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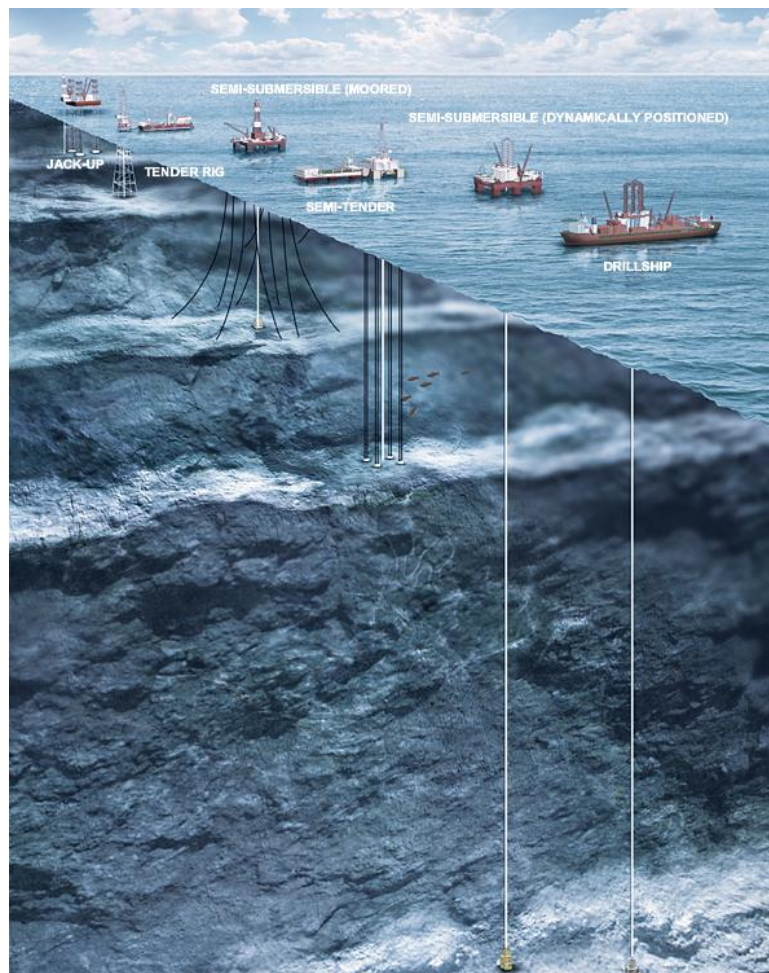
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Writer: Tone Lise Vidvei	..... (Writer's signature)
Faculty supervisor: Arnfinn Nergaard, Professor Offshore Technology UiS  External supervisor(s): Michael Simpson, AGR	
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The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on The Norwegian Continental shelf

# THE ENVIRONMENTAL & COST IMPACT OF DYNAMIC POSITIONED VERSUS ANCHOR POSITIONED SEMI SUBMERSIBLES ON THE NORWEGIAN CONTINENTAL SHELF



MASTER THESIS IN PETROLEUMS TECHNOLOGY  
BY  
TONE LISE VIDVEI

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2

The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on The Norwegian Continental shelf

## PREFACE

This task is written as a part of my master's degree in petroleum technology at the University of Stavanger.

AGR is the largest well management company in Norway, drilling several exploration wells per year. For that reason, I established contact with AGR and the following discussions with AGR provided the opportunity to write my master thesis in collaboration with them. We concluded on a topic that they thought would be of great interest for the petroleum industry on the Norwegian Continental Shelf (NCS). The topic involved environmental, cost and safety impact. This with regards to marine operations of exploration drilling with semi submersibles, the type of rig used most frequently on the NCS for exploration activity.

The process of writing this thesis has been useful learning, as I have established many new contacts and gained a better understanding of which variables and risks that must be considered for keeping a rig in position.

I would like to express my appreciation to the following for their help in this thesis:

Drilling Superintendent Michael Simpson from AGR  
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AGR and their entire team

Best Regards

Tone Lise Vidvei



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## 1 ABBREVIATIONS

AHVT:	Anchor Handling Tug Supply Vessels
AHV:	Anchor Handling Vessel
BOP:	Blow Out Preventer
CO <sub>2</sub> :	Carbon Dioxide
CPT:	Cone Penetration Testing
CWC:	Cold Water Corals
DGPS:	Differential Global Positioning Systems
DNV:	Det Norske Veritas
DP:	Dynamic Positioning
GPS:	Global Positioning Systems
GSS:	Generation of Semi Submersible
HPHT:	High Pressure High Temperature
IMO:	International Maritime Organization
Klif:	The Climate and Pollution Agency
LBL:	Long Base Line
LCD:	Liquid Crystal Display
LMRP:	Lower Marine Riser Package
LWT:	Light Weight Taut Wire
NCS:	Norwegian Continental Shelf
NML:	Naturmangfoldloven
NO <sub>x</sub> :	Nitrogen Oxide
NPD:	Norwegian Petroleum Directorate
OLF:	Oljedirektoratet
PCP:	Permanent Chaser Pennant
PW:	Pennant Wire
ROV:	Remotely Operated Vehicle
SJA:	Safe Job Analysis
SSBL:	Super Short Base Line
SSS:	Side Scan Sonar
Te:	Metric ton
TMC:	Traffic Massage Channel
UPS:	Uninterruptible Power Supply
VOC:	Volatile Organic Compounds
WH:	Well Head
WOW:	Waiting on Weather

## 2 INTRODUCTION

### 2.1 OBJECTIVE OF THE THESIS

The primary objective of this thesis is to compare the environmental and cost impacts of dynamically positioned versus moored semi submersible drilling rigs.

In addition to the environmental concerns the cost of an operation is an important element for the oil and gas industry. As basis for this thesis the cost of an operation is based on day rates of the rig, fuel consumption, AHV rental cost, pre laid anchor rental cost and duration of the operation. These costs are based on the characteristics of the type of rig that is chosen for the operation.

Information and data have been collected from contacts from some drilling contractors such as Dolphin Drilling, Transocean and Seadrill.

A secondary objective of the thesis a calculation model for pre laying anchor and rig move costs are prepared, for both dynamically positioned and anchor positioned semi submersible drilling rigs.

The outcomes of the calculation model were:

- The most cost efficient semi submersible rig
- The rig type with the lower environmental impact

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## 2.2 BACKGROUND OF THESIS

An increased environmental focus on the NCS (as well as globally) has been evident the recent years. The petroleum industry is one of the biggest culprits with regards to burned fuel; its emissions, chemicals and oil spill to the environment. Measures have been studied and performed in the petroleum business with results, but still there can be done more to reduce the emissions and discharges to the environment.

At a meeting with AGR, both the environmental and cost considerations (see Figure 1) of the two types of semi submersibles were highlighted and establishing the variables that contribute to these was agreed. With technical assistance from AGR and other involved companies, these variables are included into the thesis for reasons of comparison.



Figure 1 - Burned emissions from a rig (ref./1/) and USD (ref./2/)

## 2.3 THE NORWEGIAN CONTINENTAL SHELF

The Norwegian Continental Shelf (NCS) is the submarine extension off the coast of Norway (see Figure 2). The NCS is divided into three seas: The North Sea, the Norwegian Sea and the Barents Sea. The North Sea and the Barents Sea consists of mainly shallow water of an average depth of 94m to 230m. However, the Norwegian Sea has an average water depth of 1,600m (ref./3/). The North Sea is the most explored part of the NCS and is less affected by water depth fluctuations and environmental considerations such as corals and arctic conditions.



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The Norwegian oil and gas adventure started in the 70's and since then number of fields and wells expanded. Permanent installations, sub sea production systems, jack-ups, drilling floaters and pipelines for transportation of treated gas are distributed over the NCS. To take care of the sensitive areas on the NCS, particularly in the Norwegian Sea, it is important that sufficient mapping of the seabed activities is documented.

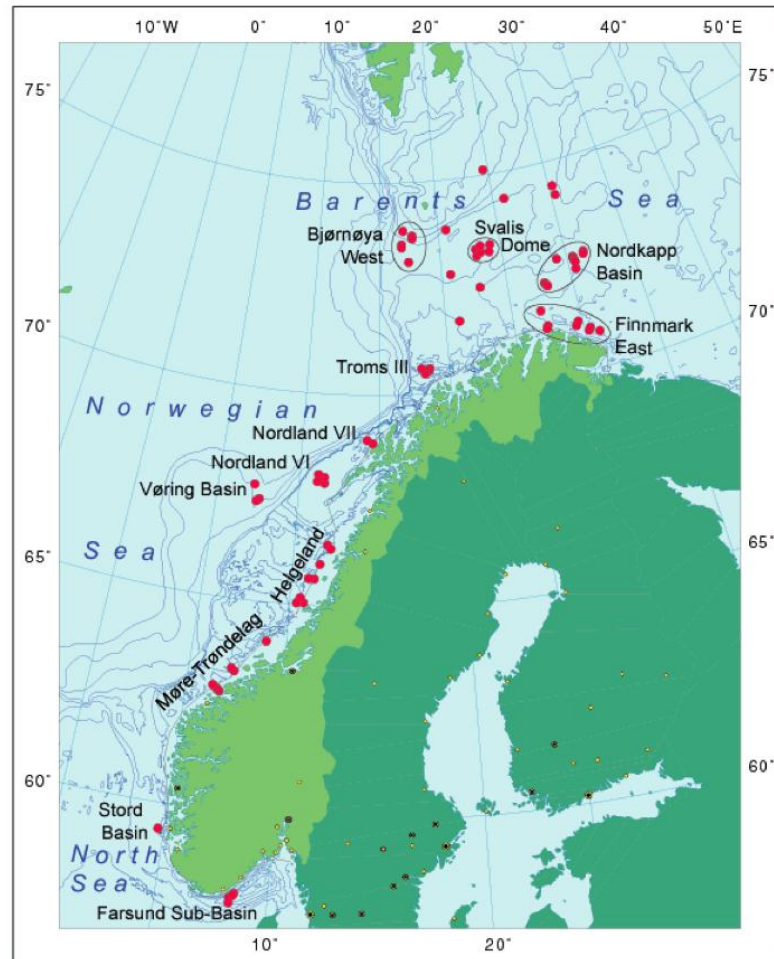


Figure 2 - The Norwegian Continental Shelf. The red dots show drilled core samples (ref./4/).

## 2.4 SEMI SUBMERSIBLE DRILLING CONTRACTORS

Drilling contractors provide drilling rigs to operators. They also provide the equipment, crew and some expertise to drill the wells. On the NCS there is a majority of semi submersibles for exploration drilling (see Table 1). Semi submersibles drilling rigs are easy to move and can be used at different water depths, but not for shallower water than approximately 90m and less.

### 2.4.1 MAIN DRILLING CONTRACTORS ON THE NORWEGIAN CONTINENTAL SHELF

#### ***Dolphin Drilling:***

Provides exploration and production services to the offshore oil and gas industry building on 50 years of experience in offshore drilling. Dolphin Drilling own and

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operates four semi submersibles drilling rigs where three of them are operating on the NCS in exploration drilling (ref./5/).

***Odjell Drilling:***

Provides over 40 years of experience in offshore drilling and is a leading platform drilling contractor involved in operations on floating production platforms. They are now operating with two new 6<sup>th</sup> GSS on the NCS (ref./6/).

***Songa Offshore:***

Has less than ten years of experiences of operating semi submersibles. They own six semi submersibles where three of them are operating on the NCS (ref./7/).

***Transocean:***

The world's largest drilling company with over 50 semi submersibles operating all over the world with about 40 years of experience on the NCS. At the moment, there are seven semi submersibles on contract on the NCS (ref./8/).

***Seadrill:***

A leading offshore deep water drilling company. The company operates 12 semi submersibles for harsh environment where three of them are operating on the NCS (ref./9/).

**Overview over the main drilling contractors operating semi submersibles on the NCS:**

Unit Name	Year/ Upgrated	Generation (GSS)	Depth (ft)	DP/Moored	Drilling Contractor
West Alpha	1986	4	2,000	Moored	Seadrill
West Hercules	2008	6	10,000	DP/Moored	Seadrill
West Venture	2000	5	6,000	DP	Seadrill
Aker Barents	2009	6	10,000	DP/Moored	Transocean
Aker Spitsbergen	2009	6	10,000	DP/Moored	Transocean
Polar Pioneer	1985	4	1,640	Moored	Transocean
Transocean Artic	1986	4	1,640	Moored	Transocean
Transocean Leader	1987/1997	4	4,500	Moored	Transocean
Transocean Winner	1983	3	1,500	Moored	Transocean
Transocean Searcher	1983/1988	3	1,500	Moored	Transocean
Bideford Dolphin	1975/1999	4	1,500	Moored	Dolphin Drilling
Borgland Dolphin	1976/1999	4	1,500	Moored	Dolphin Drilling

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Bredford Dolphin	1976	2	1,500	Moored	Dolphin Drilling
Deepsea Atlantic	2009	6	10,000	DP/Moored	Odfjell Drilling
Deepsea Bergen	1983	3	1,500	Moored	Odfjell Drilling
Songa Dee	1984	2	1,800	Moored	Songa Drilling
Songa Trym	1976	3	1,300	Moored	Songa Drilling
Songa Delta	1980	3	2,300	Moored	Songa Drilling

Table 1 - Overview over the operating semi submersibles on the NCS (ref./10/)

## 2.5 AGR

AGR Well Management is a service of AGR and is the largest independent well management company globally. In addition to well management AGR provides enhanced drilling solutions and seabed intervention. AGRs expertise in extended reach, horizontal wells, under balanced drilling, operations in sensitive areas, deep water and HPHT have led to an impressive track record (ref./11/).

Due to their frequent rig moves and often sensitive environments AGR has focused an interest on anchor handling. To be able to protect the sensitive areas there has been research conducted on environmental impacts from anchors and chains lying on the seabed (ref./12/).

### 3 FIELD DEVELOPMENT/WELL VARIABLES

When planning a new well there are many factors and variables that have to be taken into account.

#### 3.1 FIELD LOCATION & OPERATIONAL WATER DEPTH

Environmental and operational issues depend on where the field is located. In the Norwegian Sea there is registered more sensitive areas than in the North Sea and the Barents Sea. The operational water depths in the Norwegian Sea have an average of 1,600m, while the average is only 230m in the Barents Sea and 94m in the North Sea (ref./3/). Exploration drilling performed by semi submersible drilling rigs is usually conducted at water depths between 100m – 400m for the selected rig contractors (ref./13/). What type of semi submersible drilling rigs preferred at the different water depths is discussed in chapter four; Equipment variables.

Different monitoring methods are used to make a thorough and detailed analysis of the seabed. These methods provide an overview of the seabed structure in different perspectives and photo transects taken with ROV and freeze-frame photos to be able to document sensitivities on the seabed. In order to know the composition of the seabed, sediment samples are taken. These samples give important information of the mooring and catenary touchdown areas. The methods do also address the topographic and geological issues that may be a threat for the mooring of the rig (ref./14/).

##### 3.1.1 SITE SURVEY

A site survey is performed ahead of a mooring operation to prepare for the anchoring of an anchor rig.

Side scan sonar, pinger, mini airgun, high resolution seismic, CPT, environmental camera and multi-beam echo sounder (shown in Figure 3) are commonly used methods when collecting data of the seabed.

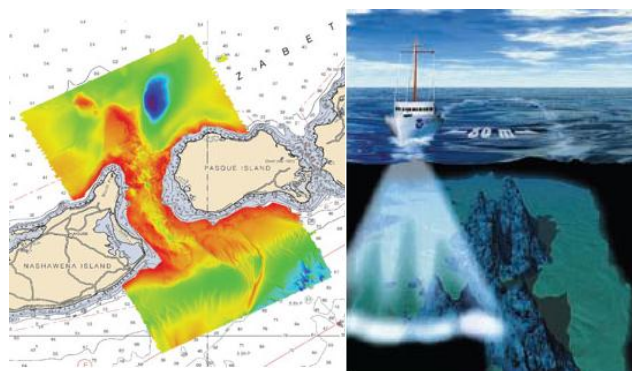


Figure 3 - Multibeam echo sounder (ref./14/).

By using these methods, usually an area of 4x4km or 6x6km is covered (usually dependent on length of anchor chains).

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The side scan sonar is scanning the seabed and creates a mosaic image, which interprets the potential coral structures, pockmarks and iceberg plough marks within the survey area. The multi-beam echo sounder collects depth data and recognizes significant features, which may have an impact of the anchoring. The site survey provides infrastructure, bathymetry, seabed gradients and presence of potential shallow gas under the seabed (illustrated in Figure 4).

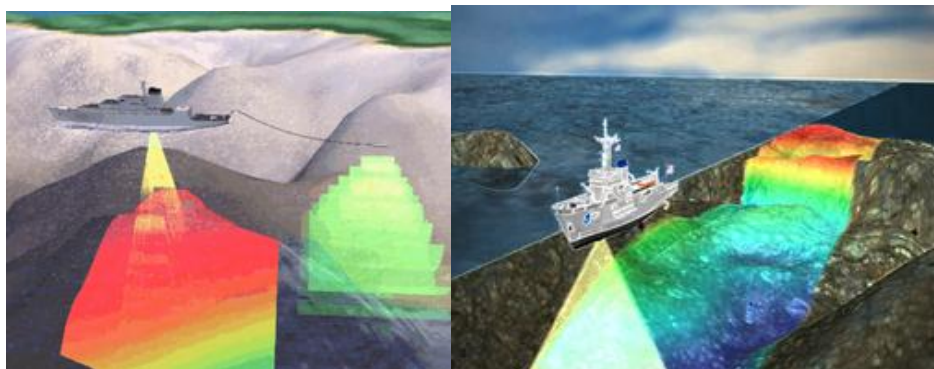


Figure 4 - Multi Beam Sonar and Side Scan Sonar (ref./14/).

## 3.2 SEABED STRUCTURE

Tectonic movement and sediments from various sources create the seabed structure. Before an anchor operation the seabed gradients, seabed inclination and other obstacles must be known, this to be able to determine the anchor's fluke angle and to keep the anchors in place at the seabed. This particularly applies to newer generation of DP rigs as well which has the ability to be positioned with anchors up to a certain depth (2,000m).

### 3.2.1 INFRASTRUCTURE

Infrastructure is the basic map over the seabed where a ROV is used to take clear and colour pictures of the seabed. The images provide an indication of where the sensitive areas and resources are. Depending on the size of the vulnerable areas, the anchor chains will be maneuvered around or over the reef structure.

### 3.2.2 BATHYMETRY

Bathymetry data are used to measure accurate water depth across the area by colour banded images (see Figure 5). Returned backscattered values from the seabed are logged and processed to support the side scan sonar data. Bathymetry data are digitally recorded, obtained by high frequency, narrow, single beam hydrographical echo sounder. This system is used to set up recorded data across the range of water depth expected in the survey area (ref./15/).

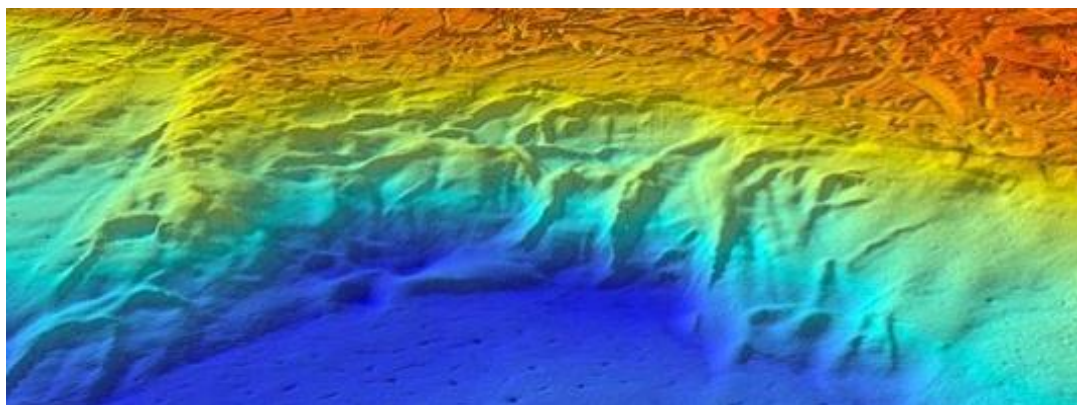


Figure 5 - Bathymetry image. Blue is deep and orange is shallow water depth (ref./16/)

### 3.2.3 SEABED INCLINATION

The seabed inclination has to be known before performing a catenary mooring (most used on the NCS). The information is used when calculating the length and spread angle of the mooring lines. Along the flanks of the iceberg plough marks, seabed gradients are relatively steep. The largest plough marks are up to 100m across and 10m deep (ref./17/).

