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Technology challenges for year-round oil and gas production at 74°N in the Barents Sea

OG21

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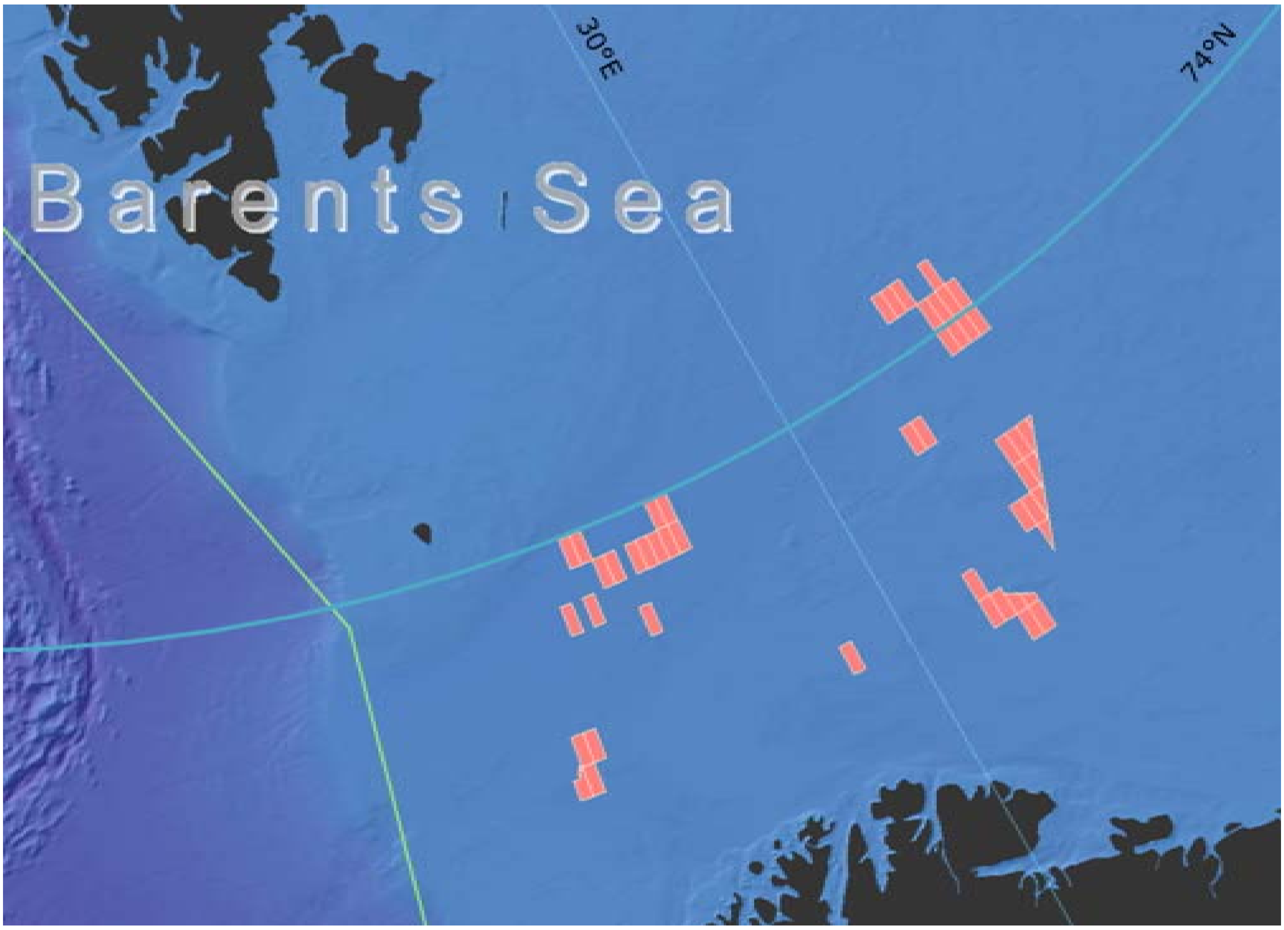

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The objective of the project was to describe and prioritize the technology challenges for year-round oil and gas production on 74°N in the Norwegian part of the Barents Sea.

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1 EXECUTIVE SUMMARY

DNV GL was given the task by OG21 to describe and prioritize the technology challenges for year-round oil and gas production on 74°N in the Norwegian part of the Barents Sea. The northernmost blocks in the 23rd licensing round are at 74°N and the physical environment in this area differs from other areas on the Norwegian Continental shelf where there is oil and gas production today.

The work has been conducted in close cooperation with OG21 and its Technology Target Area (TTA) groups. The premises for the project have been that DNV GL should focus on the arctic specific technical challenges with production in this area. Activities further north than 74°N should not be considered and the scope should be limited to technologies that could be realized within 5 – 10 years. The study is a high-level assessment and more detailed analysis of each technology is warranted for a specific field development.

DNV GL and OG21 agreed to use the following three specific field development examples as an instrument to further describe the technology challenges:

- Oil production from an FPSO in the south-western Barents Sea
- Subsea oil production in the south-western Barents Sea
- Gas production from an FPSO in the south-eastern Barents Sea

DNV GL provided a description of the physical environment on the two locations. In general the wind and wave conditions are less severe than for instance in the Norwegian Sea. However, due to the low temperatures and subsequently wind chill, working restrictions are expected especially on the eastern location. Sea ice and icebergs are not common occurrences in either of the two locations, but is still expected often enough to be considered for design and operations. Due attention should be made to the combination of conditions as in isolation the conditions might not be worse than in other operating environments.

Through a literature study as well as input from the most recent relevant projects a number of technology needs relevant to the three cases are identified. The technology challenges were presented, discussed and prioritized in a workshop with the OG21 TTA groups. Each technology was evaluated, in a qualitative manner, with respect to maturity (TRL - Technology Readiness Level), complexity and possible added value for the operator. The technologies are also grouped into which technologies that are considered vital for enabling production, and which can enhance the production in either reducing CAPEX and OPEX or increasing production.

The technologies enabling production are in general related to safety for personnel, prevention and preparedness of accidents and consequence reducing measures. More specifically this entails systems for detecting, forecasting and handling drifting ice, solutions and infrastructure for evacuation and rescue of personnel as well as technologies related to oil spill response and preparedness.

For enhancing technologies, there seem to be particular potential in making drilling operations more efficient as well as technologies improving reservoir performance and well control. Better solutions for more efficient and more environmental friendly offshore power generation are needed.

The report further details the technology needs for year-round oil and gas production in the Barents Sea, All identified technologies have a relatively high technology maturity level. This means that in many cases the technologies need further optimization and full scale testing.

