural damage, loss of jacking capability, difficul recovery operation and collapse	4	2	8

Table 9: SEU Installation - Risk Assessment

11.2 SEU assisted by Barge

This solution proposed for Marinel has as a foundation, a submerged jacket as the concept of the previous point. Therefore, the risk assessment regarding to jacket transportation and Installation is the same as in the float over case. On the other hand, this concept does not have buoyancy so the transportation would be carried out by an installation barge.

11.2.1 SEU assisted by Barge Transportation

SEU Assissted by barge					
Task	Hazard	Risk	Consequence	Probability	Risk
Departure/Arrival	Unsuitable tug & barge	Tow cannot proceed	3	2	6
	Adverse Weather	Damage to quay/vessels	1	3	3
	Barge grounded	Damage to barge	4	2	8
	Tug grounded	Damage to tug	4	2	8
Connect/Disconnect Moorings	Breaking Rope	Personal Injury	4	2	8
	Unsafe access mooring points	Personal Injury	4	2	8
Transport	Adverse weather	Damage to barge/SEU	3	3	9
	Adverse Weather	Lost control over tow	4	2	8
	Barge instability	Damage to barge/SEU	4	2	8
	Collision	Damage to the tug, barge or/SEU	4	2	8
Tug break down	Lost control over tow	Damage to tug or barge	3	2	6
Towing line break	Lost control over tow	Damage to barge	3	3	9
	Uncontrolled movement of towing wire	Personnel injury	4	2	8
Shifting load	Damage to the load and barge	Loss of asset	3	2	6

Table 10: SEU assisted by Barge Transport - Risk assessment

11.2.2 SEU assisted by Barge Installation

SEU Assissted by barge Installation					
Task	**Hazard**	**Risk**	**Consequence**	**Probability**	**Risk**
Positioning	Leg-footing collision with jacket	Damage to jacket and jack-up legs	3	2	6
	Anchors/moorings contacts with pipelines or cables	Damage to pipalines or cables and jack-up legs	2	2	4
Jacking and Preloading (If need it)	Leg impact on jacket	Damage to jack-up legs and loss of jacking capability	2	3	6
	Jacking system mechanical or power failure	Cannot elevate above the wave crests and cannot raise legs and move to shelter	4	2	8
	Punch-through	Damage to jacket and jack-up legs	4	2	8
Disconnect/cut seafastenings	Hot work	Personnel injury & Damage to materials	3	2	6
	Dropped Objects	Personnel injury & Damage to materials	2	3	6
	Incomplete disconection	Damage to objects	3	2	6
	Difficult access	Personnel injury	3	3	9

Table 11: SEU assisted by Barge Installation – Risk Assessment

11.3 Semisubmersible

Semisubmersible risk assessment consists in a transportation risk assessment and a mooring lines installation risk assessment.

11.3.1 Semisubmersible Transportation

Semisubmersible Transport					
Task	**Hazard**	**Risk**	**Consequence**	**Probability**	**Risk**
Departure/Arrival	Unsuitable tug & Semi	Tow cannot proceed	3	2	6
	Adverse weather	Damage to quay/vessels	1	3	3
	Semisubmersible grounded	Damage to Semisubmersible	4	2	8
	Tug grounded	Damage to tug	4	2	8
Connect/Disconnect Moorings	Breaking Rope	Personal Injury	4	2	8
	Unsafe access mooring points	Personal Injury	4	2	8
Transport	Adverse weather	Damage to Semisubmersible	3	3	9
	Adverse Weather	Lost control over tow	4	2	8
	Semisubmersible instability	Damage to Semisubmersible	4	2	8
	Collision	Damage to the tug, Semisubmersible	4	2	8
Tug break down	Lost control over tow	Damage to tug or Semisubmersible	3	2	6
Towing line break	Lost control over tow	Damage to Semisubmersible	3	3	9
	Uncontrolled movement of towing wire	Personnel injury	4	2	8

Table 12: 7.4.1 Semisubmersible Transportation - Risk Assessment

11.3.2 Semisubmersible Installation

Semisubmersible Installation					
Task	Hazard	Risk	Consequence	Probability	Risk
Transfer anchors to AHV	Dropping anchors	Damage to materials	2	2	4
		Personnel Injury	3	2	6
Secure anchor on AHV	Uncontrolled movement of anchors and wires	Personnel Injury	3	2	6
AHV drops Anchor	Drop anchor on subsea structure or cable	Damage to subsea structure	3	2	6
	Winches/wires are in motion	Personnel Injury	3	2	6
	Uncontrolled drop of anchor	Personnel Injury	3	2	6
		Damage to subsea structure	3	2	6
Mooring system	Anchor winch failure	Losing position	2	2	4
	Anchor wire failure	Uncontrolled sweeping wires	2	2	4
		Personnel Injury	3	2	6

Table 13: Semisubmersible Installation - Risk Assessment