### 3.2.4 SHALLOW GAS

Presence of unknown gas pockets, so-called shallow gas, can be a hazard and a risk challenge when positioning a rig at the seabed. Shallow gas is detected by 2D or 3D seismic surveys, high frequency acoustic surveys and site surveys. The very high frequency acoustic surveys are capable to penetrate about 25m into the seabed and the presence of shallow gas will be detected (ref./18/). The site survey can also detect the presence of shallow gas.

Pockmarks are created in the seabed all over the world. They are created by gas and water eruption from the sediments (see Figure 6). Pockmarks indicate that there is an activity in the sediments, and there is often existence of light hydrocarbons or deep water corals in these areas (ref./19/). Shallow gas can also be recognized as shallow bright spots and flat spots at the seabed that indicates migration or leakage of gas from the sediments (ref./18/).

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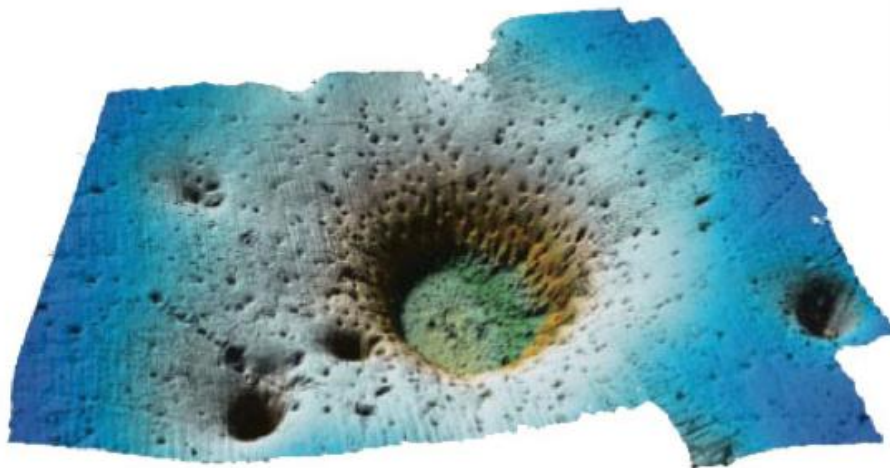


Figure 6 - Pockmarks in the North Sea, taken as a bathymetry image (ref./20/).

The planned well will usually be moved if shallow gas is anticipated. If not, it is planned for setting a conductor before a pilot hole is drilled. Pilot hole is drilled to detect the depth of the gas column. Based on the depth it will be decided where the next casing will be set to avoid any gas influx.

### 3.3 IMPACT OF NUMBER OF WELLS IN A CLUSTER

Number of wells drilled in a cluster may have an impact on a moored rig, because of its narrow range of motion when it is anchored. The moored rig is able to change position within a weather window by pulling in or dropping out some of its rig chain. In relation to an anchored rig, a DP rig is more flexible as it changes its position quicker and there is no need to take into account the anchor chains on the seabed. If the density of e.g. corals, sponges and/or pipelines is high in the spud area, a cluster of wells can be challenging in order to avoid these sensitive areas. These elements must be considered in advance of a drilling operation.

### 3.4 WEATHER WINDOW

A weather window is a specification of maximum allowed weather as wind, waves and currents when performing an operation for a specific time period. The weather window is based on forecast from two different weather forecasters, which are handed over every sixth hour, in front of and during the rig move (ref./21/). Consequently the weather forecast with the worst predicted weather is the one taken into account for the operation.

A conventional anchor handling operation requires typically a 54 hours weather window with wave height less than 3.5m, while pre laid anchors needs approximately 29 hours. These weather windows are required if the

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conventional anchor operation takes approximately 36 hours (4,5hrs per anchor) and 19 hours for prelaying operation (2,4hrs per anchor). During summer time the anchor handling is more straightforward than during winter when the performance of mooring and anchor handling is less than 15% due to the weather (ref./22/). As illustrated in Figure 7 there are better opportunities for pre laying of anchors through the whole year than for conventional anchor handling.

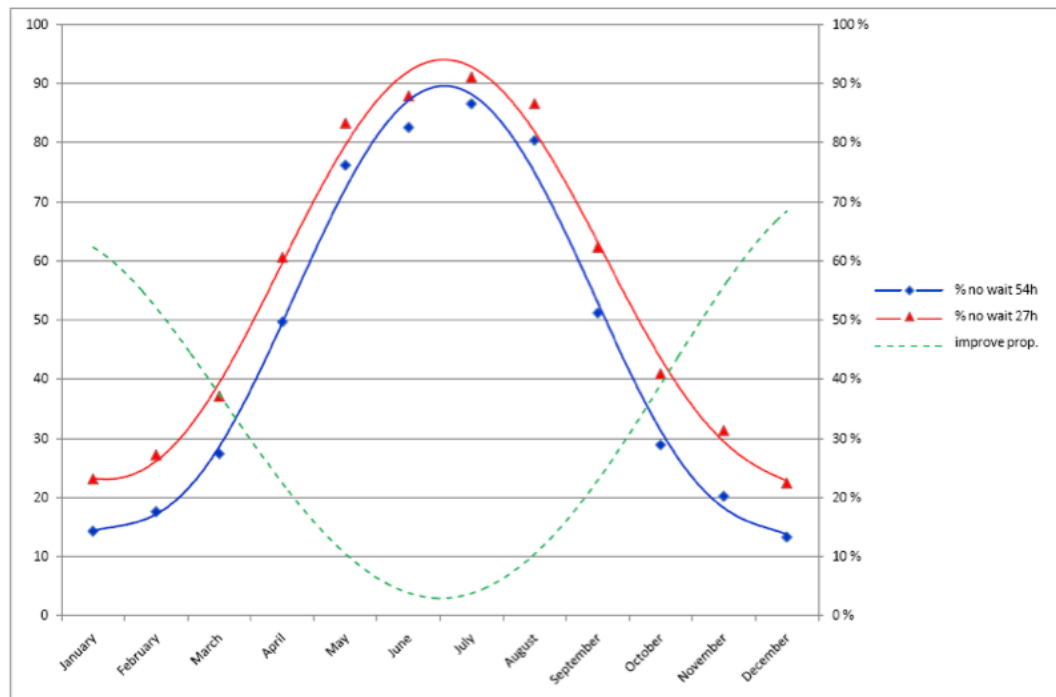


Figure 7 - Weather window for anchor handling. Solid blue line represents the probability of obtaining a 54 hours weather window on first try for conventional anchor handling. The solid red line represents the probability of obtaining a 29 hours weather window on first try for pre laid anchors, and the dashed green line indicates the improved probability (ref./22/).

The Norwegian sector require a weather window 1.5 times of (quote regulation) expected duration of the rig move and anchor handling before the rig move can start (ref./22/). The peak of the graph above there will be an optimal period and less risk of performing a rig move- and mooring operation. In summer time, the transit time will usually be reduced because of less strict weather at sea.

A DP semi submersible drilling rig requires an operational weather window often within the Beaufort scale, in different levels (see Figure 8). This scale describes the conditions on the sea, wave height, wind speed and description of the weather, such as a light breeze, high wind, storm etc. Taken into consideration the weather window, it is allowed a maximum heave of approximately 1.5m when connecting the BOP at the seabed.



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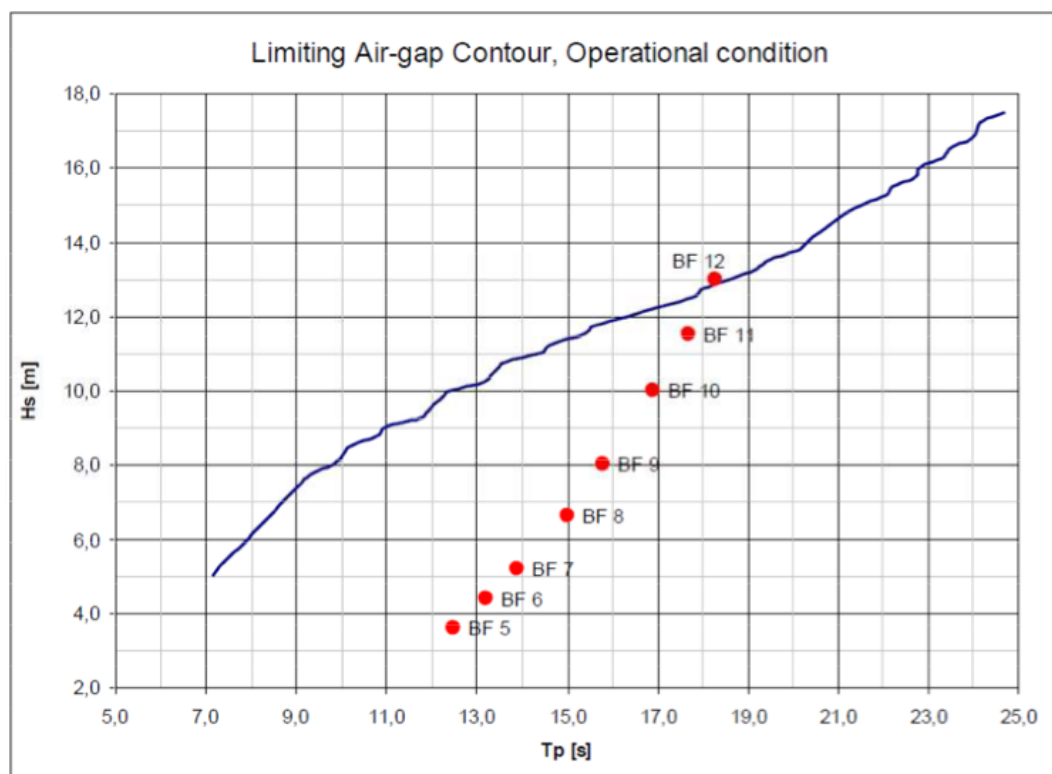


Figure 8 - Beaufort Scale containing wave height (Hs) and rigs periode (Tp) (ref./23/).

Calculating needed weather window, distance of rig move, mooring time and positioning time has to be taken into account. The duration of a rig move depends on the AHV's expected speed used from one location to another or on the DP rigs' speed capability. The capability depends on the draft height and environmental condition. If the transit draft is about 9.7m, the environmental condition may be limited to 6m high waves (Hs). If this wave high exceeds, the rig will be ballasted down to survival draught (ref./23/).

### 3.5 PROJECT RISK FACTORS

Performing an anchor operation involves some risks and consequences for the operation and the surrounding environment.

Project risk factors are future conditions, are something that not yet have occurred and will have a great impact on the operation if they occur. There are high and low levels of risks, some dependent on the value and time consumptions. Due to this work there will be two main categories of risks; operational and environmental.

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### 3.5.1 OPERATIONAL RISK

#### **Weather window**

During a rig move, there are associated risks within the timeline and sudden change in weather. Towing a rig needs a stable weather window to be able to perform a reliable operation.

Anchoring can be critical if the weather suddenly change. Setting anchors can be challenging if the waves, wind and currents becomes too high and too strong. This will also have an effect on the environmental risk, as i.e. sponges, corals and pipelines can be harmed.

Due to station keeping in bad weather a DP rig is able to change the rig heading to reduce the rig movement, while an anchor positioned rig has limited possibilities to adjust the rig heading.

#### **Anchoring**

Anchor handling operation is a critically important and often complicated process. Weight and shape of the anchors, type and weight of mooring line, nature of the soil, water depth, weather conditions and the availability of handling equipment influence the anchor handling (ref./24/).

Failure and degradation of the materials can occur during the operation. Human resources including human actions are risk factors that in the worst case can lead to accidents. On 12<sup>th</sup> March 2007 an AHV accident occurred on the Bourbon Dolphin caused by a lack of anchor handling and stabilization expertise among the crew, while anchoring. It resulted in the loss of eight lives.

Fiber ropes are easy to damage. The fiber rope in Figure 9 was fractured by a 5t buoy that where supposed to keep the buoyancy of the system, but instead was spinning into the link between the fiber and the bottom chain. This can cause a drift off situation if the fiber rope or chain breaks. In case of line rupture, the newer generation of anchor positioned drilling rigs are equipped with DP system that will compensate for this movement.



Figure 9 - Broken fiber rope (ref./25/).

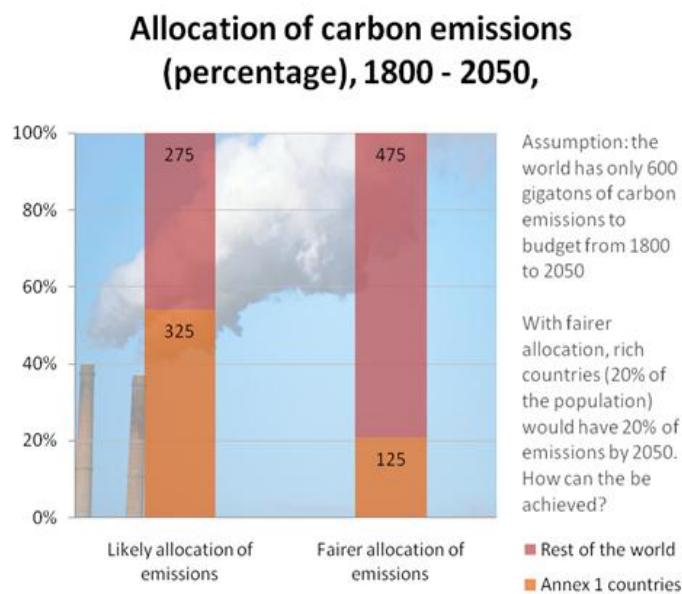
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### Shallow gas

If a shallow gas leakage is detected on a DP rig, it can change location quick while an anchor positioned rig needs time.

## 3.5.2 ENVIRONMENTAL RISK

The North Sea is highly affected by human activity and is one of the busiest areas in the world. The biggest culprits for greenhouse gases, worldwide, are the industrialized nations. On behalf of this, the rich countries have to face the responsibility to address the climate change and support new technology and financing (ref./26/). Allocation of the world carbon emissions is shown in Figure 10. The environmental condition in the Norwegian Sea is estimated to be good, but there are still huge environmental challenges due to change in climate, acidification of the ocean and green house effects. This is a concern regarded to the coral areas, fish population, and acidification of the sea and bird populations.



In order to assess the risk inflicted upon cold water corals (CWC) during anchoring, it has to be performed a risk assessment. The risk analysis is used as a reference document and a decision support for the anchoring analysis. The anchoring analysis gives the best solution for location of anchors, chains and pennant wires etc. Also with regards to pre layed anchors, it is recommended to develop a description of the lying and pick-up procedure (ref./3/).

Figure 10 - Assumptions of the world CO<sub>2</sub> emissions (ref./26/).

Coral survey data confirms the species, presence, condition and distribution of corals. Possible mechanical damage caused by anchor handling and anchors are assessed by an anchor analysis containing the following elements:

- DP-rig
- Stevpris anchors
- Pre-laid w/wo ROV
- Pennant wire grappling
- ROV pick-up buoys
- Lifting of chains over corals with buoys
- Survival positions

## The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

To minimize the risk for damaging the corals (if high density) it is recommended to use DP semi submersibles instead of moored semi submersibles.

As a part of the environmental impact assessment, oil and gas companies are obliged to map the presence of corals and other vulnerable seabed fauna in the intended areas. The mapping is necessary for planning and selection of spud location, to place the anchors, pipelines and cables, and to observe the effect on CWC caused by particles. Monitoring is done with ROV's or cameras to give an indication of the quality of coral life in the sea. CWC are long lived, slow growing and fragile. Factors that generally are believed to make them particularly vulnerable are physical disturbances. The recovery of reefs from physical damage may take decades to centuries (ref./27/).

Emissions to air due to diesel consumption, by the azimuth thrusters and engines of rig and AHV's, lead to acidification. One-third of all CO<sub>2</sub> emissions to the atmosphere absorb to the ocean and cause a pH decrease. The dissolved CO<sub>2</sub> in seawater results in more acidic water that give poorer living conditions and growth for animal life in the sea. Acidification is a worldwide issue, but it is a bigger issue in cold water areas when the CO<sub>2</sub> is more soluble in cold water.

## 4 EQUIPMENT VARIABLES

When the oil and gas industry is going to explore and drill wells they need drilling rigs. There are different types of drilling units for different water depths; jack-up rigs and tender rigs which are used in shallow water, moored semi submersibles for shallow water to deep water and floating units as vessels and dynamic positioned semi submersibles, which can operate in water depths of 10,000 - 12,000 ft. (3,048m - 3,658m).

For anchor positioned semi submersibles, there will be needed anchor handling vessels used to perform the rig move and anchoring.

### 4.1 SEMI-SUBMERSIBLE RIGS

The first existing semi submersible rig and first rig operating on the NCS in the North Sea arrived in 1966. The Ocean Traveller drilled an exploration well of 9,892 ft. (3,015m) in 84 days for Esso, without finding hydrocarbons (ref./2/). Ocean Traveler had big problems with the weather in the North Sea, and the experiences gave the foundation for improvements and stronger structure for the sister platform.

The newer semi submersible drilling rigs can handle deeper water (see Table 2), and because of this there are needed more equipment on board the rig and a longer riser to reach the seabed. This means more mud/drilling fluid to be used, and consequently more mud have to be stored in order to perform a drilling operation. Because of increased need of storage place, the rigs have become bigger which also achieves better stability in harsher environment.

#### Generations of semi submersible drilling rigs:

Generation	Water Depth (ft.)	Water Depth (m)	Years of construction
1.st	600 ft.	200 m	Early 1960s
2.nd	1,000 ft.	300 m	1969 - 1974
3.rd	1,500 ft.	500 m	Early 1980s
4.th	3,000 ft.	1,000 m	1990s
5.th	7,500 ft.	2,500 m	1998 - 2004
6.th	10,000 ft.	3,000 m	2005 →

Table 2 - Approximately water depth on different generations of semis (ref./3/)

The semi submersibles show less motion in waves and are therefore more suitable in strict motion areas. As explained in Wikipedia, a semi submersible offshore drilling rig is a specialized marine vessel with good stability and sea keeping characteristics. When the operational water depth offshore becomes 120 meters or more it is required to use a floating vessel such a semi submersible drilling rig. A semi submersible rig is a stable platform for offshore

## The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

drilling oil and gas, and it is the most common rig because of its ability to move and change position fast (ref./28/).

The rig obtains its buoyancy from ballasted water filled pontoons located below the sea level and wave action. By these ballasted pontoons, the rig can be raised or lowered by adjusting the amount of ballast water, dependent of deep or shallow draft. If the operating deck is located high above the sea level due to good stability, it is less affected by the wave loadings. The pontoons are connected to the operating deck with structural columns. Figure 11 shows a semi submersible rig with its six columns. Due to a rig move the rig will have a transit draft height. This transit draft height is regulated to obtain the rigs stability depending on the transit distance, weather condition and amount of equipment stored on deck. The higher draft height the lower transit speed.



Figure 11 - West Alpha- Anchor positioned drilling rig (ref./29/).

Semi submersibles can be towed into position by AHV's or tugboats and anchored, or moved by and kept in position by their own propellers/ thrusters, called dynamic positioning (see Figure 12). During the last five decades, the drilling rig has increased its capable water depth from 200 meters to more than 3,000 meters, which allows a greater operational area offshore and worldwide.

Factors that decide either to use an anchor positioned rig or dynamically positioned rig depends upon the nature of the seafloor and duration of the operation.

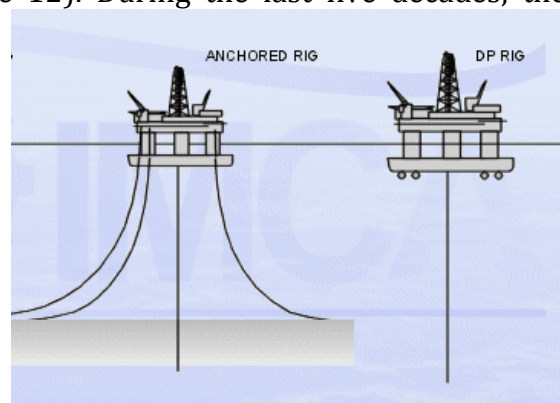


Figure 12 - Anchor Positioned - versus DP Semi Submersible Drilling Rig (ref./30/).

The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

#### 4.1.1 DYNAMIC POSITIONED RIGS

DP semi submersible rigs are floating offshore drilling units which is maintained in position over a fixed location, often by eight computer controlled propellers or thrusters. By DP, it means changing or moving positioning. DP rigs are better suited than moored semi submersible drilling rigs in deep water. The newest DP semi submersibles can today operate in approximately 3,658m (ref./31/). The newest generation of DP rigs do also have anchoring possibilities in water depths up to 2,000m. Figure 13 show a DP rig (5<sup>th</sup> GSS) and a combined DP/moored rig (6<sup>th</sup> GSS).