2 ABBREVIATIONS

API	American Petroleum Institute
AWSAR	All Weather Search And Rescue
CAPEX	CAPital Expenditure
CBM	Center for Biosystems Modelling
DP	Dynamic Positioning
EBSA	Ecologically and Biologically Significant Area
EER	Escape, Evacuation and Rescue
EOR	Enhanced Oil Recovery
FPSO	Floating Production, Storage and Offloading unit
FRDC	Fast Rescue Daughter Craft
GLONASS	GLObal NAvigation Satellite System
GOR	Gas to Oil Ratio
GPS	Global Positioning System
HSE	Health Safety and Environment
HVDC	High-Voltage Direct Current
IIMR	Inspection, Intervention, Maintenance, Repair
IOR	Increased Oil Recovery
IMO	International Maritime Organization
LDHI	Low Dosage Hydrate Inhibitors
LFAC	Low-Frequency Alternating Current
LNG	Liquefied Natural Gas
NCS	Norwegian Continental Shelf
MOB boat	Man Over Board Boat
NOROG	Norsk olje og gass
OPEX	OPerating EXpense
PVA	Particularly Vulnerable Area
SAR	Search And Rescue
SE	South-East
SSRWD	Same Season Relief Well Drilling
SW	South-West
TRL	Technology Readiness Level
TTA	Technology Target Area
WCI	Wind Chill Index
WCT	Wind Chill Temperature

3 INTRODUCTION

When the Ministry of Petroleum and Energy announced the 23rd licensing round in January 2015, 57 blocks/parts of blocks were announced, of which three were in the Norwegian Sea and 54 in the Barents Sea. Out of these blocks, there are blocks close to 74°N, and in the eastern part of the Barents sea it is close to 74°30'N.

For several years there has been drilling activities in the Barents Sea, but there has never been production this far north. The closest is the Snøhvit field, located at 70°N, with no surface installations, and Goliat, located at 71°N, which is developed with a Floating Production, Storage and Offloading unit (FPSO). At 74°N there is a possibility of having production when sea ice is present; with satellite data showing that sea ice has been observed on the locations, latest in the winter 2003/2004. Compared to other locations on the Norwegian Continental Shelf (NCS) the physical environment is harsher in terms of lower temperatures and increased potential for marine icing, but the wave conditions are less severe in the Barents Sea than in other locations on the NCS where there exists operating experience (OD, 2012). In addition there is a lack of access to a pipeline export network of gas to the continent, as well as the infrastructure for emergency, evacuation and rescue is less developed than further south on the NCS.

DNV GL has been commissioned by OG21 to describe and prioritize technology challenges that needs to be addressed to enable year-round oil and gas production at 74°N in the Barents Sea. To ensure that these challenges become specific, three field development cases have been used at two different locations in the Barents Sea, one south west (SW) and one south east (SE) (Figure 3-1). The two locations are both within the announced blocks of the 23rd licensing round, and represent the varying physical conditions from east to west.

The current OG21 strategy (OG21, 2012) is already covering many of the technology gaps especially through their business case 1: Exploration and development in environmental sensitive areas and case 2: Barents Sea gas & condensate field development. This reports aims to narrow down the most important technology challenges for some possible field developments.

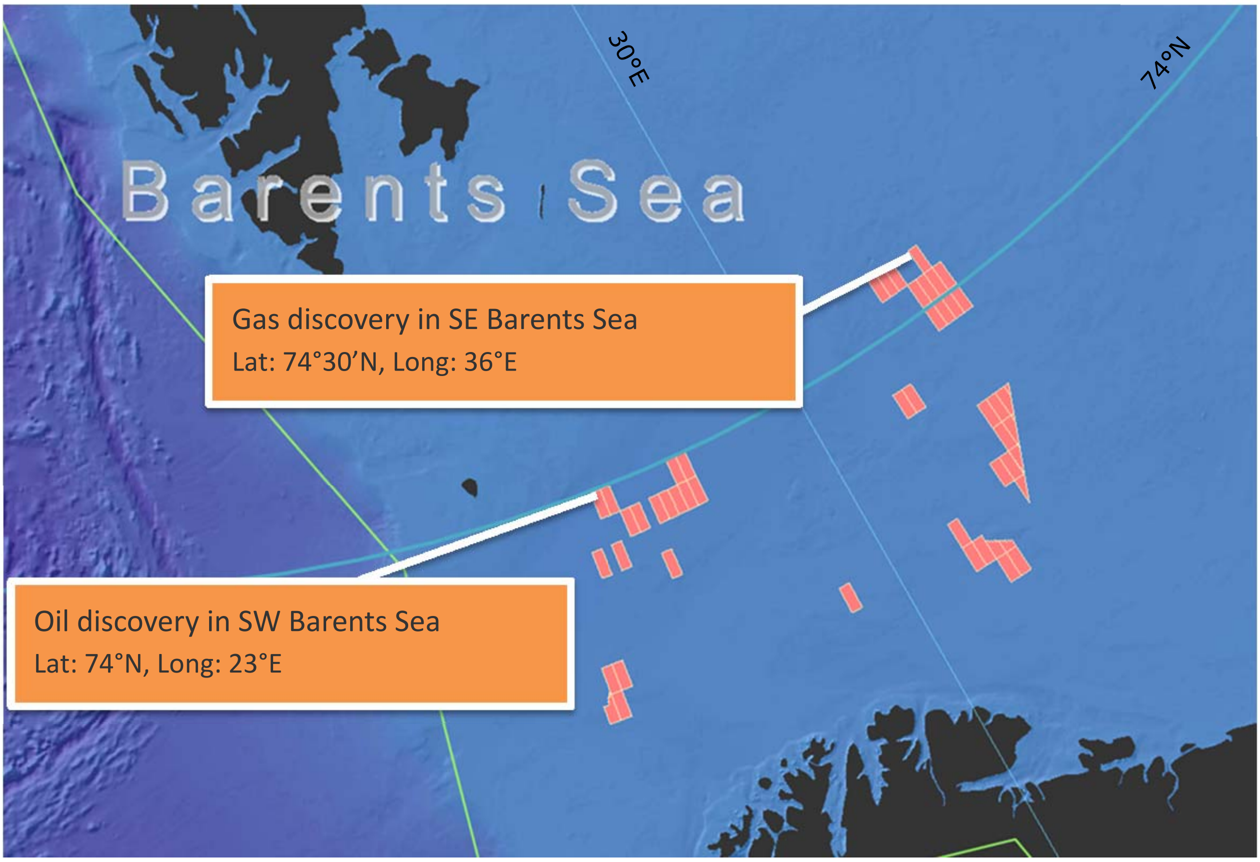


Figure 3-1: The two selected locations in the Barents Sea with the blocks for the 23rd licensing round.

Section 3 of this report describes the varying physical conditions at these two locations. This is followed by a description of the three different cases in section 4. At the SW Barents location an oil field is assumed. The concept solution is likely to depend on whether other fields have been developed further south, e.g. Johan Castberg at 72°N where an investment decision is yet to be made. Two different field development scenarios are therefore used;

1. FPSO at location
2. Subsea production with pipeline to other existing facility further south.

The SE Barents location gas field scenario is also assumed developed with an FPSO. In section 5 all the different technical challenges that need to be solved for the different cases are described. Section 6 ranks the technical challenges based on a qualitative assessment of their added value for the different field development solutions together with cost.

The work was conducted in close cooperation with OG21 Technology Target Area (TTA) groups and commenced 7 May 2015. DNV GL initially suggested the field development examples and prepared the pre-read material for the first workshop. The pre-read material contained information about the physical environment at the two selected locations and the initial field development examples. The first workshop was conducted 17 June 2015 at the Norwegian Petroleum Directorate in Stavanger. The scope of the workshop was to (i) discuss and adjust the field development examples and (ii) representatives from Norsk olje og gass (NOROG), INTSOK, DNV GL, SINTEF, ENI, AkerSolutions and ARCeX presented some of the findings from recent relevant projects. See Appendix A for the agenda and list of participants for the first workshop. Following the first workshop, DNV GL used the presentations from the workshop and available literature to prepare a screening of the technology challenges. This overview was distributed to OG21 and the leaders of the TTA groups in advance of the second workshop which was conducted 2 September 2015 at the Norwegian Research Council at Lysaker. The objective of the second workshop was to (i) agree upon the most important technology needs for year-round O&G production at 74°N, and (ii) evaluate the technology needs with respect to Technology Readiness Level (TRL), development complexity and cost, and added value. See Appendix B for the agenda and list of participants for the second workshop. Based on the material and discussions from the workshops and the pre-read material developed by DNV GL, this report was written summarizing the technology gaps for year-round petroleum production on 74°N of the Norwegian part of the Barents Sea.

The project only considered areas south of, or close to the 74°N latitude in the Norwegian part of the Barents Sea. It is common to refer to the area south of the 74°N latitude as Barents Sea South. In this report the locations are referred to as South-East (SE) Barents Sea and South-West (SW) Barents Sea. The geographical references are approximate and refer only to Norwegian waters (as the eastern part of the Barents Sea is in Russian waters).

The focus has been on the development of technology for fields at 74°N, assuming a development decision within in a 5 – 10 years' timeframe. This means that new innovative technologies that may improve the business case for the different cases is not covered in detail in this report. The identified technologies address HSE challenges in the Barents Sea on a general level. Detailed risk assessment will be needed for specific field development projects.

Conducting safe operations in the Barents Sea does not only entail using adequate technology fit for purpose. There is also a need for competent personnel who are prepared and trained for working in challenging conditions. The next section describes these conditions.

4 THE PHYSICAL ENVIRONMENT IN THE BARENTS SEA

4.1 Introduction

Two different locations in the Barents Sea, SE Barents and SW Barents, were selected to represent the varying physical conditions from east to west. Both locations are within blocks relevant for the 23rd licensing round (Figure 3-1). The selection of the locations was based on:

(i) being within the 23rd licensing round,

(ii) assuming the northernmost blocks have the most demanding physical environment and,

(iii) different locations giving a large spread in physical conditions.

The physical environment in the Barents Sea is often characterised as being harsh, however to substantiate to which extent the physical environment on these two locations can be said to be harsher than other locations on the Norwegian Continental Shelf (NCS), the properties of the physical environment have been compared with the location of the Skarv field in the Norwegian Sea (65.7°N, 7.7°E). The location of Skarv was selected since there has been a number of producing fields in this part of the Norwegian Sea for a number of years and in many ways the physical environment in the Norwegian Sea can be considered harsher than in the North Sea.

In this section, the following information is presented:

- Distance to different types of infrastructure, such as ports, helicopter bases, hospitals.
- Amount of daylight.
- Ice and metocean data (wind speed, wave height, air and sea temperatures, marine icing, wind chill, sea ice and iceberg extent).
- Sensitive biological resources in the area.

In the Barents Sea, being relatively far north, there can be sudden atmospheric disturbances due to magnetic storms in addition to reduced satellite coverage due to low elevation angles that lead to technology challenges for communication and positioning. The details of such conditions are not covered in this section, but the challenges due to such events are covered in section 6.5.

This section does not cover what the combination of the different conditions mean to operations. For instance in some cases it may not be the individual condition that is a challenge (for instance darkness), however when combined with long distances, occurrence of icing etc. it may become a challenging operational environment. In other cases, when looking at the joint occurrence of temperature and wind, one would see that the coldest weather occurs due to high air pressure when there is modest wind speeds. Proper analysis of such combinations is crucial to understanding the actual conditions.

Fog and cold fronts occur regularly and are well recognized weather phenomena in the Barents Sea. Fog occurs regularly during summer in the Barents Sea as warm air passes over the colder ocean. A characteristic of the cold fronts (squall lines or ‘tråg’ in Norwegian) is the heavy precipitation following the low pressure front. In wintertime this precipitation comes as snow and with reduced visibility making operations more demanding during such events.

4.2 Distance to infrastructure

Port facilities

Port facilities are important for field logistics and to serve as onshore oil spills preparedness bases. In comparison to fields further south, the Skarv field is for instance 210 km from its supply base in Sandnessjøen, which is similar to the distance between the Statfjord field (practically on the border to UK) and the supply base outside Bergen. Table 4-1 shows the distances from different port facilities on the northern coast of Norway and the two selected locations. DNV GL has not been investigating the port facilities in detail, meaning additional upgrade/investment might be needed before the present facilities fulfil all the needs for an oil/gas production field.

As an example, journey time with a vessel transiting from Polarbase with 13 kts average speed is for the SW Barents location 15 hours and for the SE Barents location 25 hours respectively.

Table 4-1: Distances between ports on the northern coast of Norway and the two selected locations.

Destination	From SW Barents [km]	From SE Barents [km]	Comments
Hammerfest	374	597	Polarbase, Melkøya. Expansion plans
Honningsvåg	354	519	Serves today as the most important rescue operations and "waiting for weather window" port. Also selected by Statoil as the most likely location for shore-based oil terminal in the Barents region.
Kirkenes	538	574	Supply services related to drilling and seismic activity – Norterminal planning to build new oil terminal by 2018
Tromsø	506	800	Currently base for maintenance activities. Started on new industrial harbor at Tønsnes to facility future activity

Helicopter bases

During field development and production helicopters are used for different purposes such as personnel transfer and search and rescue. In most cases the helicopters are based on onshore bases, however in order to provide adequate offshore search and rescue preparedness (NOROG, 2012) some helicopters are also based offshore on the NCS where agreements for area emergency preparedness are established. Table 4-2 list the major helicopters in the northernmost counties in Norway. The list is not complete. For more information on the national, regional and local airports and their suitability for being used as helicopter preparedness bases see Avinor (2012).

Table 4-2: Distances between helicopter bases in Finnmark, Troms and Northern part on the northern coast of Norway together with the two selected locations.

Destination	From SW Barents [km]	From SE Barents [km]	Comments
Alta	452	668	Used by domestic aircraft, main back-up airport, but roads can be closed in winter
Berlevåg	406	471	Possibility to develop a base, however existing infrastructure is not suited.
Bjørnøya	124	506	Not sufficient sight (too much fog) to be a regular helicopter base, but used as emergency landing base.
Bodø	820	1 135	Rescue helicopter base (SAR), however too far away from the considered locations in the Barents Sea
Hammerfest	374	597	Currently base of operations for oil companies, landing restrictions due to weather and surrounding terrain
Honningsvåg	354	519	Same landing restrictions as Hammerfest
Hopen	290	378	Can possibly be used as emergency landing base for the SE location
Kirkenes	538	574	Used by domestic aircraft. Best suited as helicopter preparedness base of the airports in East-Finnmark (Avinor, 2012).
Lakselv (Banak)	447	625	Rescue helicopter base (SAR)
Longyearbyen	513	682	Rescue helicopter base
Tromsø	506	800	Air ambulance services
Vardø	493	496	Possible future base?