The factor that separates a DP rig from an anchor positioned rig is the fuel consumption. During a rig move with its own power, it is estimated to use approximately 40m<sup>3</sup> fuel per day, and by operation it will be using approximately 25-50% of this fuel consumption to keep itself in the position, and by bad weather conditions the fuel consumption can be up to three times as high (approx. 120m<sup>3</sup>). If the DP rig is old there can be a need for assistance of AHV under the rig move, to get enough power.



Figure 13 - West Venture (ref./32/) and Deepsea Atlantic (ref./33/).

#### 4.1.2 ANCHOR POSITIONED RIGS

Anchor positioned semi submersible drilling rigs are moored to the seabed and are more suitable for shallow to deeper water depths. Opposite to the DP drilling rig that use its own power to move itself, anchored positioned rigs needs towing vessels (AHV's) to move from one location to another, and to get positioned. How the rig is towed, is managed by the towing vessel captain's and often varies. It is most common to use one vessel towing bridle in front and one that just follows behind. If the rig is older and is heavily loaded there will be a need of two vessels in front, each with its own anchor chain. When the rig arrives at the spud location, the AHV's perform the anchor handling operation of the rig, also called the mooring operation. The rig is then anchored with chains to the seafloor,

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either with conventional anchors or pre-laid anchors. If a conventional rig move is within a short distance, the anchors will be retrieved by four AHV's and kept up to the next location where they are set. This for saving time and reduce cost.

Anchor positioned rigs do also have engines and thrusters for power support during rig move or/and under strict weather conditions during the operation.

On the latest generation of semi submersibles and upgraded semi submersibles it is more common with a combined dynamic positioning system and mooring lines. The combined solution provides a wider weather window for the rig, and it can perform operations on both shallow and deep water. Because of the dynamic positioning system on board there will be no need for AHV's, which also will reduce costs by a rig move. For example Aker Spitsbergen is a 6GSS that can perform exploration and drilling activities in harsh environments and ultra deep water. This rig has the combined system of positioning, where the rig can be self-moored in water depth up to 2,000m. Figure 14 show two older generations of mooring rigs.

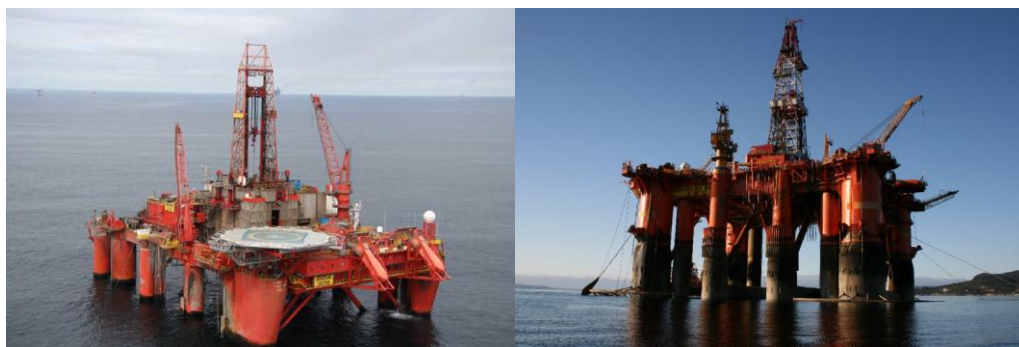


Figure 14 - Borgland Dolphin (ref./34/) and Songa Delta (ref./35/).

## 4.2 BOATS

Boats are needed to pull the rig out to the specified location, to pre-lay anchors on the seabed and complete the mooring when the anchor rig arrives the specified position. For these operations there are two types of boats that can be used; anchor handling vessels (AHV's) and tugboats. Tugboats have during the last years resigned from the rig move market on the NCS, so it will not be mentioned in this scope.

### 4.2.1 ANCHOR HANDLING VESSELS

The main purpose of an anchor handling vessel (illustrated in Figure 15) is to tow the rig to the spud location and handle anchors and chains for keeping the rig in position.

AHV's are equipped with winches for towing, anchor handling and deck space for transportation of mooring equipment. AHV's are designed for anchor handling



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operations and to tow drilling units in deep water, this because of their high horsepower support to increase the bollard pull. The bollard pull can be an attachment for measuring the force of the mooring lines, called tension testing. Tension testing is performed on both conventional rig move and pre lay anchoring to be sure that the anchorlines are within its requirements.



Figure 15 - Anchor handling tug supply vessel (ref./36/).

Newer constructions are hull-designed anchor handling tug supply vessel (AHTV) that has reduced the fuel consumptions dramatically (refs./37/and/38/). With electric propulsions emissions of environmentally hazardous gasses are reduced and has a financial effect (ref./39/).

Anchor handling is a high risk operation. Enormous forces acts on the AHV from the anchors and chains lowered into the sea because of their weight. A critical zone is within an area of 500m where more than one AHV can be involved in addition to the rig. Security is extremely important and the operation is carefully planned. On the basis of this the companies are not looking at the prices of the AHV, but at the operational issues as capacity, previous experiences and skilled personnel.

## 5 POSITIONING METHODS

A semi submersible drilling rig can either be positioned by a dynamic station keeping system or by a mooring stationkeeping system. Today, the newest generations of drilling rigs are capable to use a combination of these two methods.

Factors as water depth, seabed infrastructure and duration of operation decide which position method to be used. Positioning methods can have influences on the sensitive structures at the seabed.

### 5.1 THE MOORING OPERATIONS

Mooring is for keeping an installation or floating facility to a fixed location. The mooring can either be temporary or permanent. In older days the mooring systems were designed for mooring ships for a short time, called temporary mooring. When exploration drilling and production of oil and gas started there was a need for more permanent mooring systems, i.e for longer stationkeeping operations (ref./24/).

After an anchor positioning semi submersible drilling rig has arrived at the new location, anchors are required to provide station keeping while conducting drilling operations. Anchor handling is a critically important and often complicated process. Factors that influence an anchor handling operation is: Weight and shape of the anchors, the nature of the soil, depth of water, the weather conditions, the availability of handling equipment and the type and weight of mooring line. Wind, wave and current acting on the drilling rig cause loads in a mooring system, depending on the location of the drilling rig, drag length and horizontal distance travelled (ref./24/). By performing this kind of operation it has to be performed a safe job analysis (SJA) on board at the AHV. An anchor handling operation requires location, drawings, site surveys, weather reports and information about the infrastructure on the seabed to avoid damaging of i.e. pipelines, corals and sponges. If the vulnerable species are located in the anchor corridors, there are used a nonsymmetrical mooring spread to avoid impact. Presence of pockmarks can have an impact of the stability on the chains and anchors.

An anchor handling operation is quite expensive; the contribution may be 10-20% of the exploration well's cost. Including rig move cost, anchor handling and mooring costs represent the most costly singular operation in offshore exploration drilling (ref./40/).

### 5.1.1 MOORING DETAILS

When the anchored semi submersible drilling rig arrives the spud location, there will be a need for anchors and chains to keep it in position during the drilling operation. There are different mooring systems that are keeping the offshore drilling units in place. The most common systems for semi submersibles on the Norwegian continental shelf are eight points mooring with two mooring lines from each column of the rig. These mooring lines are usually symmetrical spread. The newer generations of semi submersibles are bigger in size than the older ones; therefore it can be needed 10-12 mooring lines may be needed to keep the rig in position. The mooring operation is mainly divided into two options; conventional anchoring and pre-laid anchoring.

The *catenary*- and *taut leg systems* are the two most used methods in oil and gas exploration and production in the world. The *catenary* system is the most common mooring system used under exploration drilling on the NCS, because of temporary mooring and depth of water.

*Catenary systems* consist of chains or wire ropes. This system is most common in shallow to deep water. The *catenary system* arrives at the seabed horizontally, which give horizontally forces at the anchor point (see Figure 16). The huge weight of the mooring line generates most of the restoring forces. Stevpris' anchors are preferred (ref./24/).

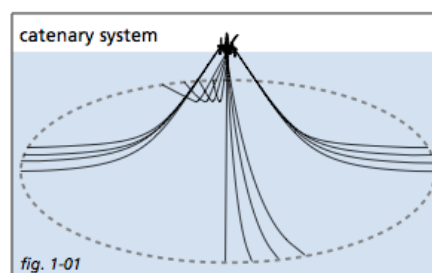


Figure 16 - Catenary System (ref./24/).

*Taut leg systems* are more suited for deep to ultra-deep water. Because of the weight issue the mooring lines are replaced with synthetic ropes. This system arrives the seabed with an angle to resist both horizontal and vertical forces that the restoring forces that are generated by the elasticity of the mooring line. The advantage of a *taut leg system* is that the footprint is smaller which gives a smaller mooring radius, shown in Figure 17 (ref./24/). This method needs heavier anchors than the *Catenary system*; i.e. suction anchors to keep the mooring lines in tension.

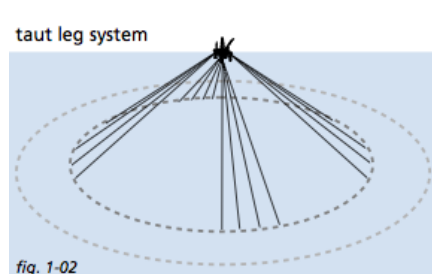


Figure 17 - Taut Leg System (ref./24/).

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### Deployment of conventional Stevpris anchor

Stevpris is a typical anchor deployed on the NCS. This anchor is able to change fluke angle by a simple pin. Depending on the type of stevpris anchor there is usually connected a swivel directly to the shank or the shackle of the anchor. It is extremely important that the swivel is connected bow to bow to minimize fatigue and to keep the tension of the anchor line during the deployment.

To be able to retrieve the anchor there are introduced chasers, which make it easier for the AHV's to picking up the anchors. This was developed after the earlier used pendant wires that were breaking due to the continuous wave movements. This chaser is introduced to the mooring line by pulling it along a slack mooring line or by keeping high tension in the chaser work wire when chasing a tensioned mooring line, which is the best way to perform the chaser operation.

A typical Stevpris anchor deployment is performed by an AHV (see Figure 18), due to limited weight and space on the rig. The anchor is lowered toward the seabed by the mooring line. During the lowering, the AHV has to move slowly forward so that the anchor will land with the back of its shank towards the seafloor. The anchored mooring line is then connected to the rig chain and tension is tested. The bollard pull must always be equal or larger than the line tension, and because of this minimum pendant line length is recommended to be 1.3-1.5 times the water depth (ref./24/).



Figure 18 - Laying out anchors (ref./24/).

### Recovery of Stevpris anchor

When retrieving the anchors the AHV takes the mooring line and pulls it in the opposite direction of the deployment (see Figure 19). When the mooring line is recovered by 1.3-1.5 times water depth the AHV winch is activated and pulls the anchor free from the soil. When the anchor and mooring line are detached from the soil it can be retrieved by a lower tension up to the deck. The AHV stores the mooring line and anchor while the rig pulls into the remaining part of the chain, corresponding to the rig (ref./24/).

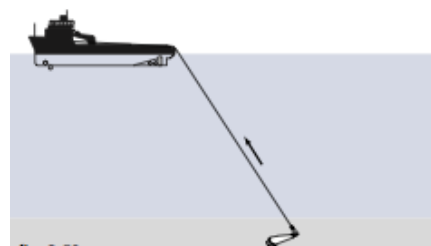


Figure 19-Retrieving anchor (ref./24/).

### MOORING DETAILS

A typical mooring system consists of three different components: mooring line, connectors and anchors.

The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

### **Mooring line**

Type of mooring line is determined from operational water depth and the type of system (*catenary or taut-leg*) to be used. If the chain is used, a stud link is preferred on the semi submersible drilling rigs, and a stud less link for permanent mooring. In deeper water, there is used a longer chain and because of this rig can have problems with keeping the weight of the chain. In this case, there is required a lighter wire rope, either six stand or spiral stand. It has the same breaking load and is more elastic than the chain. More recently, a synthetic fiber rope is the most developed. The fiber rope has less weight (approx. 1/30 of a wires weight in water), high elasticity and is terminated by a special spool, which makes it more robust (ref./24/). Images are illustrated in Figure 20.



Figure 20 - Image of Chain, wire and fibre rope (ref./41/).

### **Connectors**

There exist several types of connectors (shown in Figure 21). For both temporary and permanent mooring, the shackle type is used. The connector link kenter type is used for connecting two chains with the same dimension. Because of shorter fatigue life than the chain, this is used for temporary mooring. If the connecting chains are of different dimension, the connector is pear shaped and is also only used for temporary mooring. Swivels are used both to relieve twist and torque that builds up in the mooring line and they are used as connector between the chain and wire rope (ref./24/).



Figure 21 - Image of Shackles, Kenter Link and Swivels (refs./41/and/42/).

### **Anchors, Chaser and Grapnels**

The most common anchor used for anchoring semi submersibles is the drag embedment anchor (Stevpris Mk5 and Stevshark Mk5). This is designed to penetrate into the seabed and is held in place by the resistance of the soil. Stevpris Mk5 and Stevhark Mk5 cannot withstand large vertical loads. Because of this there has been developed a new vertical load anchor (Stevmanta VLA),

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which penetrates the anchor deeper and withstand both vertical and horizontal loads (ref./24/). Figure 22 illustrates an image of an anchor and a grapnel. Chaser or grapnels are used to reduce the weight of the anchor line or when retrieving the anchors. As seen in Figure 22 the grapnel can easily connect to the anchor chain by its form.



Figure 22 - Image of Anchor and Grapnel (ref./41/).

Type of anchor selected for the operation is based on fluke area, shank and chosen stabilizers. The penetration of the anchor depends on the soil type at the seabed and its fluke angle. Before anchoring soil samples of the seabed will be taken, and dependent on the type of soil the sample depth can be up to 15 meters (ref./24/).

To get an optimal penetration of the Stevpris anchors there are certain angles that are best suited to different types of substrates (ref./43/). Different fluke angles are shown in Figure 23:

- Stiff clay/hard sand: 32°
- Sand: 41°
- Mud/soft clay: 50°

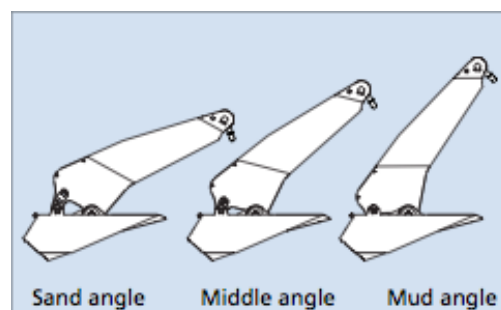


Figure 23 - Fluke angles in different soils (ref./24/).

### 5.1.1.1 CONVENTIONAL RIG MOVE

A conventional rig move is performed on anchor positioned rigs, because they need towing assistance. Conventional rig move meeting finds place approximately two weeks before the operation starts and the work specifications shall be distributed approximately one week before the meeting (ref./1/). The semi submersible drilling rig is rented from a drilling contractor, and the advisory for the rig move is given from a marine operation management, i.e. AGR, Tristein or Odfjell Drilling. Under planning, the weather is the first

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consideration for performing a rig move. Allowing the whole operation to be conducted without interruption a weather window has to be prepared with 1.5 x estimated duration of each identified activity. Since the weather is very uncertain and therefore not trustworthy, it is important that weather forecasts are updated regularly every sixth hour during the rig move.

To perform a conventional rig move it is required to use AHV's, to support the rig on its way to its new spud location. The captain of the leading AHV decides the route of the rig move and number of boats needed to pull or tow the rig to the operational location. If the distance is approximately 210nm, a typical rig move takes about two days depending on the transit speed of the AHV's and the resistance of the rig construction in the sea.

When the rig arrives the given location within the 500m zone it is ready to be moored. Chains for the mooring are leaded through fairleads on the rig legs with an anchor in end. These are pulled out with the AHVs and lowered into the sea in the direction of the specific coordinates of each mooring line. This is done with approximately four AHV's; one keeps the rig in position while the other three are setting the anchors in the opposite direction of each other. Lately, it has become more common to keep the anchors on the bolster behind the AHV's. The rig chain is connected with the PCP wire and anchor on the AHV before the line is lowered into the sea. After the anchors are set there will be performed a 100 year load tension test, called 100/100/10 for wind/wave/current. The test is performed by dragging the chains into the winches of more than 280 metric tons (Te) depending of the size of the rig and water depth. Due to stricter requirements for higher tension testing this has become a problem for the winches to handle. This is one of the reasons why pre-laid anchors are more beneficial than conventional. Figure 24 shows the sequences and duration of a conventional rig move. The pick up anchor time, lay down anchor time and tension testing take approximately 80 hours, disregarded transit time.



**Figure 24 - Sequences of a Conventional rig move of 210nm. Assumed good weather with a transit speed of 4 knots (ref./43/).**

As seen in Figure 25, a typical rig is equipped with eight lines, each of 82 mm thick mooring chain, taking into account a water depth of 300m the chains have to be about 1750m each and able to handle a breaking load of 749 Te. Usually used length of the chains is much less than the actual length, in this case about 200m. The reason why there is still chain left onboard after fairlead is that the rig must be able to change the length of the mooring lines due to weather conditions. The fairlead positions are about 15m above the seafloor. Polyester

## The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

are inserted on all lines, to satisfy the safety factor that has to be  $>1.5$ , calculated from maximum breaking strength divided by real load. The polyester is usually 160mm thick and 400m long, and has better effect the shorter rig chain is.

The polyester is joined with approximately 1200m 76mm thick chain ended with an anchor. When retrieving the anchors a reverse procedure of the anchor handling is performed (ref./44/).



Figure 25 - Conventional anchoring of a moored semi submersible rig (ref./45/).

### 5.1.2 PRE LAID ANCHORS

It is more and more common to use pre laid anchors. This because of less weather dependent operational window, less damage to sensitive areas of the seabed, easier to pretension test, more safe and reduced rig downtime when the only need is to connect the permanent chaser pennant from the platform to the pre laid chains. Based on the site surveys and seabed infrastructure it is entirely up to the operator to decide even it is best to do a pre laying or a conventional anchoring.

The distance to the rig placement location in relation to the AHV's depends on drag calculations and water depth made in the mooring analysis. One AHV is the usually needed for pre laying the anchors. If there are involved two AHV's are involved, the operational time will reduce, while the total AHV time will increase with over 50%. The AHV does also store all the equipment needed for an anchoring operation. If there is more than one AHV, the equipment will be distributed between them.

The pennant line is often equipped with a buoy (see Figure 26) for ROV identification, PCP wire, the anchor

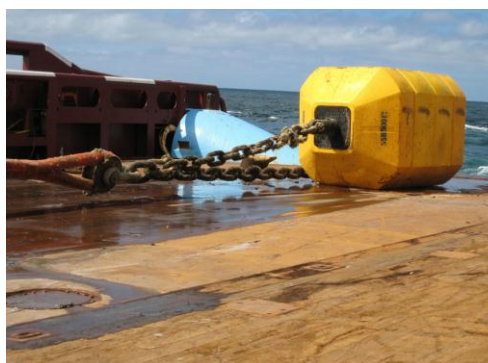


Figure 26 - Buoy on an AHV (ref./24/).



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itself, ground chain and a surface buoy as shown in Figure 27. The pennant line lays in the same direction as the ground chain. After this ground chain fiber is often inserted, this to reduce the weight of the buoy system, and it is more elastic. This fiber insert is not preferred

on pre laid anchors since movements can destroy it i.e. corals and sharp edges which cut the fibers as shown in Figure 28.

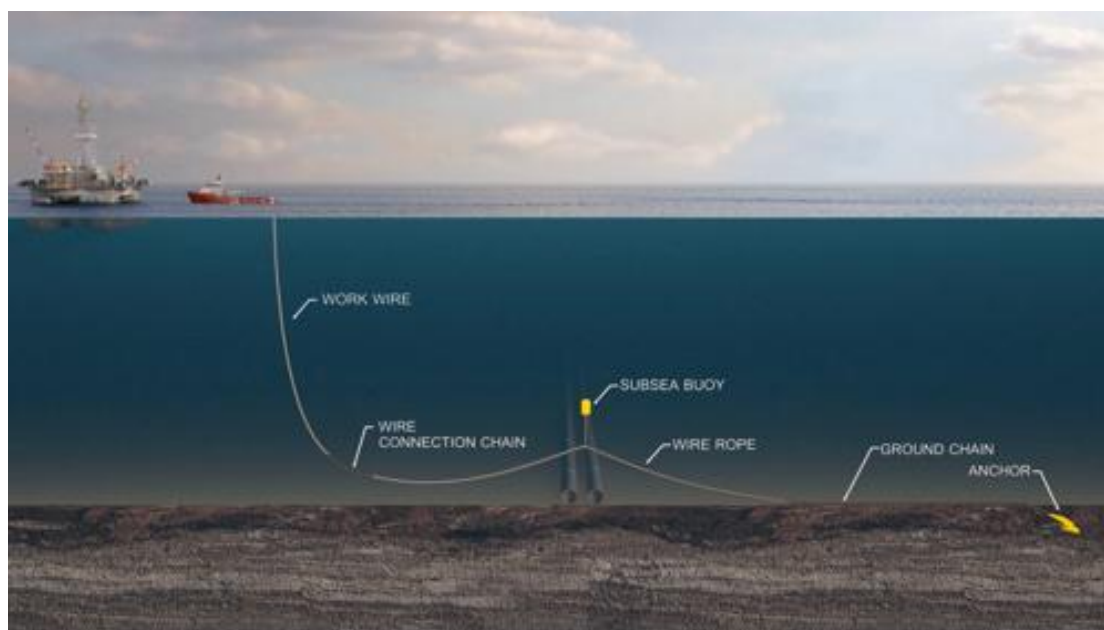


Figure 27 - Pennant buoy system (ref./41/).