The remoteness creates significant challenges with respect to ensuring a robust level of emergency response. This is particularly related to external rescue resources such as SAR helicopters, which will have longer response times. Flight distances above 300 nm (~550 km) are not considered feasible with existing helicopter technology. Distances between 200-300 nm (370-550 km) are feasible with existing helicopter technology, but with reductions in number of passengers to reduce weight. As an example the existing Sikorsky S-92 helicopters fly with 6-8 passengers for a distance of 265 nm (490 km), and with upgraded helicopters the number of passengers is expected to increase to 10. The limitations on the All Weather Search And Rescue (AWSAR) helicopters will be the similar, but to a lesser degree than for transport helicopters (Statoil, 2015).

It is a basic assumption that a helicopter base will be established onshore, to reduce the helicopter flight distance as much as practically possible.

The NOROG 064 Guideline for establishing area emergency preparedness plan defines a requirement to pick up entire helicopter crew within 120 minutes for helicopter accident within rig safety zone. Even though the NOROG 064 Guideline is only valid for areas with area emergency response, which is not the case for the two locations, the reference is used for good practice.

The Guideline defines a requirement to pick up a full helicopter (max 21 persons) from the sea within 120 minutes in case of a helicopter ditches inside the rig safety zone. The requirement is normally met with use of a Man Over Board (MOB) boat or a Fast Rescue Daughter Craft (FRDC) as recue resources when these can be launched. If a MOB boat or a FRDC cannot be launched, an AWSAR helicopter is the main resource. Due to the increased distance from shore, the AWSAR will not be able to meet the requirement. Mitigating measures focus on a possible new helicopter base onshore to reduce flight time, efficient search and tracking of persons in sea, protection against hypothermia, winterization of rescue equipment and operational limitations on transport flights when MOB boats or FRDC cannot be launched.

The remote location and with few vessels and installations in the area also require more attention on how to rescue personnel after a helicopter accident outside the rig's safety zone. Following PSA Activities regulations §17 the operator has a responsibility for safe transport to and from the installation. NOROG (2015) states that it is the government who should have the responsibility for the rescue resources outside the 500-m zone of the offshore installations. Mitigation should focus on improving protection against hypothermia, onshore helicopter bases for reducing flight distance and response times, efficient search and tracking of missing personnel, requirement to SAR operational readiness and operational limitations on scheduling of transport flights.

Figure 4-1 shows the helicopter range for a scenario when 21 persons are to be rescued from the sea within 2 hours. The circles in the figure are created with an assumption of helicopter speed 135 knots a mobilisation time of 15 minutes and a rescue time of 3 min/person (green circles) and 4 min/person (red circles). The figure shows that for the two locations, the rescue capability around the facilities cannot be ensured from an onshore-based helicopter, and this must be compensated for by a combination of operational and technical measures. Note that capability for rescuing personnel from a helicopter accident when the helicopter is en route to the facility has been questioned in the recent DNV GL position paper (DNV GL, 2015a).

Similar as for the ports, DNV GL has not to any detail assessed the present state of the helicopter bases and their possible future usability.

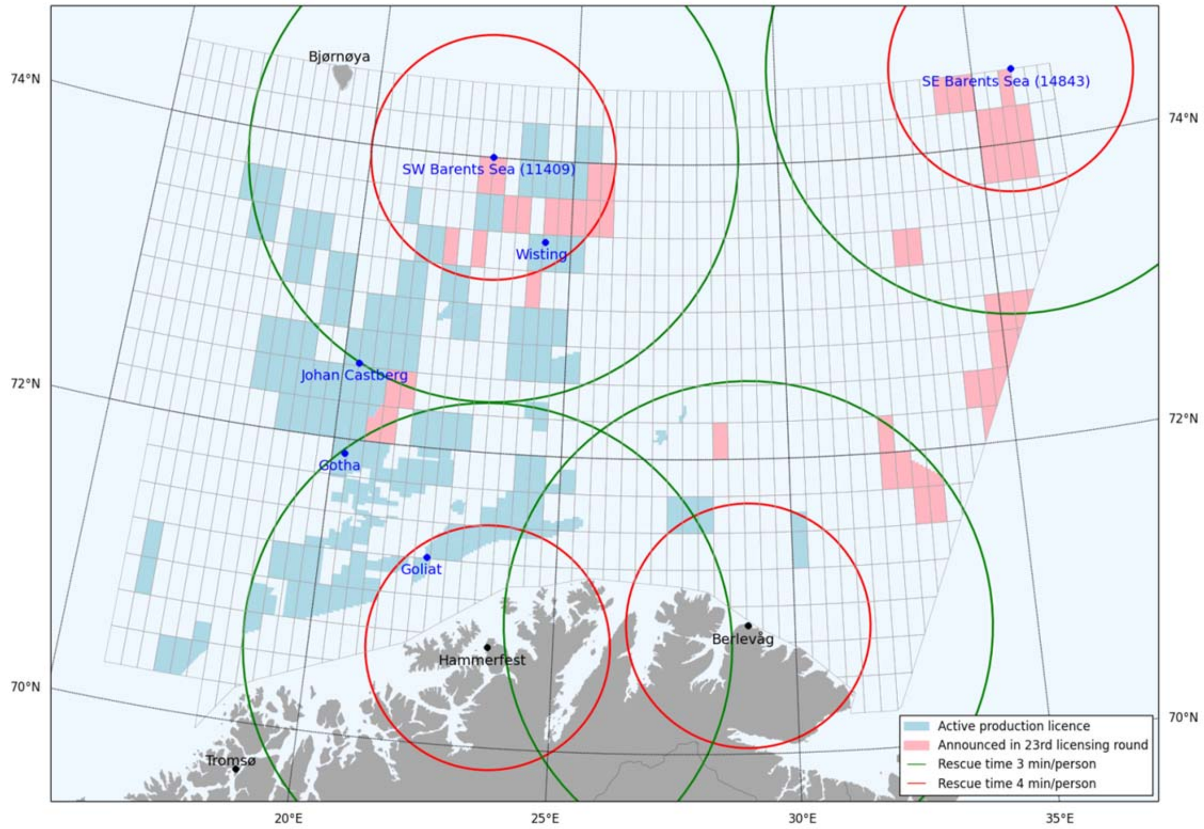


Figure 4-1: Helicopter range for rescuing 21 persons within 2 hours (speed 135 knots, mobilisation time 15 minutes).

Hospitals

In northern Norway the public hospitals are governed by the Northern Norway Regional Health Authority (Helse Nord). Helse Nord is further organised in small entities where the University Hospital of North Norway and the Finnmark Hospital are directly responsible for the public hospitals in Harstad, Tromsø, Hammerfest and Kirkenes. In most cases with serious injuries, personnel would be transferred to the public hospital in Tromsø. Although the distance to Tromsø is long, there is an ambulance air service serving northern Norway, which will quickly be able to transport injured personnel to Tromsø.

There is also a hospital in Longyearbyen, but the two locations are closer to the mainland than to Longyearbyen. Even though the hospital in Longyearbyen has limited size and capacity it could be used as a backup solution if medical personnel are mobilized from the mainland.

DNV GL has not assessed the capacity and capabilities of the different public hospitals in any detail.

Table 4-3: Distance from the two locations to hospitals in northern Norway.

Destination	SW Barents [km]	SE Barents [km]
Hammerfest	374	597
Harstad	628	939
Kirkenes	538	574
Tromsø	506	800

4.3 Daylight

Due to the suns inclination to the earth, the sun does not rise above the horizon in the north during wintertime. Similarly, during summer the sun never sets at high latitudes. Although night-time operations are common also other places on the NCS the prolonged periods of darkness in the north may constitute special challenges for operations as well being a psychological challenge (some also react to prolonged periods of daylight exposure). The amount of daylight has been calculated for the SW Barents Sea location and for Skarv (Figure 4-2) using the Center for Biosystems Modelling (CBM) model described by Forsythe et al. (1995). Daylight is here conservatively defined by sunrise and sunset when the top of the sun is even with the horizon. For most months of the year the differences are small, however during Nov – Feb the sun barely gets above the horizon at 74°N. This does not mean it is completely dark as there will be several hours with twilight.

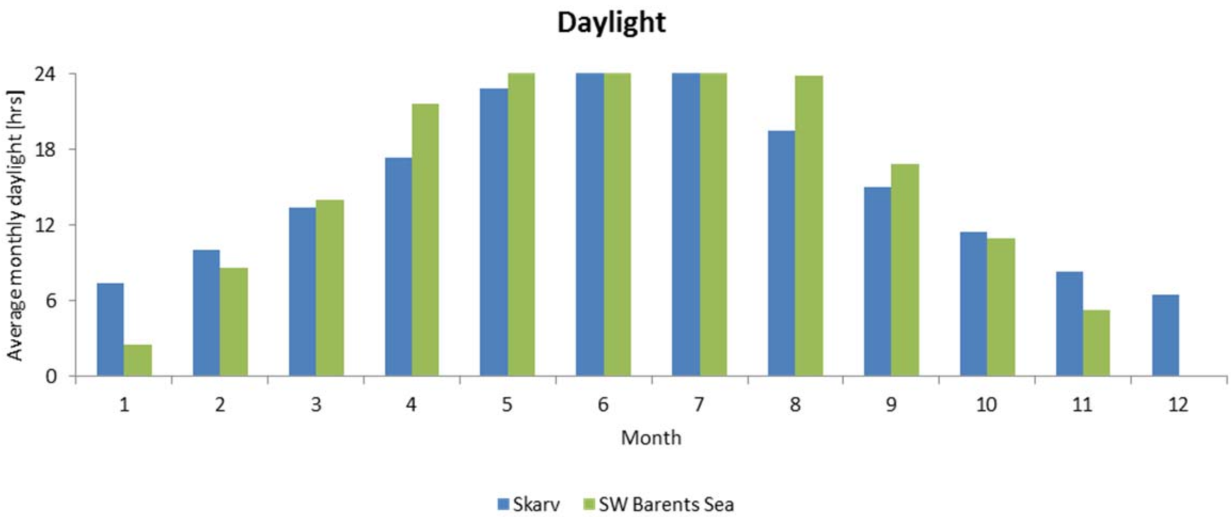


Figure 4-2: Average monthly amount of daylight for SW Barents Sea location and Skarv.

Even though there is much daylight during the summer months in the Barents Sea, visibility is hampered by the regular occurrence of fog. Based on data from met.no (2012a) for the period June – September, fog occurs about 20% of the time at Hopen and 15% of the time at Bjørnøya.

4.4 Ice and metocean

This section gives a brief overview of the ice and metocean conditions at the two locations assumed. For wind speed, significant wave height, air temperature and sea temperature, the data source is the NORA10 hindcast dataset (met.no, 2009). The main focus here is to give a comparative analysis towards Skarv, rather than establishing extreme values at given return periods. Only data from the period 2003-2012 have been used.

The information on marine icing and wind chill is processed based on the same NORA10 data as described above.

The extent of sea ice in the Barents Sea is under continuous influence of wind, waves, oceanic currents as well as air and sea temperature. The sea ice cover is dynamic, but the areal coverage has been reduced in the latest years (see for instance met.no, 2012a on the intermittent occurrence of sea ice).

Sea ice occurrence was analysed based on high resolution daily satellite data. The data was prepared and made available by the University of Bremen (DNV GL, 2014a).

For the occurrence of icebergs in the Barents Sea limited data is currently available, compared to for instance the Grand Banks where there is oil production in an area with regular occurrence of icebergs. Some information exists from Soviet surveillance flights (Abramov, 1996) from Norwegian sealers (Hoel, 1961) and more recently the Barents Sea ice data acquisition program (IDAP as reported in Spring, 1993). Information from numerical models are also useful (see for instance met.no, 2012b; Keghouche, 2010; Eik, 2009), however there is still uncertainty when it comes to the predictability of such models, mainly due to the accuracy and scale of oceanic current models.

Wind and waves

Figure 4-3 shows the distribution through the year for mean and standard deviation of the wind speed for the Skarv location and the two selected locations in the Barents Sea. In general the wind conditions are quite similar (also an effect of comparing averages), but it can be seen that there are stronger winds at the Skarv location during the autumn months than in the Barents Sea (also reported by met.no, 2012a using the same data, but for the period 1958-2011). There is no clear distinction between the two Barents Sea locations.

It should be noted that the occurrence of polar lows is not well captured by the NORA10 hindcast. As polar lows are infrequent this would not change the mean values of the wind speed significantly. See met.no (2012a) for more information on polar lows in the Barents Sea. The occurrence of polar lows with strong winds and reduced visibility is mainly an operational challenge as polar lows have been difficult to forecast. The forecasting capability of polar lows has been greatly improved in the latest years (met.no, 2014).

When looking at the wave conditions (Figure 4-4) it is in general, throughout the year, higher waves in the Norwegian Sea than in the Barents Sea and higher waves in the western part of the Barents Sea than in the Eastern part. The wave conditions alone can as such not be characterized as more severe than other parts of the NCS where there exists operating experience. Met.no (2012a) reported the 100 year return period significant wave height (Hs) to be 16.0 m for the location of Heidrun (close to the location of Skarv) while 13.3 m for 74°N, 31°E.