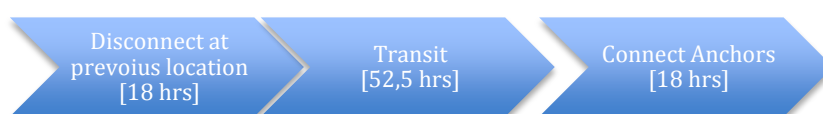
Before the rig is arriving, the anchors are pre tension tested. A normal pretension procedure is to cross tension two opposite lines at the same time (i.e. 1&5, 2&6, 3&7 and 4&8), maintained for 15 minutes each. When retrieving anchors after ended operation,, there can be problems due to the 100 years load testing. If they are stuck at the seabed it will pay to leave the anchors, instead of using valuable time trying to retrieve them.



Figure 28 - Destroyed fiber rope probably harmed by a sharp edge (ref./25/).

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When connecting the pre laid system to the semi submersible, the rig has to be placed approximately 100-500 m from the intended rig location towards pre laid lines. This is done to retain enough chain sag while connecting the rig chain to the ground chain on the AHV. While one AHV is keeping the rig in position there are performed a parallel line connection work between two AHV's, while the fourth AHV picks up the next connecting mooring line. When two anchors are connected one AHV can leave, and the last AHV's continue to connect the remaining mooring lines. Figure 29 shows the sequences and duration of a rig move with pre laid anchors. Disconnection and connection take approximately 36 hours, disregarded transit time.



**Figure 29 - Sequences of a rig move with pre-laid anchors. Assumed the same rig move distance and transit speed (210nm and 4 knots) as for the conventional rig move (ref./43/).**

For a prelay anchoring on water depths of about 330m the bottom chain are pre laid on next location and buoyed off prior to the rig arrival. 15 Te Stevpris anchors are applied and penetrated into the soil at the seabed. Between the anchors and bottom chains there are installed swivels. The bottom chains have to be between 1100-1200m, inserted with 400-800m fiber, ended with chaser stopper segments and finally 160m of rig chains. To be able to retrieve the anchors it has to be installed 60m PW behind the anchors for a ROV pick up system (ref./44/). Figure 30 shows an anchor spread of eight anchors and chains.

## The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

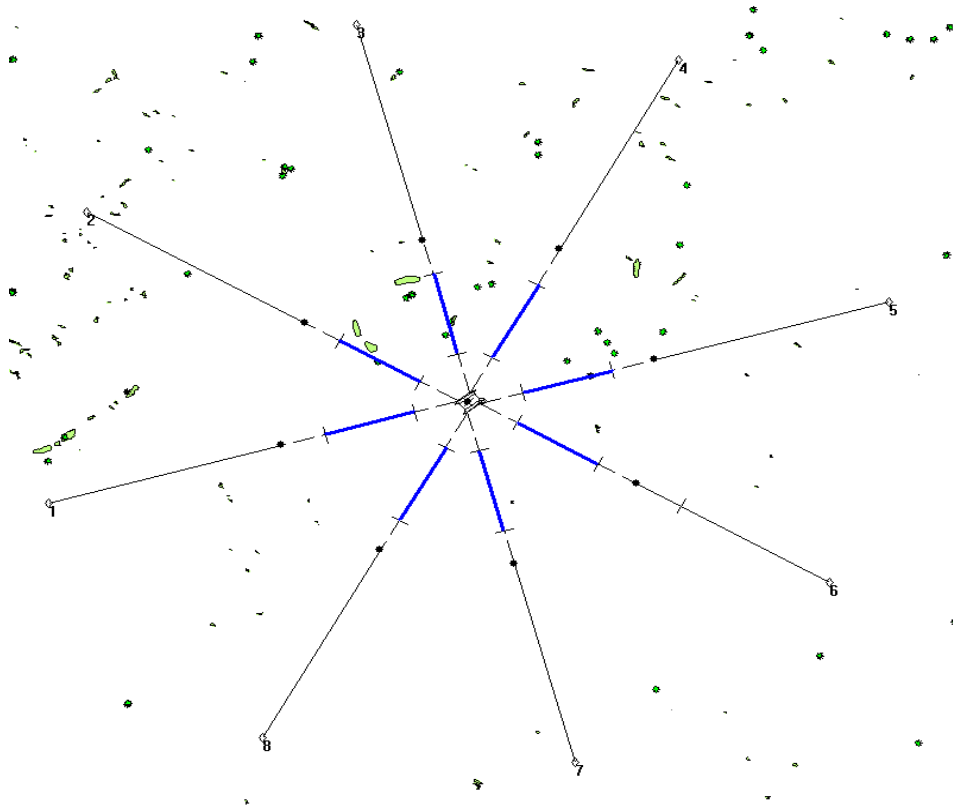


Figure 30 - Anchor spreading. Green areas are identified corals. Blue lines are fiber ropes (ref./46/).

## 5.2 DYNAMIC POSITIONING SYSTEM

The DP system is a very important navigation system, which automatically keeps the rig in place and is especially suitable for deep waters. The DP system is made in that way that the fuel consumption is that low as possible when it is positioned. It is also better in harsh conditions, in deep water operations up to a water depth more than 3000 m, because it can change position more rapidly than an anchored rig. Because of no anchors on the seabed it is more environmental friendly in vulnerable areas. Figure 31 shows one of the newer generations of DP rig.



Figure 31 - Transocean's Aker Barents (ref./47/).

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DP systems were designed for offshore drilling in deeper water with drillships in the 1960's. The concept was to keep the drilling unit in positioning above the well, which went without any problems. The system has during the decades become a popular positioning method and continuously new technology as touch-screen automatic monitoring; high definition LCD monitors and fuel saving engines are evolved.

The DP system consists of acoustic positioning system, gyrocompasses (to determine heading), differential global positioning systems (contains a fixed ground base reference station), and wind sensors with active thrusters and propellers that follow given coordinates (ref./48/).

The acoustic system sends pulses from the rigs transmitter to a receiver at the seabed. The transmitter calculates accurate position with electronics (sound waves in water) to the receiver relative to the rig. Figure 32 gives an illustration of the DP system elements and where they are located in the system.

Gyrocompasses measure the rigs' heading. To be able to do a quick compensation for the external forces, acting on the rig, the force measures have to be transmitted directly to the control computers.

The global positioning system (GPS) provides latitude and longitude references in metres (ref./30/). As explained in Wikipedia: "The GPS is a space-based satellite navigation system that provides location and time information in all weather, anywhere in on Earth, where there are unobstructed lines of sight to four or more GPS satellites. A GPS receiver calculates and transmits the position by precisely timing the signals sent by GPS satellites high above the Earth" (ref./3/). The GPS has an uncertainty of the actual location within 10 metres and because of this a differential global positioning system (DGPS) is used. This system has accuracy greater than one metre by differential corrections from a nearby DGPS site. The satellites are circle the Earth twice a day in a very precise orbit and transmit the signal information back to Earth (ref/49/).

Wind sensors are important for large changes in wind speed, which can disturb the position of the rig. The sensors calculate the wind-induced forces applied to the rig, and provide the change of position by compensate the forces (ref./30/).

The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

### Basic principles of a DP system

On the rig there are stationed control elements as computers and bridge console, controlled by a DP operator.

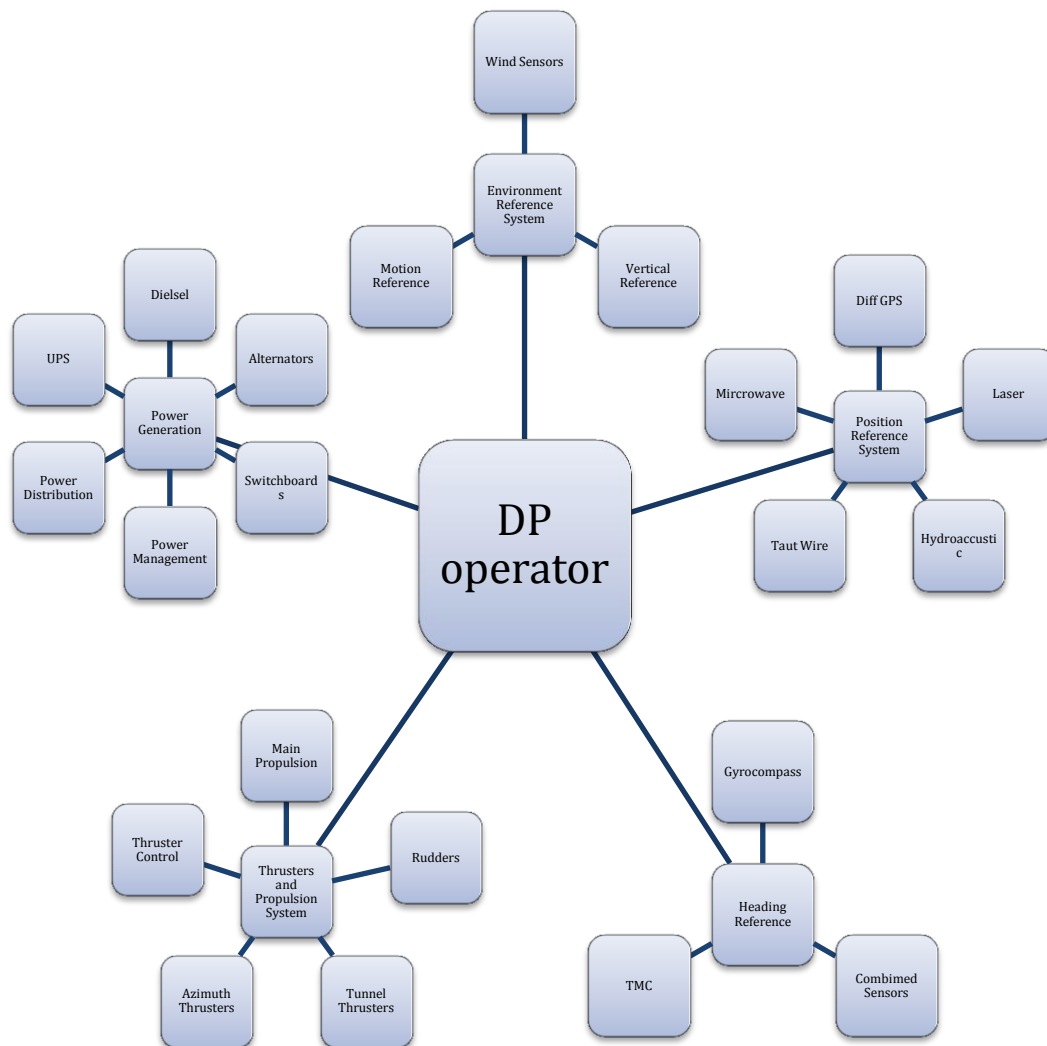


Figure 32 - Overview over the DP system elements (ref./30/).

The International Maritime Organization (IMO) has performed requirements for three different classes of DP systems to protect the environment and safety under operation (ref./3/):

- Class 1 (DP1): Due to a single failure there may occur loss of positioning where an operation can cause small pollution and damage.
- Class 2 (DP2): Due to an active system failure a positioning loss should not occur, but if a static system error occurs there may be a loss of positioning. Operations with this class can cause accidents and pollutions with larger economic consequences than for a DP3.
- Class3 (DP3): Loss of positioning should not occurs from any single failures including fire and flood compartment. DP3 is most used on semi

## The environmental & cost impact of dynamic positioned versus anchor positioned semi submersible rigs on the Norwegian continental shelf

submersibles to protect fatal accidents and severe pollutions with major economical consequences.

A single failure can be (ref./3/):

- Thruster failure
- Generator failure
- Power failure
- Control computer failure
- Positioning reference system failure
- Reference system failure

A typical DP Class 3 system uses six DP reference systems (ref./51/):

- Three Differential Global Positioning Systems (DGPS) consisting of:
  - Seatex DPS200, GPS and GLONASS
  - Seatex DPS116, GPS
  - Seatex DPS132, GPS
- Two High Precision Hydro-acoustics, SimradHiPAP 450 which can be navigated as:
  - HiPAP Super-short baseline (SSBL)
  - HiPAP Long baseline (LBL)
  - HiPAP Multi user
- One Light Weight Taut Wire (LWT), Bandak MK15. Is most accurate to about 500m of water depth (the current will curve the wire at deeper water depths).

Selection of reference systems mainly depends on the operational water depth. Figure 33 gives an example of DP rig move activities and duration. The departure, installation of the seabed transponders and testing of the DP system takes about 20 hours.



**Figure 33 - Sequences of a DP rig move. Rig move distance is the same as for the towing rigs (210nm) but with a transit speed of 6 knots (ref./23/).**

During the drilling operation, it is important to keep the position above the well so the riser is more or less vertical. In this case, a riser angle monitoring is used. If the angle between the riser and the rig exceeds approximately 4 degrees, a drift off/drive off can occur (ref/52/). In addition to downtime, this can cause major incidents like destruction of riser/WH and in the worst case blowout. This is the main reason that the DP system has to be as reliable, but it is still improved to be better. This is discussed in [chapter 6.4](#): Down time/Drift off/Slip off.

## 6 COST IMPACTS

Fuel consumption related to rig move and station keeping semi submersibles are highly dependent on weather, transit speed and type of engines. During the last decade significant updates on diesel engines have reduced fuel consumption.

Some rig contractors indicate that the daily fuel consumption for a dynamic positioned and an anchored positioned drilling rig differs with 10 tonnes per day. The reason for the relative small differences between DP and anchor positioned system is the need for the thrusters assistance in anchored mode. For older semi submersibles the differences in fuel consumption between the two systems will be relatively higher because no fuel is required during the operation for moored rigs. Current fuel cost is about 7000 kr/m<sup>3</sup>, which may account for large cost differences for the right choice or not, either to use a DP rig versus an anchor positioned rig or number of AHV's in an anchor handling operation.

### 6.1 DYNAMIC POSITIONED RIG FUEL COST

A dynamic positioned rig is dependent on its own power, to keep running the dynamic positioned system and its thrusters. This leads to high fuel consumptions, which in turn gives higher fuel cost than an anchored rig. Lately, systems have been developed which consume much less fuel during the station keeping.

Due to differences in the rig contractor's reporting routines there are no definite numbers of how much fuel a DP rig is using during an operation, because the consumption relies on the rigs size and the weather conditions. In a typical normal operation there is good weather. Typical fuel consumption in a normal operation is then 40 m<sup>3</sup>/day. This can increase up to three times due to full transit speed and considerable bad weather (ref./53/).

Fuel consumption when operating the DP system under during drilling will be approximately 25-50% of the full transit speed consumption (ref./50/).

### 6.2 ANCHOR RIG COSTS

An anchor rig can use its thrusters for station keeping support and extra power during rig move. The support of thrusters is to extend the weather under operation.

Taken into account the fuel consumption during the exploration and drilling operation same amount of fuel is consumed on an anchored rig as on a DP rig for

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all rig activities except station keeping. Therefore this fuel usage is not discussed further.

### 6.2.1 COST OF ANCHOR HANDLING VESSELS

AHV's are both used for rig move and anchor handling operations. Number of boats depends on the boat costs and efficiency of the boats. The AHV rental rate depends on the spot market price. The spot market price varies according to the availability of AHV's and can be 300,000 to 2,000,000 NOK per day. An additional cost of the operation will be the mobilization and demobilization fee that varies dependent on where the well is going to be drilled. The AHV's are usually mobilized from Mongstad, Kristiansund or Stavanger. If the AHV's are needed in the Barents Sea it has to be taken into account a longer mobilization and demobilization time than for the North Sea and the Norwegian Sea.

#### RIG MOVE

An anchor positioned rig usually needs one or two AHVs when moving the rig from the previous drilling location to the new drilling location. Although there are used two AHV's in a rig move the time will be approximately the same, but the fuel consumption becomes doubled. At full transit speed (appr. 16 knots) the fuel consumptions can be up to 80 m<sup>3</sup>/day.

#### ANCHOR HANDLING

The anchor handling is one of the most dangerous and expensive operations offshore. It has to be carefully conducted because of the enormous forces, the weight in terms of equipment, and safety of the AHV's, rig and crew. Under anchor handling approximately 25-30 m<sup>3</sup> fuel/day is used per AHV (ref./54/). The preferred number of AHV's needed for disconnection, conventional anchoring and connection are three to four vessels. Using four AHV's will give best stretch and stabilization of the rig with one in each corner. When the first in line mooring lines are installed or connected, the fourth vessel can leave or can continue with the mooring if boat rates versus rig rate are favourable. The most optimal number of vessels for a pre lay anchoring is usually one. If there is a need for two AHV's, the operational time will be reduced, but total AHV time will typically increase with 50-70% (ref/54/).

### 6.2.2 RENTAL COST OF PRE LAID ANCHORS

During the last decade it has become more and more common to pre-lay the anchors and today this represents around half of the anchor market. To be able to pre lay the anchors before the rig arrives the spud location several marine operators rent chains and anchors from rig contractors. A pre lay operation is typical done in 4-7 days, depending on water depth, weather and numbers of AHV's doing the job.



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The NCS can be divided into three categories (ref./54/):

1. Shallow water: <300m (about 500 m chains needed)
2. Between deep water: 300-500m (about 1,000m chains needed)
3. Deep water: 500-1,200m (about 1,500m chains needed)

Price for the total packet of equipment for each category is approximately (ref./54/):

1. NOK 30,000,- for shallow water
2. NOK 45,000,- for between deep water
3. NOK 60,000,- for deep water

Installation time for each category using one AHV, is approximately (ref./54/):

1. Four days + one day mob/demob (total)
2. Five days + two days mob/demob (total)
3. Seven days + three days mob/demob (total)

### 6.3 RIG RATE

Rig rate includes the daily cost of a rig in terms of operational and capital cost. During a rig move (from disconnection at previous location to disconnection at the current location) there will be a stand by rig rate that is approximately 95-98% of the ordinary rig rate. This rig move rate is lower because some of the equipment on the rig is not in use.

Rig rates data from Pareto Securities Research and RS Platou Rig Monthly give an overview over existing mid-water (<4,500ft) semi submersibles on the NCS. The numbers are registered in the last quarter (Q4) of 2011 end the first quarter (Q1) of this year, 2012. Both registered numbers from the rig contractors and numbers from Pareto and RS Platou are mentioned, this because the rig rates are differing from the rig contractors to the research companies.

During this year, 2012, there will be experienced increasing rig rates on the NCS because of the current high demand that results in lack of availability of rigs on the NCS. Pareto has given rig rate assumptions for 3<sup>rd</sup> GSS on the NCS to be increased from 375\$/day to 400\$/day. For 4<sup>th</sup> GSS in the NCS the rig rates are assumed to increase to 450\$/day. Figure 34 below shows the increasingly day rate between *high demand* and *low demand* during the last decade on the NCS.