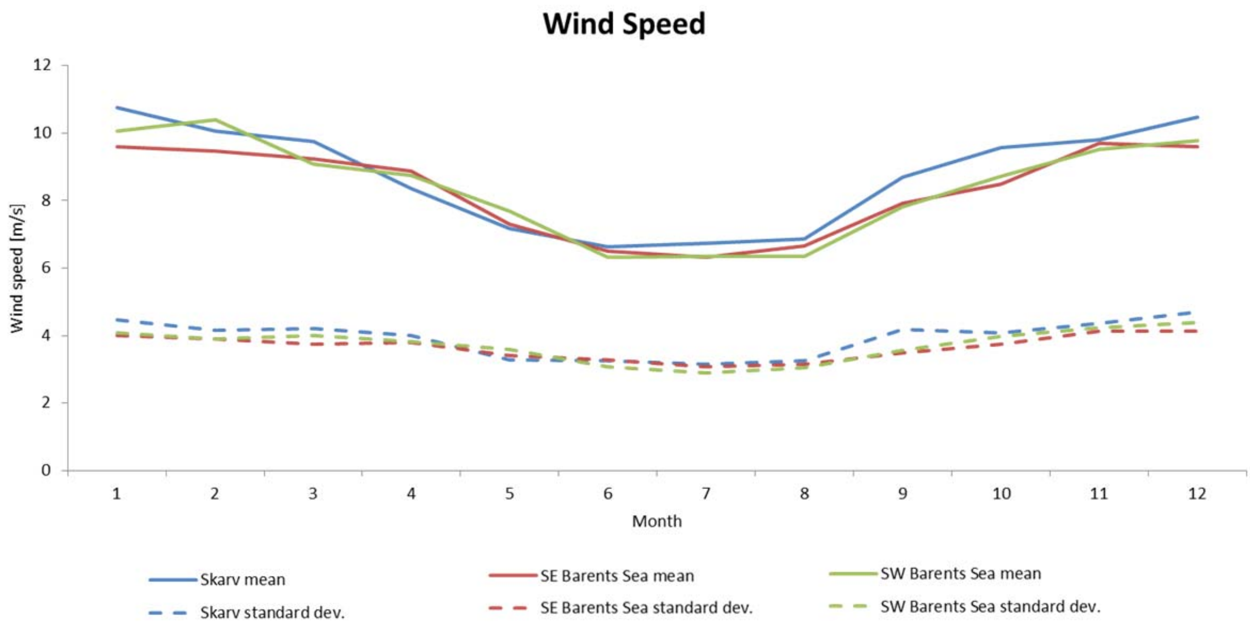


Figure 4-3: Mean and standard deviation of wind speed.

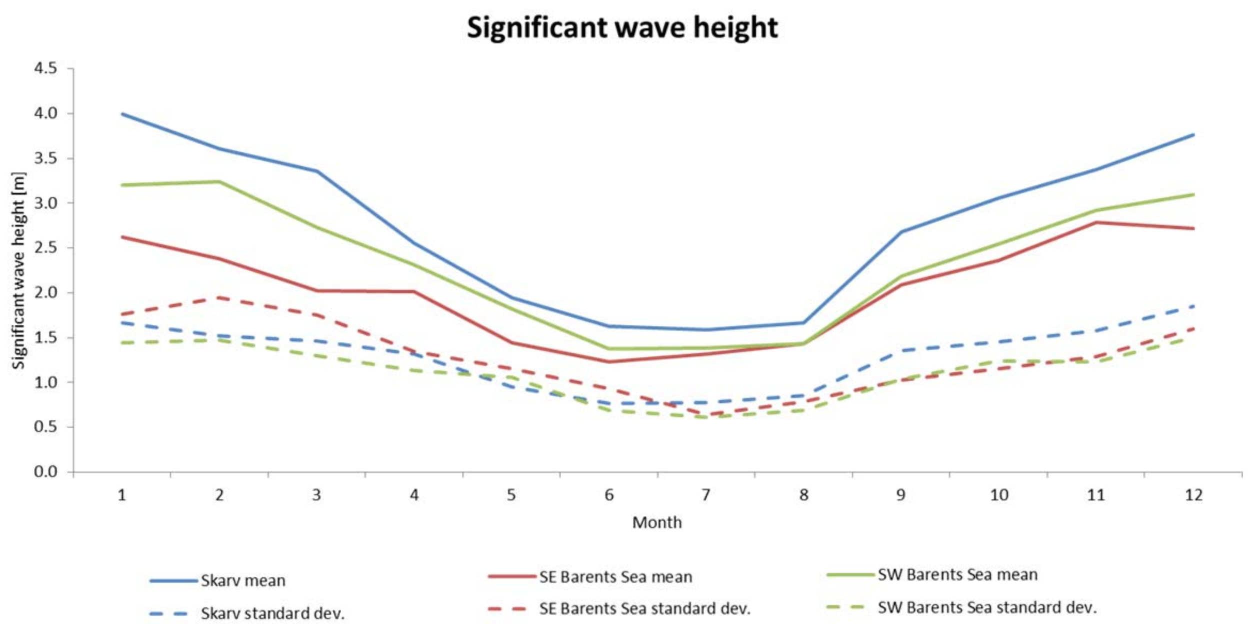


Figure 4-4: Mean and standard deviation of significant wave height.

Air and sea temperature

There is no surprise that the temperature in the Barents Sea is generally lower than in the Norwegian Sea. In average the air temperature is below freezing for 5-6 months in the Barents Sea (Figure 4-5). The sea surface temperature is also generally lower than further south (Figure 4-6). As the eastern part of the Norwegian Barents Sea is less influenced by the inflow of warm Atlantic water, the surface temperature is reduced when moving from west to east.

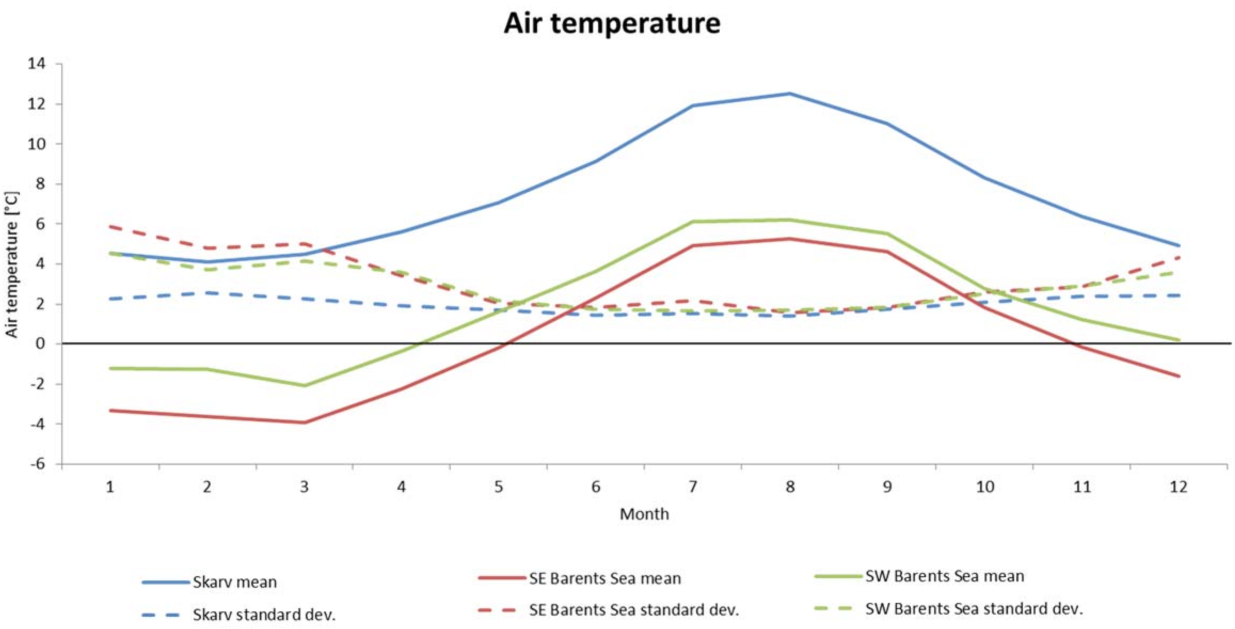


Figure 4-5: Mean and standard deviation of air temperature.