#### Mid-water semi submersible assumed rig rates

	<i>Mid-water floaters</i>				
Demand	YTD 2010 (USD \$)	YTD 2011 (USD \$)	Oct 2011 (USD \$)	Nov 2011 (USD \$)	Dec 2011 (USD \$)
High	440'	460'	505'	505'	505'
low	338'	343'	340'	355'	355'

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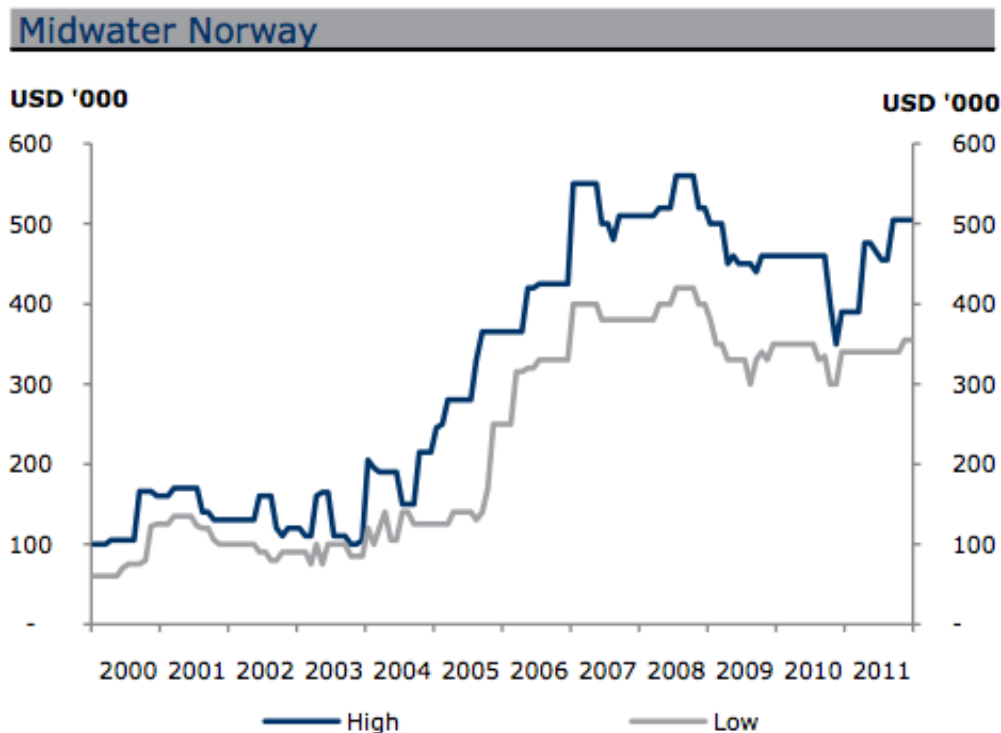


Figure 34 - Graphs showing the midwater semi submersible drilling rig rates on the NCS (ref./55/).

Figure 34 shows that the rig rates on the newest generations of semi submersibles are relatively higher than for the older semi submersibles. This because the newest GSS give lower emissions, bigger capacity and can handle deeper water depths.

Most of the older semi submersibles are modified several times, often 2-3 times. The modifications are done because they have to handle today's challenges such as harsh environmental conditions and deeper water.

Rig rate differs from type, generation of semi submersibles including number of times it has been upgraded and when the contract was signed for the rig. Today the rig rates are seen to increase due to current high demand and can therefore be unreliable for some rigs (see Figure 35).

#### Rig rate developments during the last year

Est. Values in USDm	Spec	Dec 2010 (USD \$)	Oct 2011 (USD \$)	Nov 2011 (USD \$)	Dec 2011 (USD \$)
2GSS	High	210'	220'	220'	220'
	Low	80'	80'	80'	70'
3GSS	High	250'	300'	300'	300'
	Low	150'	200'	200'	200'
4GSS	High	360'	400'	400'	400'
	Low	280'	300'	300'	400'
5GSS	High	530'	550'	550'	550'

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	Low	470'	490'	490'	490'
6GSS	High	670'	750'	750'	750'
	Low	600'	680'	680'	680'

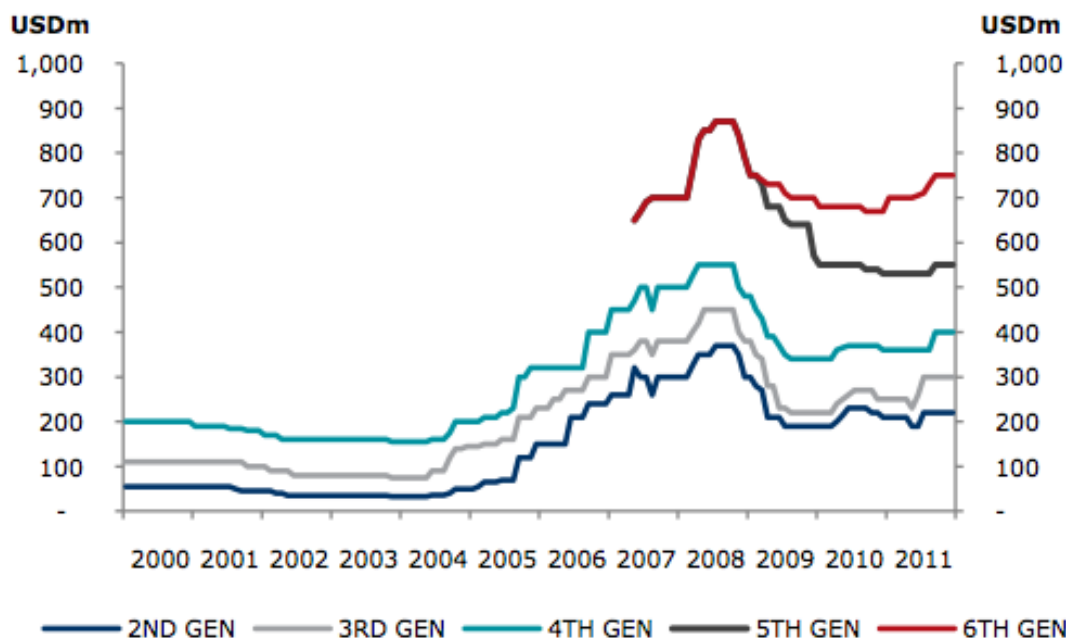


Figure 35 - Rig rate developments over the last decade for different generations of semi submersibles (ref./55/).

Comparing the research companies' numbers to the rig contractors' numbers the current rates differ quite a lot for all generations of semi submersibles (see Table 3). 2GSS-5GSS has an increasingly high rate trend while the 6GSS has reduced rate in relation to "Offshore research report January 2012" (ref./55/). Due to high demand on the NCS the rates are uncharacteristic high for the older GSS's. The reason that the 6GSS rates are that low are assumed to be because of two factors: one; that the current operations are conducted in shallow water (not deep water as they are constructed for) and two; that the operators have pushed the rates down. The rig rates are index regulated so they can vary from day to day.

**Rig contractors' current day rates of the exploration drilling semi submersibles on the NCS:**

Unit Name	Year/ Upgraded	Generation (GSS)	Depth (ft.)	DP/Moored	Current day rates (USD \$)
West Alpha	1986	4	2,000	Moored	501'
West Hercules	2008	6	10,000	DP/Moored	491'
West Venture	2000	5	6,000	DP	435'
Aker Barents	2009	6	10,000	DP/Moored	555'

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Aker Spitsbergen	2009	6	10,000	DP/Moored	564'
Polar Pioneer	1985	4	1,640	Moored	519'
Transocean Artic	1986	4	1,640	Moored	295'
Transocean Leader	1987/1997	4	4,500	Moored	465'
Transocean Winner	1983	3	1,500	Moored	482'
Transocean Searcher	1983/1988	3	1,500	Moored	429'
Bideford Dolphin	1975/1999	4	1,500	Moored	393'
Borgland Dolphin	1976/1999	4	1,500	Moored	523'
Bredford Dolphin	1976	2	1,500	Moored	361'
Deepsea Atlantic	2009	6	10,000	DP/Moored	490'
Deepsea Bergen	1983	3	1,500	Moored	320'
Songa Dee	1984	2	1,800	Moored	571'
Songa Trym	1976	3	1,300	Moored	517'
Songa Delta	1980	3	2,300	Moored	461'

Table 3 - Current rig rates on the NCS. The reliability of the numbers is referred to contract status for each company (refs./5/ to /9/).

## 6.4 DOWN TIME/ DRIFT OFF/ SLIP OFF

In rough weather the drilling semi submersible rigs are more exposed to down time. This means that the rig is not in operation. Down time is especially prone to DP drilling rigs when these are not held in place by anchors, which can lead to that the rig moves more from the spud location beyond equipment tolerances. If a line rupture occurs the other mooring lines are designed to handle the tension of the rig movements it can be exposed to in the mooring analysis. An anchor slipp can also cause anchor system failure, but this is assumed to be an insignificant event (ref./52/).

If a slip off/drift off occurs there will be a breakdown before it is connected again, and it will increase the cost of the operation and/or lost of income. Drift off/Drive off is when it has been generated static and dynamic moments on the wellhead because of to big current and wave height or by loss of DP power (ref./56/). These movements can give an excessive angle of the riser, particularly in shallow water, and there will be a need for a disconnection when the angle exceeds approximately 4 degrees (see Figure 36). In this way the LMRP connect the BOP and has to perform a safe disconnection to avoid damage to the subsea

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connection system and to prevent accidents occurring. An open hole can result into a blowout, extensive damage to the subsea equipment and environmental impacts. A research indicates that loss of position occur 1 to 1.5 times a year per vessel (ref./52/).

The rig's riser is able to quick disconnect in several minutes, while it takes approximately four hours to connect again. For reconnection of the riser to the BOP there is required maximum 1.5m of heave. By an automatic disconnection the shear rams will be able to close within 48 seconds (ref./52/).

Station keeping failure for a DP system can take place at any weather and time. Apart of drift off can this station keeping failure be caused by:

- Computer failure
- Loss of power
- Loss of DP satellite signals

### Differences between shallow and deep water drift off distance

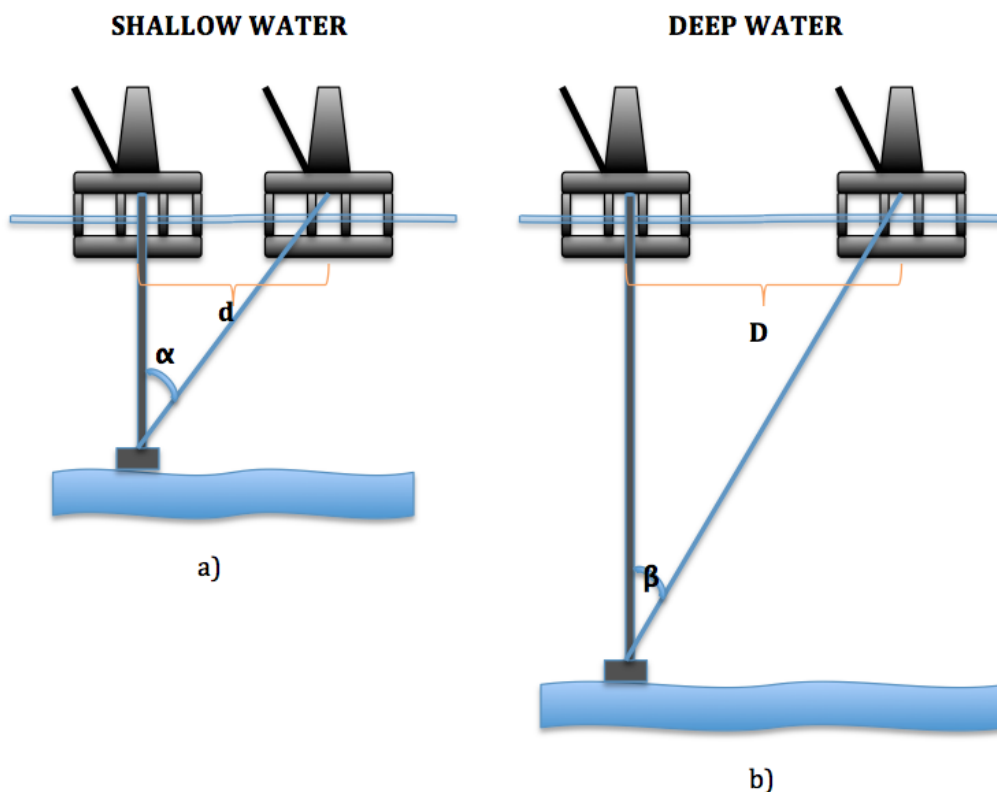


Figure 36 - Riser angle ( $\alpha$ ) in a) is deviated from the vertical axis with the same deviation as for the riser in b). This gives that the deep water can handle a longer drift off distance (D) than (d) before it will exceed the critical angle point and the need of a disconnection is necessary.

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## 6.5 RIG MOVE COST/RENTAL COST CALCULATION MODEL

To make a good overview over the rental cost and rig move cost a calculation model is made. Elements included in this model are duration of time, number of AHV, spot price, time to pre-lay the anchors, depth and day rate (see Figure 37).

Anchor Handler Details & Variables		AHV 1 AHV 2 AHV 3 AHV 4 Total				
AHV presumed rate (NOK):	267500					
Number of AHVs assigned to rig move	4					
Mob/Demob time (hrs)	6	230000	280000	300000	260000	1070000
Mob/Demob fuel consumption (m3)	12					
AHV fuel consumption cruising speed (m3)	30					
AHV cruising speed in knots (low)	12,5					
Towing fuel consumption (m3)	50					
Stby AHV time (days)	3					
Stby AHV fuel consumption (m3)	9					
Mobilisation/Deobilisation (NOK)	500000					
Mobilisation time (hrs)	6					
Transit time (days)	2					
Transit fuel consumption (m3)	22					
DP mode consumption (m3)	12,5					
AHV used by connection of anchors	4					
AHV used after first parallell line connection	3					
Time for first parallell line connection/disconnection	2					
AHV pick up time per anchor (hrs)	3					
AHV for rig move using pre-laid anchors	2					
<b>Semi Submersible Rig Move Information</b>						
Sailing Distance (nm)	40					
Expected transit speed (knots)	4					
<b>Pre-lay Equipment Costs + Variables</b>						
Rental rate for anchors and chains on seabed pr day	45000					
AHV used to pre lay	1					
Additional Anchor rental (NOK)	675000					
Days for pre-lay operation	5					
Pre lay fuel consumption (m3)	27,5					
Connection/Disconnection time (hrs)	18					
Connection/Disconnection fuel consumption (m3)	6					
Retrieve pre laid anchor time (hrs)	24					
Retrieve pre laid anchor fuel consumption (m3)	15					
<b>Conventional Rig Move Variables</b>						
Hook up to anchors time (hrs)	18					
Tension test (hrs)	4					
Pick up anchors time (hrs)	20					
Rig time for laying anchors (hrs)	20					
Fuel consumption conventional anchoring (m3)	22,5					
Connection/disconnection fuel consumption (m3)	6					
<b>Dynamic Positioning Rig Move Variables</b>						
Transit speed (knots)	5					
Transit fuel consumption per day (m3)	40					
Operational fuel consumption per day (m3)	20					
Positioning/departure (hrs)	4					
Installation/Deinstallation of seabed transponders (hrs)	12					
<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>				
Rig Transit Time (hrs)	10	Rig Transit Time (hrs)	10			
Total Cost (NOK)	121 851 673	Total Cost (NOK)	116 020 052			
Weather window required (days)	5,6	Weather window required (days)	2,9			
AHV Fuel Consumption (NOK)	3 291 773	AHV Fuel Consumption (NOK)	5 294 794			
<b>Dynamic Positioned Rig Move</b>						
Rig Transit Time (hrs)	8					
Total Cost (NOK)	123 289 367					
Weather window (days)						
Rig Fuel Consumption (NOK)	5 366 667					

Figure 37 - Rig move calculation model.

## 7 ENVIRONMENTAL IMPACT

Due to increased oil and gas activities on the Norwegian Continental Shelf it has become increasingly more emphasis on the environment, the industry's effect on the surroundings and its measures for improvement. When planning a new well there has to be performed analysis of the well location and mapping of the seabed to monitor environment impact by the operation and its discharges. Drilling activities such as produced water, chemicals, discharge of oil, cuttings and acute spills are not included as the focus is anchoring operations.

### 7.1 SENSITIVE AREAS AT SEABED

During the last decade there has been an increased focus on impacts on the seabed features caused by anchor handling activities. As known there are several semi submersible drilling rigs on the NCS that are station-kept with anchors and chains on the seabed. Placing these anchors and chains can cause damages to the vulnerable areas and species at the seabed if the mapping of the area is not performed well enough. By mapping the seabed structures, the anchors can be placed in another angle avoiding the sensitive areas as corals, sponges and pipelines.

#### 7.1.1 CORALS

The habitat of deep-water corals, also known as cold-water corals (CWC), extends to deeper, darker parts of the oceans ranging from near the surface to the abyss beyond 2,000 metres (6,600 ft) where water temperatures may be as cold as 4°C. Deep-water corals are enigmatic because they construct their reefs in deep, dark, cool waters at high latitudes as in NCS. The most common species in the NCS is the stony coral *Lopelia pertusa*. The reef system covers 60,000m<sup>2</sup> containing particularly vulnerable and physical damaged corals (ref./57/). In the recent years, there has been conducted several studies by mapping reefs, where there is believed that 30-50% of the corals on the NCS are damaged due to fishing trawlers, rig stationing and drilling activities (refs./7/and/58/). *Lopelia pertusa* is most prevalent in the Norwegian Sea as shown in Figure 38.

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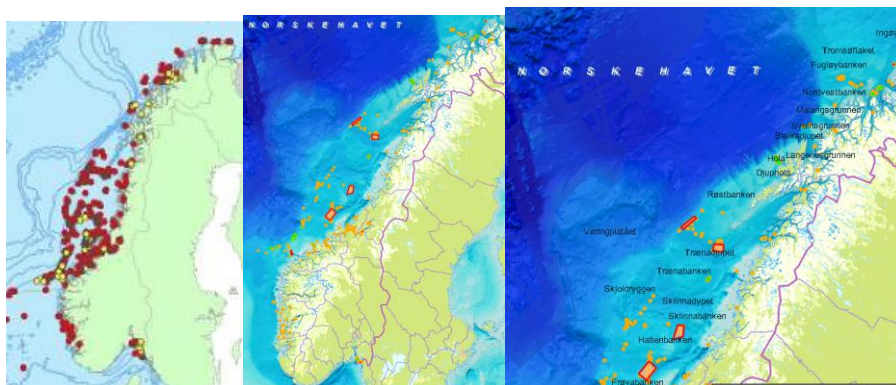


Figure 38 - Recorded *L.pertusa* (ref./59/).

Because of the deep, dark and cold water the corals grow slowly and the reconstruction takes much longer time, because of less access of sunlight at seabed. The water temperature is normally between 4-8 degrees and it grows from a water depth of 40 meters to very deep water. Most often it will be found in water depths at 200-1000m (ref./60/). *Lopelia pertusa* can become up to 25-30m high, but to achieve this height it will take up to several thousand years (when average growth per year is about 7 mm) (ref./57/). Corals (shown in Figure 39) develop reefs on the seabed where fishes and larvae's are hiding and finding food, which make it more difficult to the predatory to eat them. There are observed approximately 700 species around these reefs and it is for this reason that it is so important to protect coral reefs (ref./61/). The corals consist of colonies of single polyps that secrete calcium carbonate to create a framework.

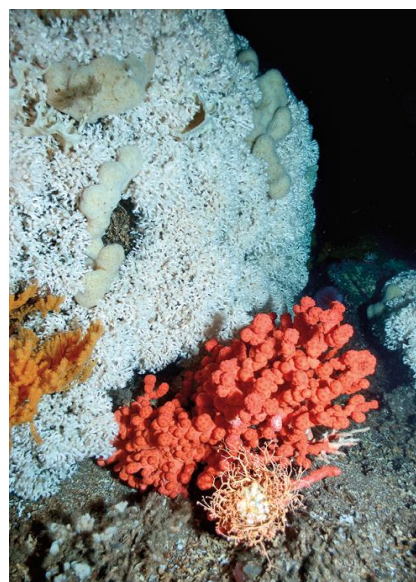


Figure 39 - Corals on the NCS (ref./60/).

The world's largest known deep-water *Lophelia* coral complex is the Røst reef as depicted in Figure 40. It lies between 300 and 400 metres deep, west of Røst Island in the Lofoten archipelago. The reef is still largely and it is approximately 40 kilometres long by 3 kilometres wide (ref./3/). The Røst reef is about 9000 years old (ref./59/). Another big reef on the NCS is the Sula reef, which is more than 13 kilometres long, up to 450-500 metres wide and more than 8500 years old (ref./62/).



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Figure 40 - *Lophelia pertusa* reef at 400m depth off Røst, the largest known CWC reef in the world (refs./58/and/63/).

Corals are regarded as biodiversity hotspots although they look like plants. Since the biodiversity in Norway is protected by the Nature Conservation Act (Naturmangfoldloven, NML), the corals are also protected. The purpose of NML is to preserve nature and its biological, landscape and geological diversity and ecological processes through sustainable use and conservation (refs./57/and/63/).