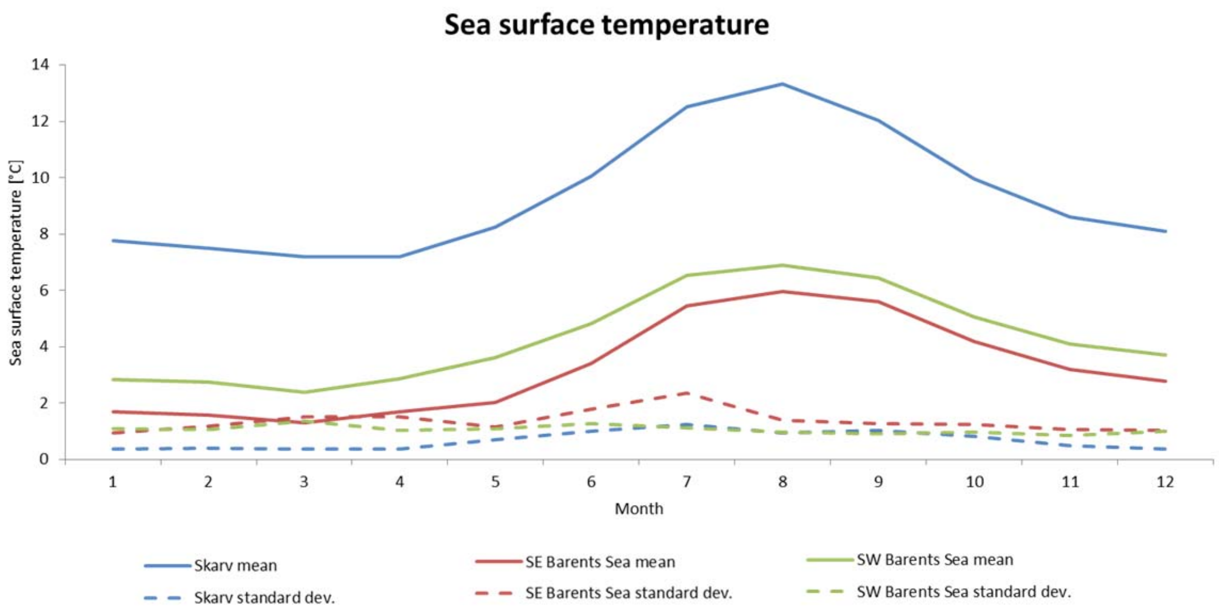


Figure 4-6: Mean and standard deviation of sea surface temperature.

Marine icing

Marine icing occurs as a result of low air temperatures, wind and waves. In this context marine icing refers to sea spray icing and not for instance atmospheric icing, frozen snow, sleet etc. as a result of for instance passing polar lows and dense snow showers. These other sources of icing might be equally important as marine icing, however the amount of icing in such events are much more difficult to predict.

The possibility and amount of marine icing has been analysed based on the algorithm originally developed by Overland (1989). This prediction algorithm is widely used, but was developed on the basis of measurements performed on relatively small fishing vessels (DNV, 2010). This means its validity for offshore structures is limited, but for the purpose of this report it is useful to highlight the average amount of days marine icing can be expected during one year. The analysis is based on the NORA10 data.

Figure 4-7 shows the result of the analysis for the different icing classes defined by Overland (1989). Note that the icing rates are not necessarily valid for offshore structures. On the location of Skarv there are practically no icing events, while it can be expected that in average there will be about 25-35 days every year with moderate, heavy or extreme icing events in the Barents Sea locations. The conditions are generally worse in the eastern part of the Barents Sea than in the western part, largely due to the lower air temperatures in the east. The reported values for SE Barents Sea are comparable to those reported by met.no (2012b) for a location further west (74°N, 32°53'E).

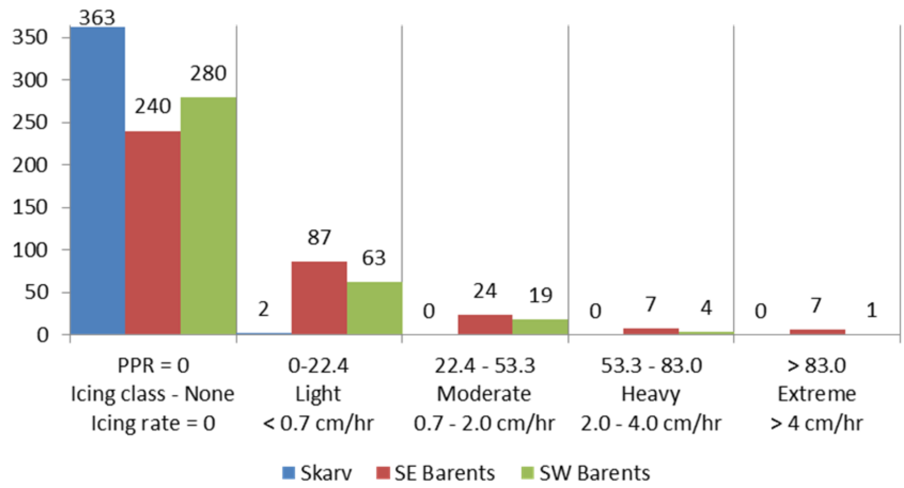


Figure 4-7: Average amount of days with marine icing using the Overland algorithm (icing rate for vessels 20-75 m). PPR (an icing predictor) and the icing class are according to Overland (1989).

Figure 4-8 illustrates how the icing events are distributed through the year. It shows that during the months May through October/November there is little occurrence of marine icing in the Barents Sea and the most severe conditions are expected during December through March.