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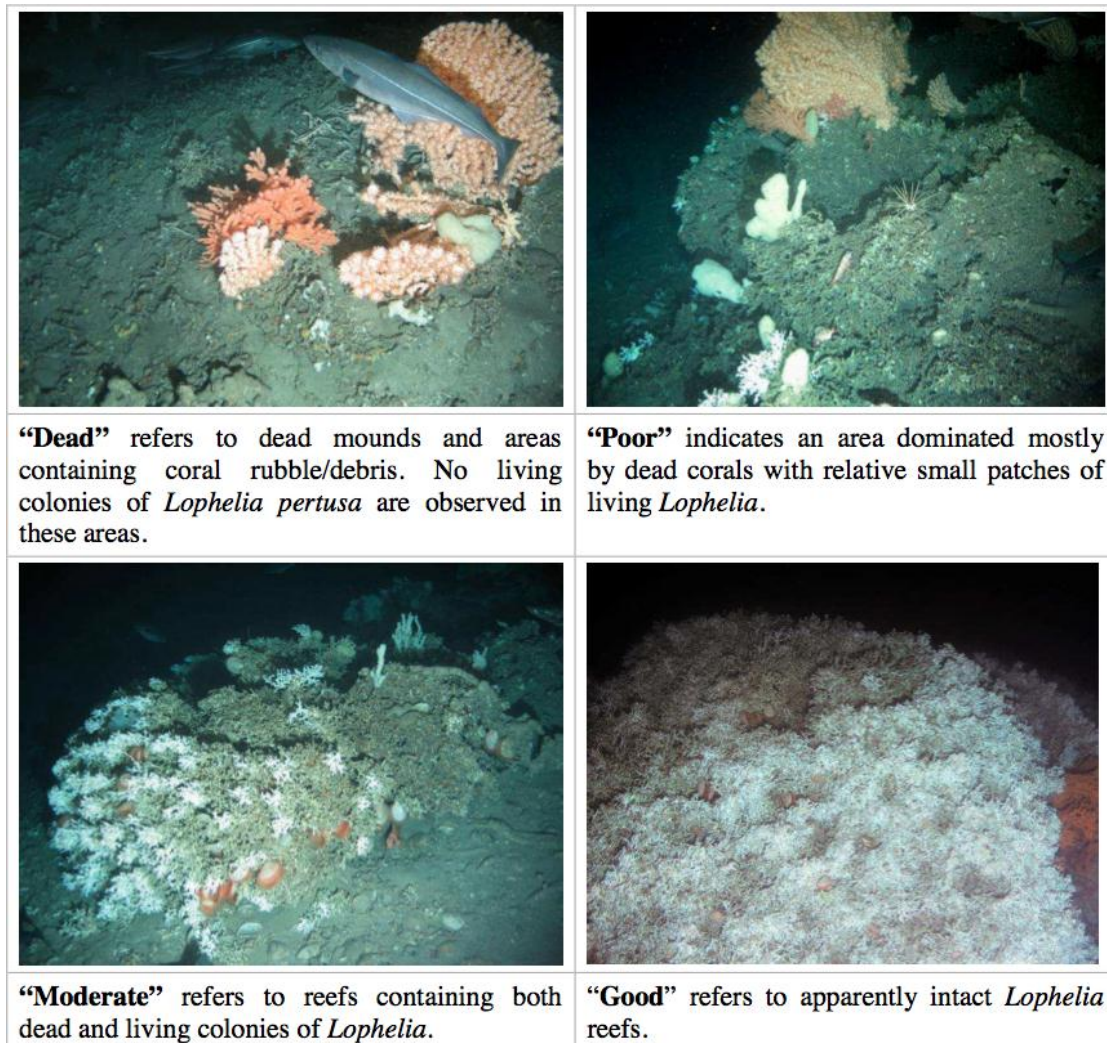


Figure 41 - *Lophelia pertusa* located along the Norwegian Coast in different phases (ref./64/).

Figure 41 shows the different phases a coral reef can be in. Anchor operations with anchors, anchor chains, grappling hooks and pennant wires can physical damage the coral structures. Particles whirled up under these operations may also effect the corals. To know what influences the anchor operation has on the corals, mapping of their conditions should be performed before and after the mooring operation. Physical damage is documented by visual mapping of the anchors, pennant wires and grappling corridors. Excessive particle loads are documented by turbidity measurements and particle traps at the coral structure. There is a potential area of influence within the 50 m wide corridor and 15 m position inaccuracies during pre-laying (ref./57/).

## 7.1.2 SPONGES

The greatest occurrences of sponge fields are registered in the Norwegian Sea and the Barents Sea. These sponges are covering the seabed in all shapes and sizes (see Figure 42) and they have the same importance as the corals by protecting the fishes and larvae (ref./65/). As for the corals the sponges are growing slow and are extremely sensitive to changes in their environment.



Figure 42 - Different types of sponges (ref./66/).

If the sponges are removed from the water they will not survive because their water filled canal systems will be replaced with air. If they are damaged by trawlers or hit by anchor chains they will most likely die within few weeks. They are also sensitive if they are exposed to water containing increased particles. Another type of sponges is illustrated in Figure 43.

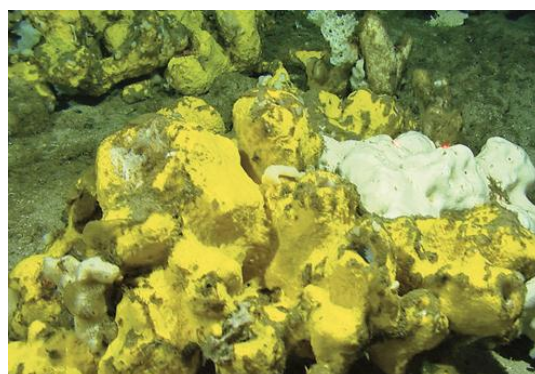


Figure 43 - Sponges (ref./60/).

## 7.1.3 PIPELINES

Totally there exists approximately 500 km with pipelines on the NCS. During a mooring operation the anchors can hit pipelines lying at the seabed, but this is not expected to be a problem. If they accidentally are hit, they are expected to be ripped off or damaged by the anchor itself or by the anchor chain. This is because the anchor is designed to penetrate the seabed to adhere itself. Depending on the holding capacity and type of mooring line the penetration depth can be more than three meters (ref./57/). By soft soil there will be deeper penetration and longer drag lengths that give a higher potential for pipeline damage.

Damages can cause high risk and cost on the pipeline system. The damage can be either local, permanent deformation, loss of weight coating and rupture. Rupture of the pipeline would be the worst case scenario where oil spill would be a disaster for the environment. To be sure the pipeline meets the requirements,

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the type of damage determine what kind of repairs or measures that will be needed to fix the pipeline.

## 7.2 BURNED FUEL EMISSIONS

In the context of oil and gas exploration on the NCS, it is discharge permits from The Climate and Pollution Agency (Klif) that determines what is permitted under the duty of care concept (ref./60/). The optimal care for the environment is when the discharge to the sea is zero and the emissions to the air are zero. This is not possible when operating a rig, but minimizing the diesel consumption will reduce the effect on the environment. Emissions from the petroleum industry are calculated from when a field is opened, explored, developed and till it plugged back and abandoned.

The emissions to air come from:

- Combustion of gas
- Combustion of diesel
- Flaring
- Well testing
- Emissions from storage and offloading of oil
- Fugitive emissions

In this document the anchor handling process and adjacent effects are discussed, so further the focus will be on diesel combustion. To mention, the petroleum industry in Norway is among the most environmental friendly sectors in the world because of the strict governmental regulations through many years (ref./60/). The most harmful emissions come from CO<sub>2</sub>, NO<sub>x</sub> and nmVOC substances where approximately 6.9% CO<sub>2</sub>, 33.7% NO<sub>x</sub> and a small amount nmVOC of total emissions are related to engine power (ref./67/). Figure 44 gives an overview over the emissions on the NCS compared with the average emissions internationally.

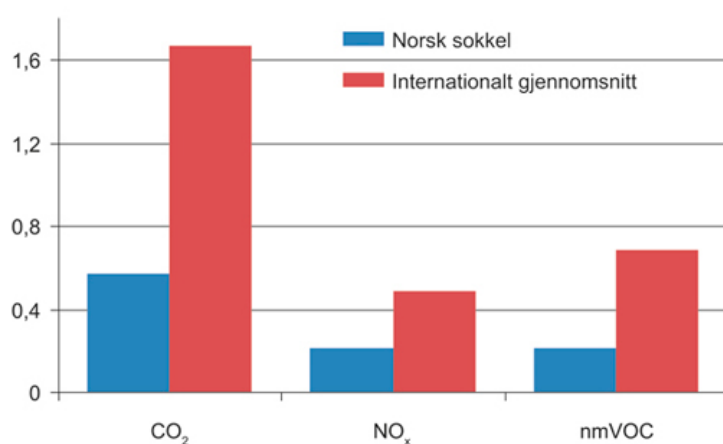


Figure 44 - Emissions to air on the Norwegian Shelf compared with the international average for oil-producing countries. CO<sub>2</sub> is indicated with 100kg and kg for the other per Sm<sup>3</sup> (ref./60/).

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A rig move is dependent of large AHV engine forces to be able to pull or tow an anchored rig, and a DP rig needs a huge amount of fuel to drive its own propellers. Regardless, with these large engines there will be burned a lot of fuel that gives high emissions to the environment. For station keeping a DP rig during an exploration and drilling operation, the emissions due to propellers or thrusters. This fuel consumption will be approximately 50-75% of a rig move consumption (40-120m<sup>3</sup>/day).

Because of strict requirements for drilling wells it must be obtained permissions for exploration drilling from the NPD. The restrictions for drilling in vulnerable areas include examination of consequences to the environment and climate effect of expected emissions during the operation.

Because of high emissions there are developed standards for powered vessels and rigs. These standards regulate emissions of CO<sub>2</sub>, NO<sub>x</sub> and nmVOC. The Norwegian government has also prepared several instruments to regulate emissions on the NCS as for example NO<sub>x</sub> tax. The NO<sub>x</sub> tax is on 16.69 kr per kg emitted NO<sub>x</sub> emissions (ref./68/). In addition to the NO<sub>x</sub> tax, the oil- and gas industry has to buy allowances for its CO<sub>2</sub>, NO<sub>x</sub> and nmVOC emissions. CO<sub>2</sub> tax is included in the fuel cost. These regulations and improvement of equipment and engines have certainly helped to reduce the pollution rate on the NCS, but with increased drilling activity on the NCS has the emissions increased overall (ref./69/).

### 7.2.1 CO<sub>2</sub> EMISSIONS

Klif and NPD have required emission reports from mobile units when they are performing a drilling operation. CO<sub>2</sub> emissions from burned fuel have an emission factor given by OLF. The factor depends on the carbon number in the used fuel. Emission factor for diesel is 3.17 kg CO<sub>2</sub> pr.kg diesel. This results in more than three times larger emission rate than the fuel consumption rate is (ref./69/).

On the NCS there are aquifers that consist of porous and permeable rock which are filled with water and stores huge amounts of CO<sub>2</sub>. During a project it was estimated that the NCS has a storage capacity of approximately 280,000 Mt CO<sub>2</sub>. In the long term, Norway will through the next decades get large storage in empty oil- and gas fields, but not until more fields are empty and more research is performed (ref./59/).

During the last 20 years the CO<sub>2</sub> emissions have increased, this due to increased activity on the NCS. Although the emissions have increased, they would still be half of the value 20 years ago (ref./69/).

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## 7.2.2 NO<sub>x</sub> EMISSIONS

All operating companies on the NCS joined the NO<sub>x</sub> Environmental Agreement for reducing the NO<sub>x</sub> emissions in 2008-2010. Det Norske Veritas (DNV) found that the NO<sub>x</sub> emissions were reduced with six times compared the period before the agreement. During this agreement period it was found effective and cost appropriate solutions to reduce emissions.

The NO<sub>x</sub> emissions occur from all combustion processes, likely through oxidation of bound nitrogen in the air or through oxidation of nitrogen in the combustion. New technology of diesel engines can reduce emissions by 50% in addition to a conventional diesel motor. The OLF emission factor for NO<sub>x</sub> is 0.07 kg pr kg diesel (ref./69/), but several rigs have calculated a rig specific NO<sub>x</sub> factor based on the type of engine (ref/68/).

## 7.2.3 NMVOC EMISSIONS

NmVOC is a collective term for all hydrocarbon gases exclusive methane. The emissions decrease with increased load on the combustion machine. Therefore, is this emission factor is only one tenth of the NO<sub>x</sub> emissions, i.e 0.007 kr pr. kg diesel (ref./69/). Since 2001, the total nmVOC emissions have been reduced by more than 85%, achieved by new facilities investments (ref./1/).

## 7.2.4 ACIDIFICATION OF THE SEA

Acidification is caused by CO<sub>2</sub> emissions to air. Huge amount of gases dissolves in the sea as carbonic acid. The seas in the north are more exposed for acidification than in south, because CO<sub>2</sub> dissolves faster in cold water than warm water. A report from Klif tells that the increased CO<sub>2</sub> content in the atmosphere has lead to 30% more acidic sea. Research shows that the Norwegian Sea can be as much as 120% more acidic than today by the end of this century (ref./69/).

## 7.3 CONSEQUENSES

The consequence of air pollution is primarily the breakdown of the ozone layer and increased greenhouse effect. Degraded ozone layer increases the UV radiation and greenhouse gases change the living conditions on earth. As a consequence of this, the global temperature increases, there will be more extreme weather conditions, and shift of climate zones and the sea level may rise.

### **Corals and Sponges**

Harmed and destructed corals and sponges will affect the organism and fish life at the seabed. The species will have loose good hiding places and important

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nutrients will be lost. This may lead to smaller diversity and to the worst extent extinction of species.

Corals and sponges may damage equipment by their sharp edges as for example polyester ropes used in mooring operation. This can split the polyester rope and the mooring is not complete anymore. Not only is this a dangerous factor, but it has also impact on the mooring cost and safety of personnel and stability of the rig during the operation.

### **Pipelines**

Consequences of torn pipelines can cause frayed ends sticking up of the seabed that can cause damage to equipment such as anchors and polyester ropes. If anchors have damaged pipelines that still are in function, there can be discharge of hydrocarbons that will be worst conceivable case. Destruction of pipelines can be time consuming and expensive to fix. In addition, the anchor can get stuck in the pipeline and not able to unfasten. This can result in loss of anchor and further loss of value.

### **Acidification**

Increased CO<sub>2</sub> emissions may result in more acidic marine environment, which raises the risk for damaging corals and sponges. This is because CO<sub>2</sub> is taken up faster in cold water, causing a greater degree of acidification of the water. Acidification is expected to give serious consequences for the ecosystem in the sea. The biggest concern is what will happen with organisms with skeletons of chalk and shells because acidic water contains less chalk and will cause problems for organisms for their needs of chalk to their skeletal, eventually it can lead to poor growth or death (refs./70/and/71/). The only way to reduce acidification to the sea is to reduce the CO<sub>2</sub> emissions from the engines (ref./71/).

### **CO<sub>2</sub>/NO<sub>x</sub>/nmVOC**

Acidification caused by these gases gives increased greenhouse effects. Combination of NO<sub>x</sub> and nmVOC provides ground level ozone at high concentrations, which provide damage on the nature and humans health (ref./60/).

Newer technology of diesel engines and other fuel assemblies are still under development. By applying new technologies, gas emissions will be reduced and the greenhouse effect will diminish. In addition to newer technology, systems for introducing emission taxes for the gases have become a decisive factor for reduced emissions.

## 8 COMPARISON

The calculation model gives a comparison of emissions and costs associated with DP rigs versus moored rigs. This gives an indication of the rig that is the most beneficial to the environment and cost effective based on several variables.

### 8.1 COMPARISON OF EMISSIONS

A moored rigs' only emissions to the environment during the operation will be from the engines used for the operation, not for the station keeping (assumed good weather). So, by comparing daily fuel consumptions from a DP/moored rig (eg. Aker Barents) with alternative positioning methods it will give (as shown in Table 4) the result should provide the emissions related to station keeping only.

#### Emissions per day for station keeping a DP/moored rig.

Type of positioning	Engine			
	Fuel consumption (ton)	CO <sub>2</sub> (ton)	No <sub>x</sub> (ton)	nmVOC (ton)
DP	40,0	126,800	1,184	0,200
Anchor	30,0	95,100	0,888	0,150

Table 4: Example of a day emission of gases from a DP versus moored (with DP support) solution during an exploration operation (ref./50/).

In this view, there has been taken into account the transit time for the rig move dependent of selected rig type. Daily fuel emission during a DP rig move is related to its thrusters' fuel consumptions, while for an anchor positioned rig it is mainly the AHV's fuel consumptions for towing and mooring the rig (see Table 5). The latest drilled exploration wells on the NCS have an average rig move distance of 210 nm from previous to a new location of assignment. DP rig transit speed is approximately between 5-9 knots and an AHV transit speed is between 10-16 knots (refs./25/and/50/). Although the AHV speed is high, the rig is not towed faster than approximately 4-5 knots in good weather. Usually there are used two AHV's on older anchor positioned semi submersibles because of their heavy load of equipment and one AHV on newer rigs (transit time will be approximately the same). Fuel consumption is also related to the weather conditions.



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### Emissions during a rig move for DP versus anchor positioned rigs per day

Type of rig	Engine				Transit time (hrs)
	Fuel consumption (ton)	CO <sub>2</sub> (ton)	No <sub>x</sub> (ton)	nmVOC (ton)	
DP	40,0	126,800	1,184	0,200	42,0
AHV	30,0	95,100	0,888	0,150	52,5
AHV*2	60,0	190,200	1,776	0,300	52,5

Table 5 - Fuel consumption and transit time for each alternative of rig move. Due to the weather the chosen transit speed is 5 knots for the DP rig and 4 knots for the anchor rig (refs/50/and/54/).

The likelihood for the shortest transit time is small, this because of full transit speed of the rig get resistance in the water arising from its construction and weather conditions. The operators usually have regularities of maximum transit speed that is allowed for the AHV's during a rig move, often between 10-12.5 knots. Table 6 shows the difference between low AHV speed and high AHV speed fuel consumptions and emissions.

### Fuel consumptions and amount of emissions between low and high AHV speed per day

Speed (knots)	Engine			
	Fuel consumption (ton)	CO <sub>2</sub> (ton)	No <sub>x</sub> (ton)	nmVOC (ton)
10,0	20	63,400	0,592	0,100
12,5	30	95,100	0,888	0,150
16,0	80	253,600	2,368	0,400

Table 6 - Fuel consumptions and emissions to air by different AHV velocities (ref./25/).

Emissions to air related to a conventional rig move, a rig move with pre laid anchoring and dynamic positioning rig move (incl. mob/demob) are given in Table 7.

### Fuel consumptions and amount of emissions for different rig move (210nm) and positioning methods

Type of positioning	Engine				Rig positioning time (days)
	Total fuel consumption (ton)	CO <sub>2</sub> (ton)	No <sub>x</sub> (ton)	nmVOC (ton)	
Conventional	811,00	2,570,870	24,006	4,055	1
Pre-laid	960,00	3,043,200	28,416	4,800	1
DP	123,00	389,910	3,641	0,615	2/3

Table 7 - Mooring/positioning time is initially considered for mid water depth (300-500m), included mob/demob time (refs./ 25/,/50/and/53/).

Table 7 shows that emissions related to AHV's during the rig move and the positioning operation becomes approximately 7 times higher than for a DP rigs' emissions.

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### Total emissions during an operation of 50 days

Type of positioning	Engine				Duration of drilling (days)
	Total fuel consumption (ton)	CO <sub>2</sub> (ton)	No <sub>x</sub> (ton)	nmVOC (ton)	
Conventional	811,00	2,570,870	24,006	4,055	50
Pre-laid	960,00	3,043,200	28,416	4,800	50
DP	1,123,33	3,559,910	33,241	5,615	50

Table 8 - Total fuel consumption after 50 days in operation with the different positioning methods (refs./25/,/50/and/53/).

Table 8 shows that the emission related to a DP rig exceeds an anchored rig by approximately 20 % after 50 days in operation.

By plotting the emission factors (CO<sub>2</sub>, NO<sub>x</sub> and nmVOC) it will give an indication of how many days with exploration drilling it takes before the emissions will exceed each other.

### Emissions related to the rig move transit distance of 40nm and positioning operation.

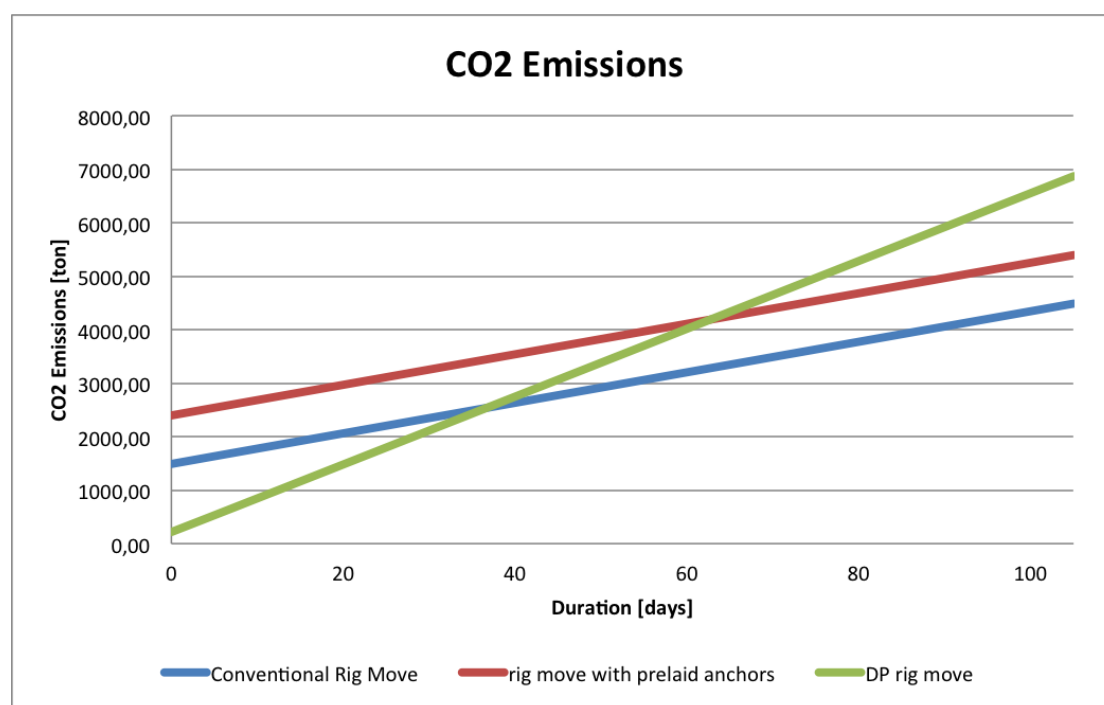


Figure 45 - CO<sub>2</sub> emissions related to the rig move and the rig positioning from AHV's and the DP rigs' thrusters (ref./Figure 37/).

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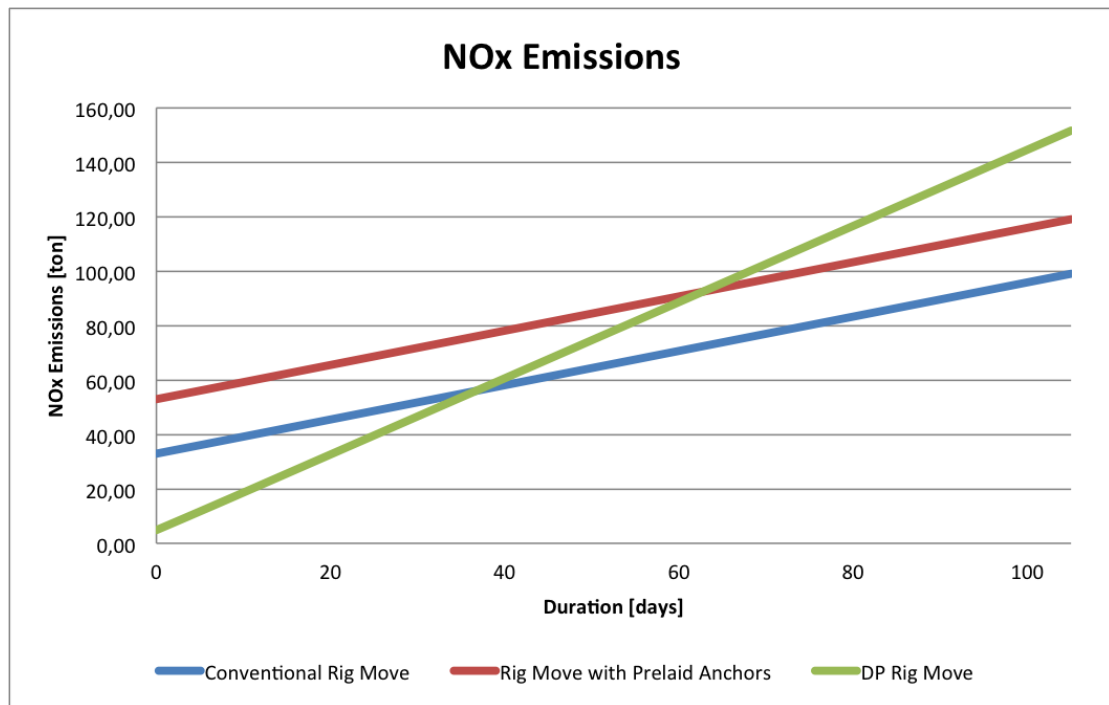


Figure 46 - NO<sub>x</sub> emissions related to the rig move and rig positioning from AHV's and the DP rigs' thrusters (ref./Figure 37/).

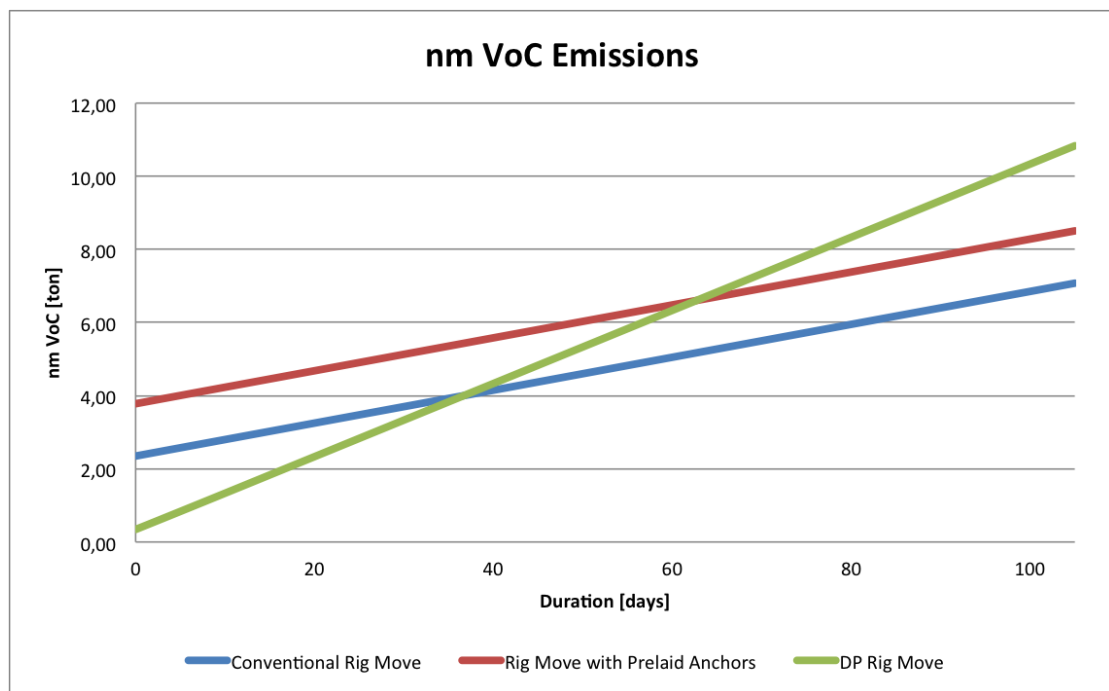


Figure 47 - nm VOC emissions related to the rig move and rig positioning from AHV's and the DP rigs' thrusters (ref./Figure 37/).

According to figures 45, 46 and 47 the most environmentally friendly semi submersible type is a conventional anchor positioned rig in front of a DP rig, if the operation lasts for more than 35 days. After approximately 65 days the DP rig fuel emission exceeds the anchored rig.

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**Emissions related to the rig move transit distance of 210nm**

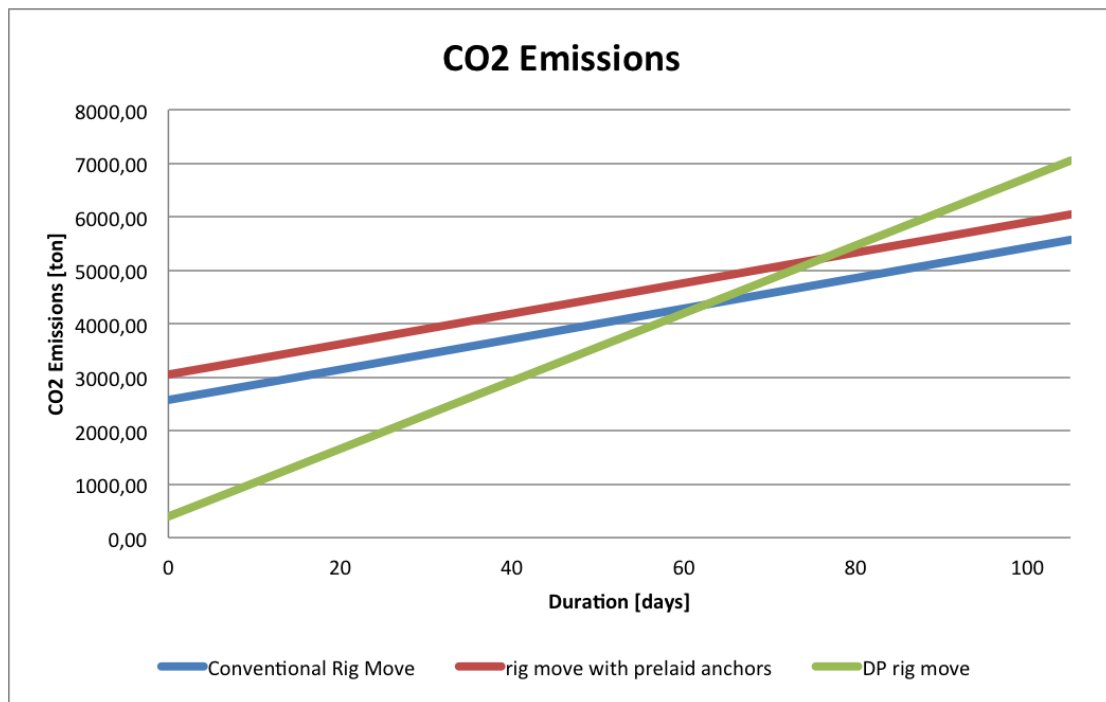


Figure 48 - CO<sub>2</sub> emissions from different rig move methods and durations (ref./Figure 37/).

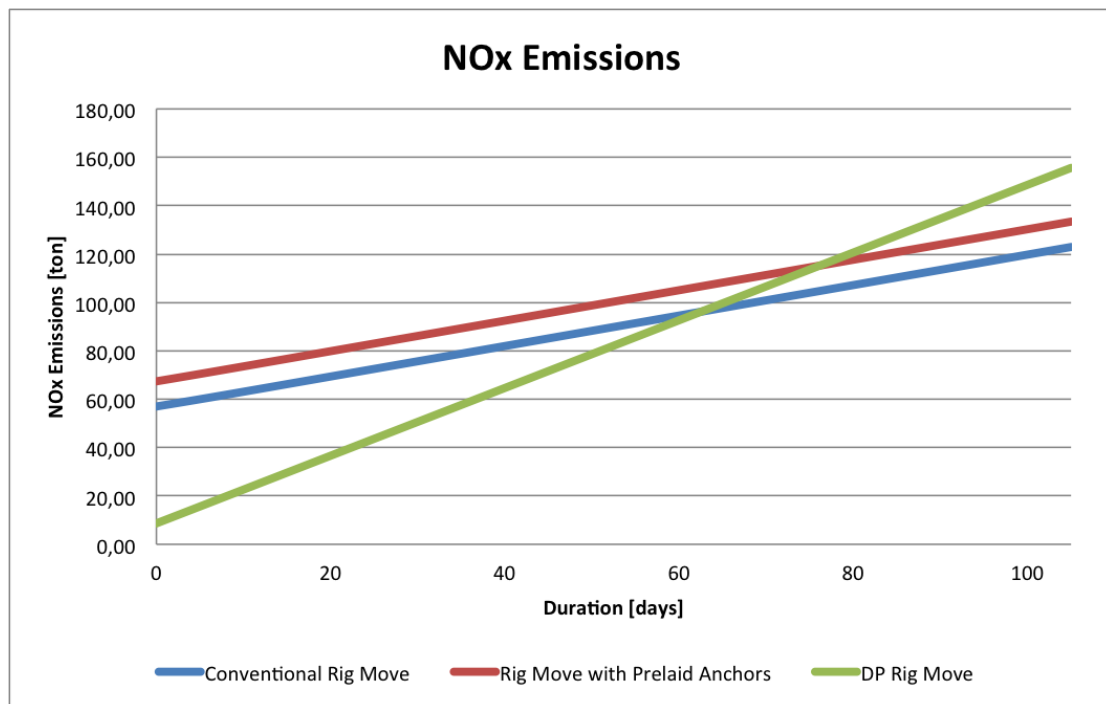


Figure 49 - NO<sub>x</sub> emissions from different rig move methods and durations (ref./Figure 37/).

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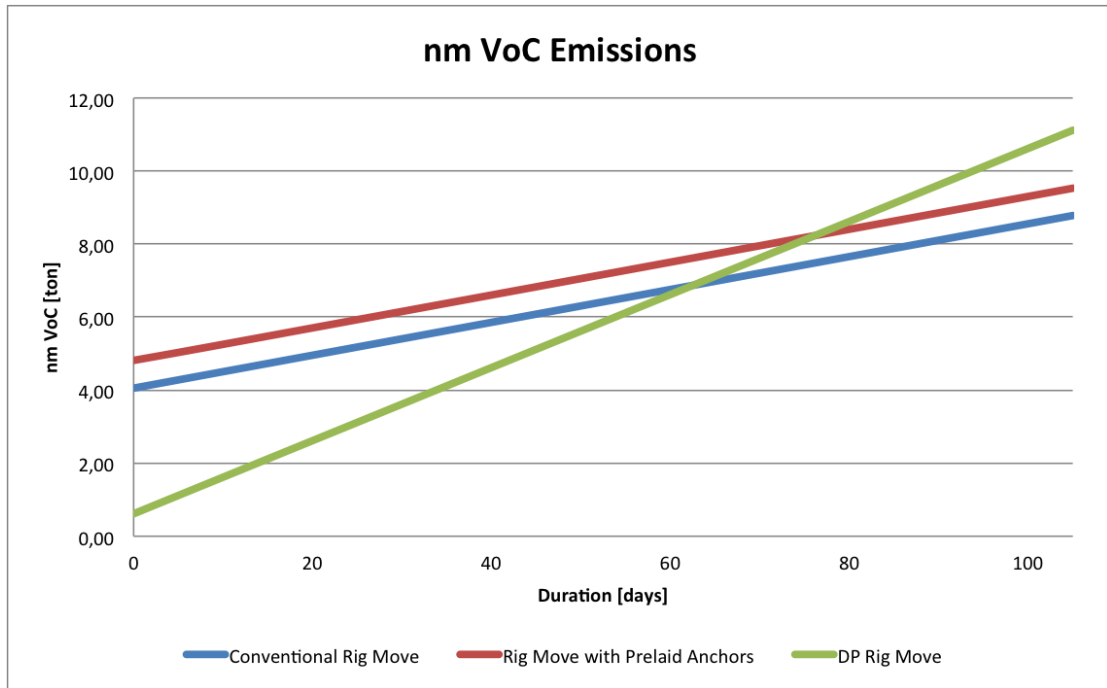


Figure 50 - nm VOC emissions from different rig move methods and durations (ref./Figure 37/).

Figures 48, 49 and 50 show that a DP rig exceeds the fuel emission for the moored rig after approximately 75 days.

### Emissions related to the rig move transit distance of 400nm

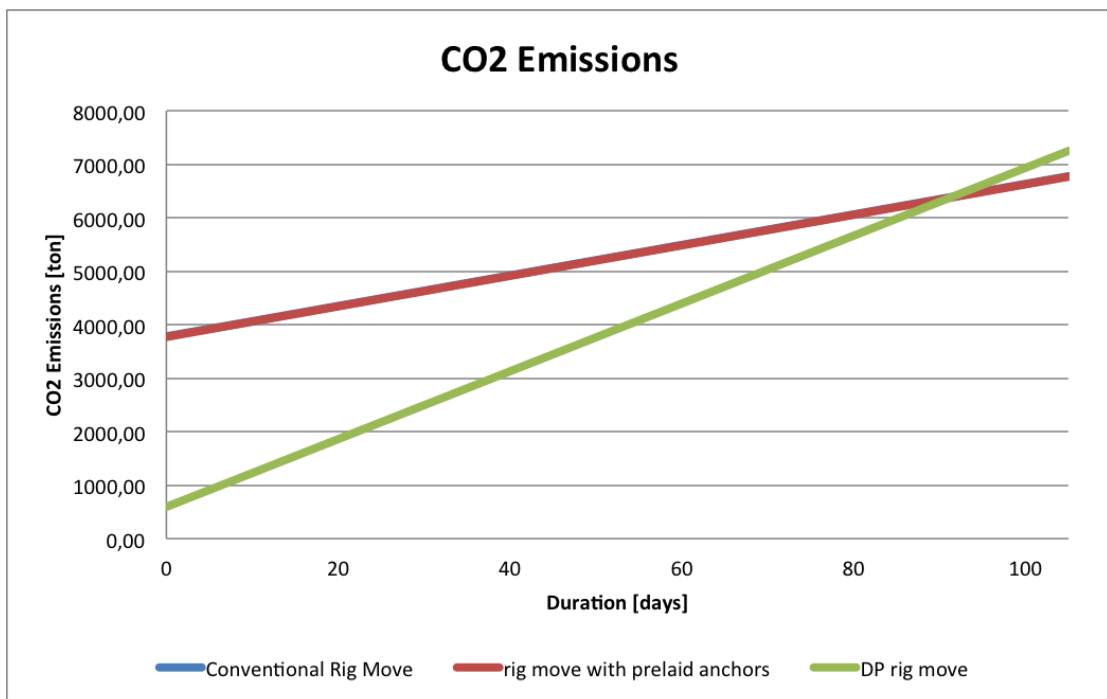


Figure 51 - CO<sub>2</sub> emissions (ref./Figure 37/).

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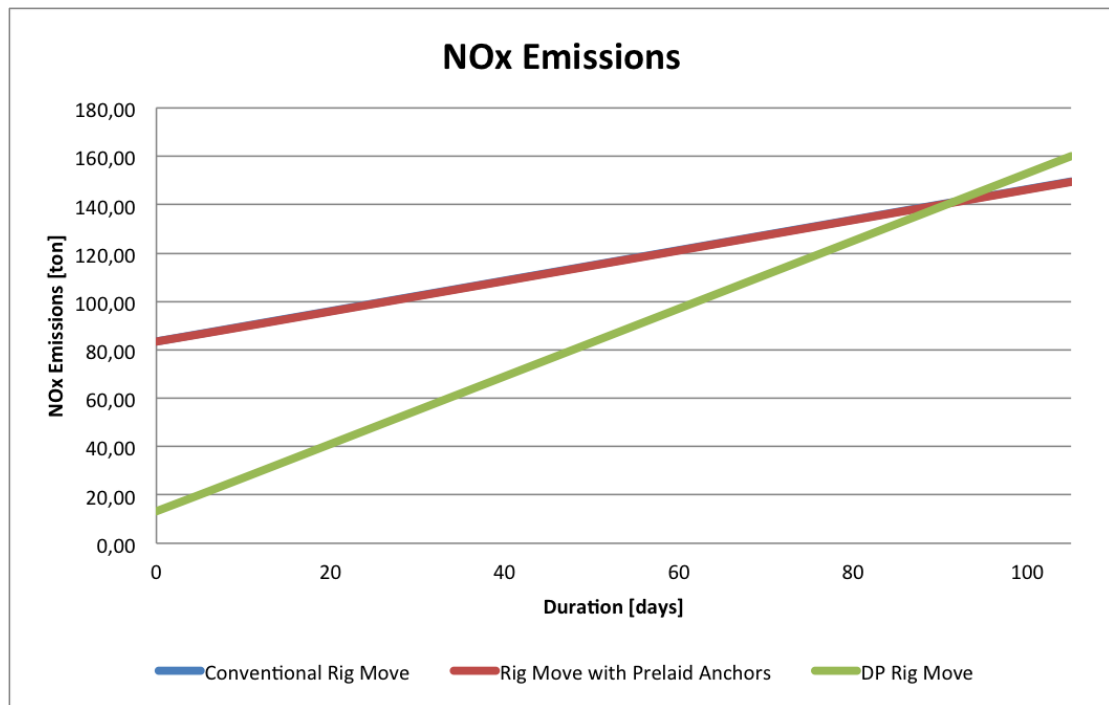


Figure 52 - NO<sub>x</sub> emissions from different rig move methods and durations (ref./Figure 37/).

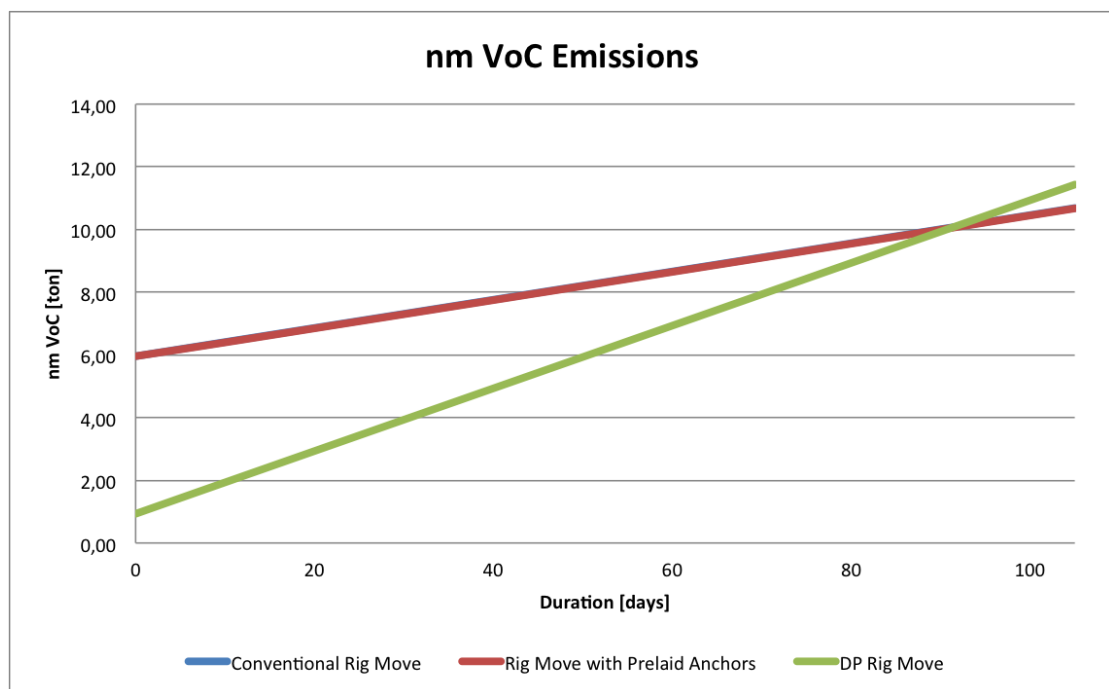


Figure 53 - nm VOC emissions from different rig move methods and durations (ref./Figure 37/).

Figures 51, 52 and 53 show that both conventional rig move and rig move with pre laid anchors have the same amount of emissions to air. The DP rig move has lower fuel emissions until approximately 90 days in operation.

Emission from CO<sub>2</sub>, NO<sub>x</sub> and nmVOC graphs above show that the rig move distance has an important influence on the emission to the environment. The

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longer the rig move is the longer will a DP rig be able to keep operating before it exceeds a moored rigs' emissions.

## 8.2 COMPARISON OF COSTS

Rig rates of the semi submersible drilling rigs and AHV's rental vary greatly from time to time, and from place to place. Because of great exploration activity and today many new upcoming wells, the demand of drilling rigs and AHV's on the NCS are extremely high. In addition to rig rates and AHV's rental rates there have to be taken into account rig move cost, fuel consumption, anchor rental, number of AHV's ect.

The calculation model (Figure 37) compares three rig move distances:

1. Normal Distance: 210 nm
2. Short Distance: 40 nm
3. Long Distance: 400nm

These three distances show the differences in total cost of a rig move for anchor positioned conventional rig move, anchor positioned rig move with pre laid anchors and dynamic positioned rig move.

Rig move costs for a transit distance of 40nm:

<i>Anchor Positioned Conventional Rig Move</i>		<i>Anchor Positioned Rig Move with Prelaid Anchors</i>	
Rig Transit Time (hrs)	10	Rig Transit Time (hrs)	10
Total Cost (NOK)	19 108 858	Total Cost (NOK)	13 277 237
Weather window required (days)	5,6	Weather window required (days)	2,9
AHV Fuel Consumption (NOK)	3 291 458	AHV Fuel Consumption (NOK)	5 294 479
<i>Dynamic Positioned Rig Move</i>			
Rig Transit Time (hrs)	8		
Total Cost (NOK)	5 724 367		
Weather window (days)			
Rig Fuel Consumption (NOK)	466 667		

Figure 54 - Costs of a rig move of 40 nm and its positioning (ref./Figure 37/).

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Rig move costs for a transit distance of 210nm:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	52,5	Rig Transit Time (hrs)	52,5
Total Cost (NOK)	28 019 940	Total Cost (NOK)	19 641 598
Weather window required (days)	8,3	Weather window required (days)	5,5
AHV Fuel Consumption (NOK)	5 677 656	AHV Fuel Consumption (NOK)	6 725 578
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	42		
Total Cost (NOK)	10 590 078		
Weather window (days)			
Rig Fuel Consumption (NOK)	863 333		

Figure 55 - Costs of a rig move of 210 nm and its' positioning (ref./Figure 37/).

Rig move costs for a transit distance of 400nm:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	100	Rig Transit Time (hrs)	100
Total Cost (NOK)	37 979 383	Total Cost (NOK)	26 754 707
Weather window required (days)	11,3	Weather window required (days)	8,5
AHV Fuel Consumption (NOK)	8 344 583	AHV Fuel Consumption (NOK)	8 325 042
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	80		
Total Cost (NOK)	16 028 227		
Weather window (days)			
Rig Fuel Consumption (NOK)	1 306 667		

Figure 56 - Costs of a rig move of 400 nm and its' positioning (ref./Figure 37/).

Figures 54, 55 and 56 show that a conventional rig move is the most expensive alternative while a DP rig move is the less costly alternative.

In addition to the various distances, there are compared different durations of exploration drilling on the NCS:

1. 35 days: Easy exploration
2. 70 days: Average exploration well integrity
3. 100 days: production + completion + flow back sub sea well



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Rig move of 40nm and positioning costs included 35 days of exploration drilling:

<i>Anchor Positioned Conventional Rig Move</i>		<i>Anchor Positioned Rig Move with Prelaid Anchors</i>	
Rig Transit Time (hrs)	10	Rig Transit Time (hrs)	10
Total Cost (NOK)	121 851 673	Total Cost (NOK)	116 020 052
Weather window required (days)	5,6	Weather window required (days)	2,9
AHV Fuel Consumption (NOK)	3 291 773	AHV Fuel Consumption (NOK)	5 294 794
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	8		
Total Cost (NOK)	123 289 367		
Weather window (days)			
Rig Fuel Consumption (NOK)	5 366 667		

Figure 57 - Rig move distance of 40 nm and positioning costs included 35 days of exploration drilling (ref./Figure 37/).

Although a DP rig is the least cost related rig move alternative it becomes the most expensive after 35 days in operation (see Figure 57).

Rig move of 40nm and positioning costs included 70 days of exploration drilling:

<i>Anchor Positioned Conventional Rig Move</i>		<i>Anchor Positioned Rig Move with Prelaid Anchors</i>	
Rig Transit Time (hrs)	10	Rig Transit Time (hrs)	10
Total Cost (NOK)	224 594 488	Total Cost (NOK)	218 762 867
Weather window required (days)	5,6	Weather window required (days)	2,9
AHV Fuel Consumption (NOK)	3 292 088	AHV Fuel Consumption (NOK)	5 295 109
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	8		
Total Cost (NOK)	240 854 367		
Weather window (days)			
Rig Fuel Consumption (NOK)	10 266 667		

Figure 58 - Rig move distance of 40 nm and positioning costs included 70 days of exploration drilling (ref./Figure 37/).

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Rig move of 40nm and positioning costs included 100 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	10	Rig Transit Time (hrs)	10
Total Cost (NOK)	312 659 758	Total Cost (NOK)	306 828 137
Weather window required (days)	5,6	Weather window required (days)	2,9
AHV Fuel Consumption (NOK)	3 292 358	AHV Fuel Consumption (NOK)	5 295 379
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	8		
Total Cost (NOK)	341 624 367		
Weather window (days)			
Rig Fuel Consumption (NOK)	14 466 667		

Figure 59 - Rig move distance of 40 nm and positioning costs included 100 days of exploration drilling (ref./Figure 37/).

After 70 days (see Figure 58) and 100 days (see Figure 59) in operation the differences between the alternatives becomes bigger. These differences are an outcome of the fuel consumptions for keeping the DP rig in position during the operation.

Rig move of 210nm and positioning costs included 35 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	52,5	Rig Transit Time (hrs)	52,5
Total Cost (NOK)	130 762 755	Total Cost (NOK)	122 384 413
Weather window required (days)	8,3	Weather window required (days)	5,5
AHV Fuel Consumption (NOK)	5 677 971	AHV Fuel Consumption (NOK)	6 725 893
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	42		
Total Cost (NOK)	128 155 078		
Weather window (days)			
Rig Fuel Consumption (NOK)	5 763 333		

Figure 60 - Rig move distance of 210 nm and positioning costs included 35 days of exploration drilling (ref./Figure 37/).

If a normal rig move distance is performed the conventional anchor positioned rig will be the most expensive alternative after 35 days in operation (see Figure 60).

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Rig move of 210nm and positioning costs included 70 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	52,5	Rig Transit Time (hrs)	52,5
Total Cost (NOK)	233 505 570	Total Cost (NOK)	225 127 228
Weather window required (days)	8,3	Weather window required (days)	5,5
AHV Fuel Consumption (NOK)	5 678 286	AHV Fuel Consumption (NOK)	6 726 208
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	42		
Total Cost (NOK)	245 720 078		
Weather window (days)			
Rig Fuel Consumption (NOK)	10 663 333		

Figure 61 - Rig move distance of 210 nm and positioning costs included 70 days of exploration drilling (ref./Figure 37/).

Rig move of 210nm and positioning costs included 100 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	52,5	Rig Transit Time (hrs)	52,5
Total Cost (NOK)	321 570 840	Total Cost (NOK)	313 192 498
Weather window required (days)	8,3	Weather window required (days)	5,5
AHV Fuel Consumption (NOK)	5 678 556	AHV Fuel Consumption (NOK)	6 726 478
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	42		
Total Cost (NOK)	346 490 078		
Weather window (days)			
Rig Fuel Consumption (NOK)	14 863 333		

Figure 62 - Rig move distance of 210 nm and positioning costs included 100 days of exploration drilling (ref./Figure 37/).

After 70 days (see Figure 61) and 100 days (see Figure 62) in operation the DP rig becomes the most costly alternative and the anchor positioned rig move with pre laid anchors the least expensive.

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Rig move of 400nm and positioning costs included 35 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	100	Rig Transit Time (hrs)	100
Total Cost (NOK)	140 722 198	Total Cost (NOK)	129 497 522
Weather window required (days)	11,3	Weather window required (days)	8,5
AHV Fuel Consumption (NOK)	8 344 898	AHV Fuel Consumption (NOK)	8 325 357
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	80		
Total Cost (NOK)	133 593 227		
Weather window (days)			
Rig Fuel Consumption (NOK)	6 206 667		

Figure 63 - Rig move distance of 400 nm and positioning costs included 35 days of exploration drilling (ref./Figure 37/).

As for a rig move of 40nm and 210 nm is also the conventional anchor positioned rig alternative the most expensive alternative for 400nm (see Figure 63).

Rig move of 400nm and positioning costs included 70 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	100	Rig Transit Time (hrs)	100
Total Cost (NOK)	243 465 013	Total Cost (NOK)	232 240 337
Weather window required (days)	11,3	Weather window required (days)	8,5
AHV Fuel Consumption (NOK)	8 345 213	AHV Fuel Consumption (NOK)	8 325 672
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	80		
Total Cost (NOK)	251 158 227		
Weather window (days)			
Rig Fuel Consumption (NOK)	11 106 667		

Figure 64 - Rig move distance of 400 nm and positioning costs included 70 days of exploration drilling (ref./Figure 37/).

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Rig move of 400nm and positioning costs included 100 days of exploration drilling:

<b>Anchor Positioned Conventional Rig Move</b>		<b>Anchor Positioned Rig Move with Pre-laid Anchors</b>	
Rig Transit Time (hrs)	100	Rig Transit Time (hrs)	100
Total Cost (NOK)	331 530 283	Total Cost (NOK)	320 305 607
Weather window required (days)	11,3	Weather window required (days)	8,5
AHV Fuel Consumption (NOK)	8 345 483	AHV Fuel Consumption (NOK)	8 325 942
<b>Dynamic Positioned Rig Move</b>			
Rig Transit Time (hrs)	80		
Total Cost (NOK)	351 928 227		
Weather window (days)			
Rig Fuel Consumption (NOK)	15 306 667		

Figure 65 - Rig move distance of 400 nm and positioning costs included 100 days of exploration drilling (ref./Figure 37/).

The calculation model gives that a DP rig move included 70 days (see Figure 64) and 100 days (see Figure 65) in operation is the most expensive alternative while an anchor positioned rig move with pre laid anchors is the less costly alternative.

Between the anchored rigs there are approximately three days in difference in weather window. The longer rig move is the bigger weather window is needed, which can be a challenge.

### 8.3 COMPARISON OF RIG TIME

Figure 66 below shows rig time operation for different semi submersible positioning methods. This figure gives a clearly indication of which positioning method that gives the lowest rig time. The reason for a DP rig move included positioning has the shortest rig time, is higher rig move speed and saved time by its dynamically positioning system. It is seen that the mooring operation for both conventional and prelaying anchors is time consuming. The outcome of the figure shows that a DP rig is able to start drilling approximately 1-3 days ahead of an anchored rig.

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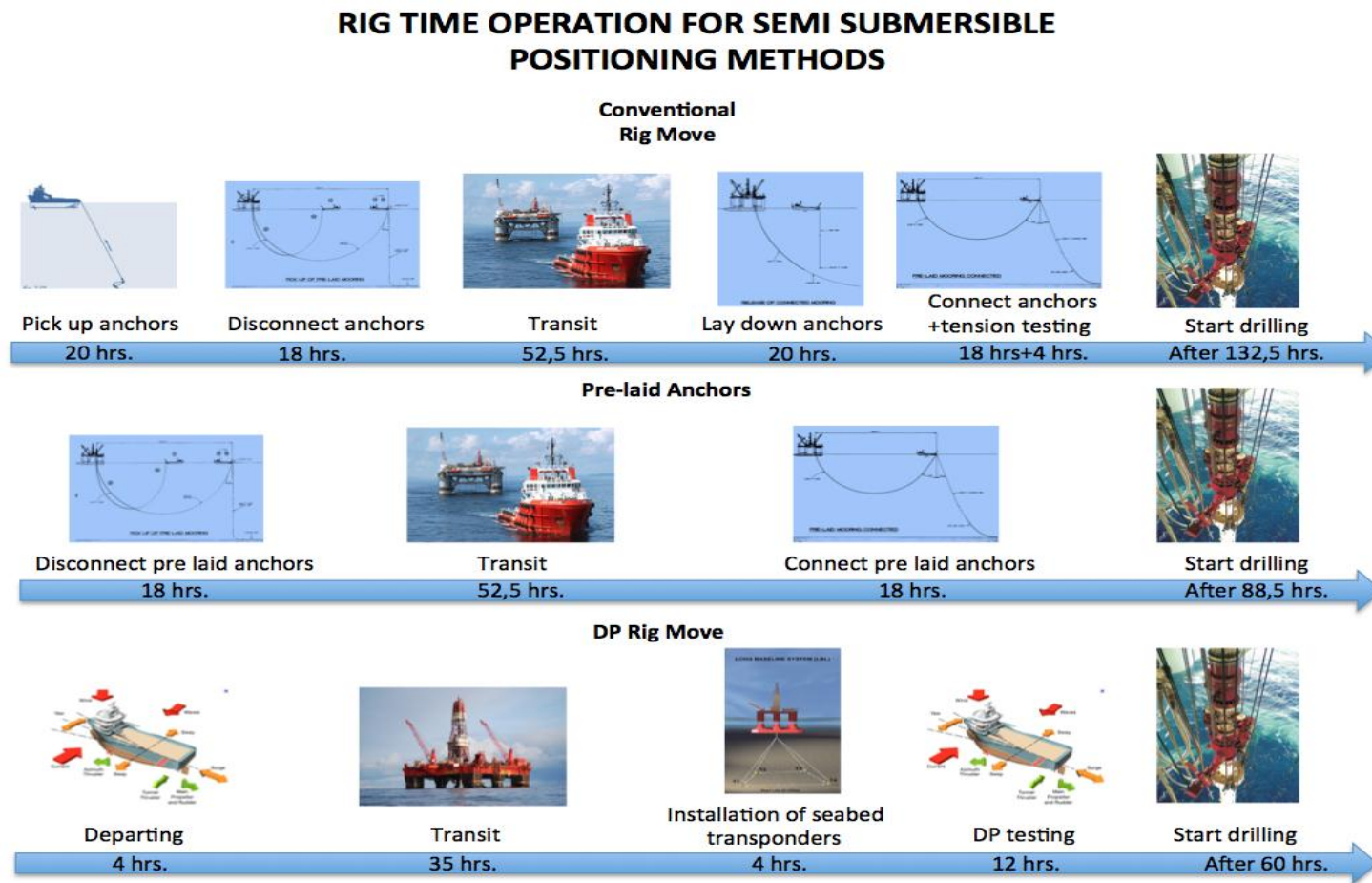


Figure 66 - Comparison between the three different positioning methods with a rig move distance of 210nm. Transit speed of moored rigs is calculated with 4 knots and the DP rig with 6 knots (refs./ 25/,/50/and/53/).

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## 8.4 COMPARISON OF PROS AND CONS

By comparing advantages and disadvantages of a dynamic positioned versus an anchor positioned semi submersible rig it will give an overview of which type that will be the most favourable to use on the current exploration well.

### **DP advantages** (ref./30/):

- No tugs are required
- No dependency of AHV that has uncertainty of time due to mobilization and demobilization
- Positioning on location is quick and easy -> Less rig time
- DP system is very manoeuvrable
- Rapid change of heading due to bad weather to reduce rig movements
- Versatility within system
- Operations in deep and ultra-deep water
- Less risk of AHV personnel and rig personnel during a mooring operation
- Less load on deck from anchors, chains ect.
- Avoid ship collision
- Easier re-location by a well-cluster or by detection of shallow gas
- Avoidance of risk of damaging seabed hardware from mooring lines and anchors
- Avoidance of cross-mooring with other vessels or fixed platforms
- Can move to a new location rapidly
- Less planning
- Little or no effect on corals, sponges and pipelines
- No hazards related to anchor handling
- No anchor analysis

### **DP disadvantages** (ref./30/):

- High capital and operational expenditure
- Can fail to position due to equipment failure
- Higher day rates than comparable moored system
- Higher fuel consumption – higher fuel cost
- Can lose position in harsh weather or drift off
- Position control is active and relies on human operator
- More personnel to operate and maintain equipment
- Rig motion (WOW)
- More expensive
- Underwater hazards from thrusters

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**Anchor positioned advantages (ref./30/):**

- No underwater hazards from thrusters
- No complex system with thrusters
- No failure in positioning system or drift off
- Less to no fuel consumption for station keeping during the exploration drilling
- More suitable for shallow water depths
- More suitable in extreme weather
- Low to no risk of drift off

**Anchor positioned disadvantages (ref./30/):**

- Can not move once anchored
- AHV's are required
- Can harm features at seabed
- Less suitable for ultra- and deep water
- Requires more planning and mooring analysis
- Varying anchoring time
- More weather dependent (WOW)
- Higher risk associated to the anchor handling operation
- Can not change heading if bad weather
- Higher risk of chip collision
- Expensive rig move
- High mooring cost
- Higher rig time

The comparison shows that the advantages are the doubled for a DP rig as for a moored rig. This will necessarily not have any impact of which rig positioning type that will be the best option, because the rig should be assessed based on the environment around the well location and the estimated duration of the exploration drilling.



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## 9 CONCLUSION

All semi submersible rig moves for exploration wells should be evaluated for cost and environmental impact on a case by case basis.

The evaluation is a comparison of a rig move calculator that reflects:

- Market rates for rigs and Anchor Handler Vessels
- Duration of the well and associated emissions
- Cost impact of DP versus moored rigs
- Seasonal weather conditions to include rig move weather window
- Environmental conditions at sea bed
- Options to prelay anchors in the case of moored rigs or DP rigs dependent on duration

The rig move calculation model needs the flexibility to incorporate changing market rates for all major costs associated with rig moves.

The use of a calculator with current market rates can be adopted to demonstrate the cost and environmental comparison. Examples of these comparisons for typical rig moves are included in [chapter 8](#) with the associated calculator.

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