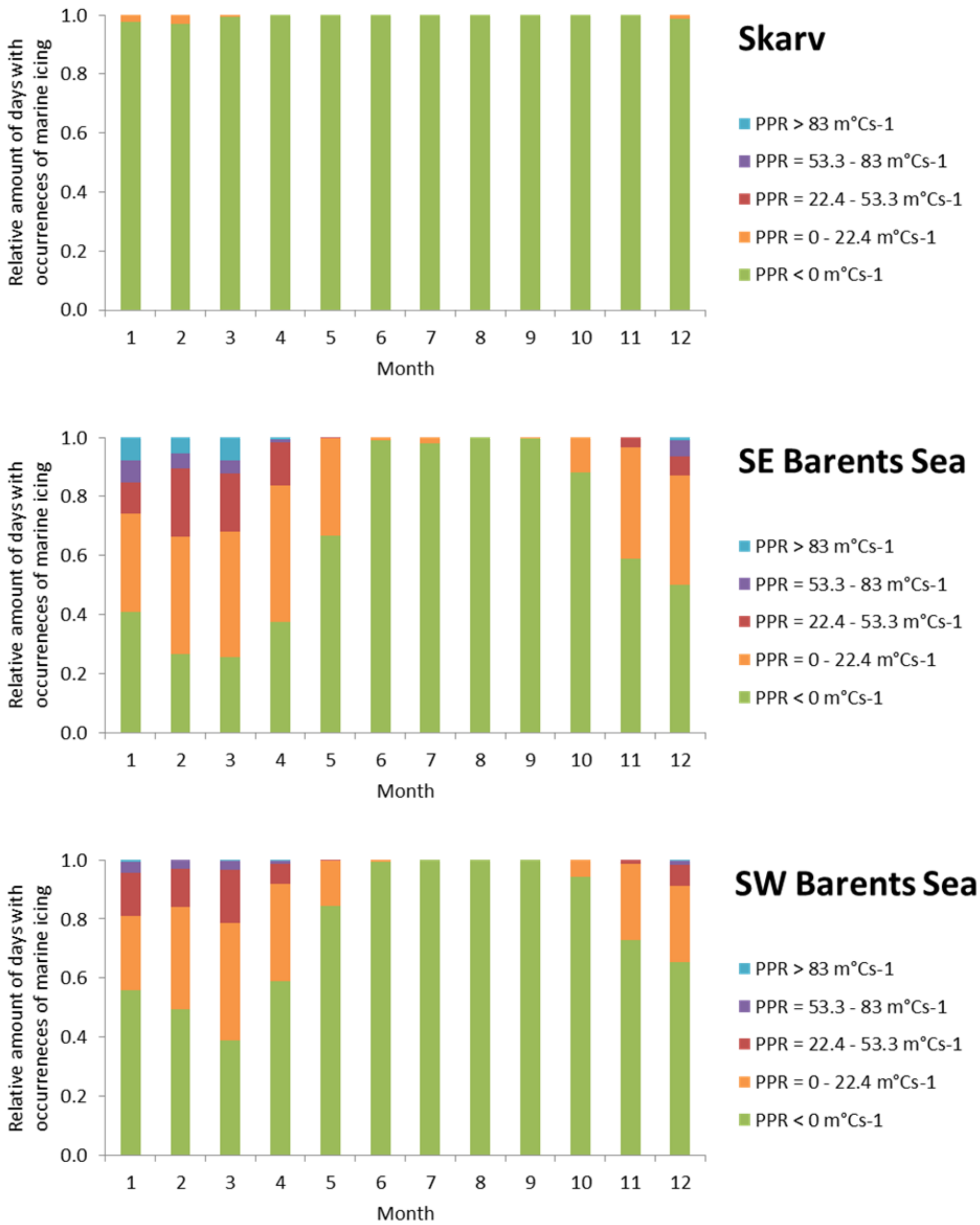


Figure 4-8: Relative amount of days through the year with occurrences of marine icing using the categorisation of Overland.

Wind chill

Low temperatures and wind result in what is commonly referred to as wind chill. Wind increases the effective heat transfer from objects (e.g. machinery or personnel) of different temperatures than the ambient air temperature. Wind chill was originally quantified as a wind chill index (WCI). However, wind chill temperature (WCT), as defined in ISO 11079, has to a large extent replaced WCI. In the current version of NORSOK S-002 there are established criteria, related to different levels of WCI, for when outdoor work is permitted. NORSOK S-002 is currently being revised and will in the next version use WCT, but since it is not yet published and the criteria relating to WCT are not yet defined, the existing NORSOK S-002 and WCI is used as a basis for this analysis. Figure 4-9 below show the recommendations given in the current version of NORSOK S-002.

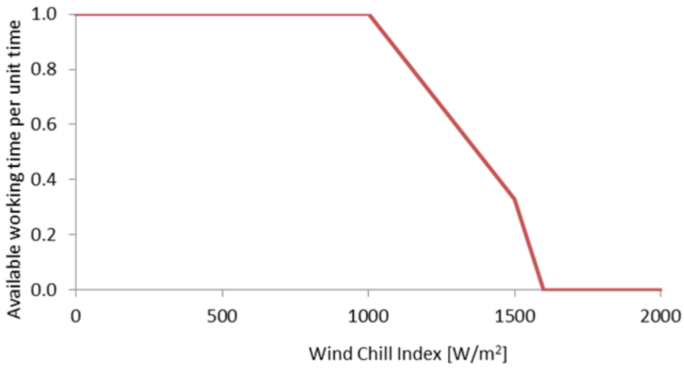


Figure 4-9: Available working time per unit time as given in NORSOK S-002.

Figure 4-10 shows the relative amount of work when outdoor work is permitted for the three considered locations with averages of 96%, 77% and 82%, for Skarv, SE Barents and SW Barents respectively. In the Barents Sea in January-March it can generally only be expected to work outside about 60% of the time. This necessitates mitigating measures such as enclosing and heating of working areas.

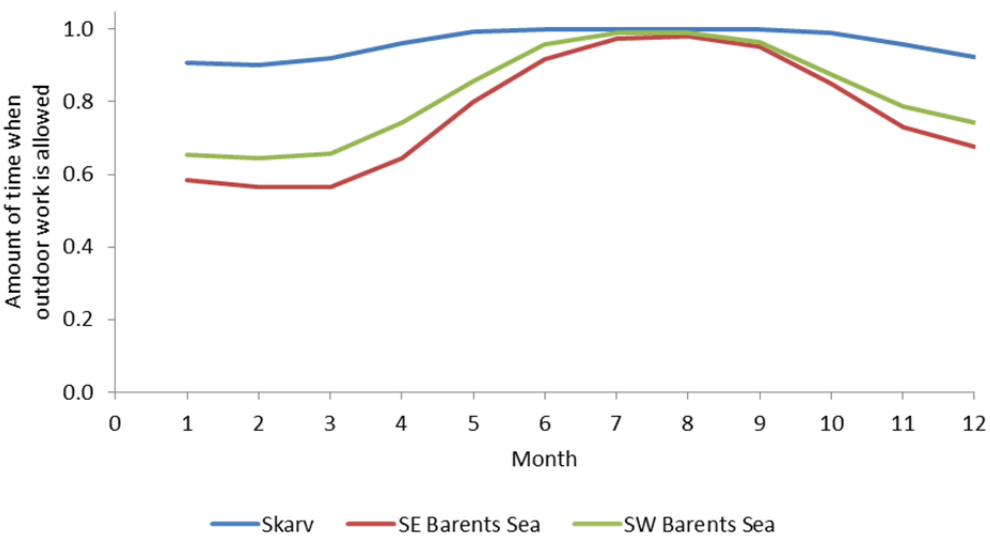


Figure 4-10: Monthly distribution of amount of time when outdoor work is permitted according to NORSOK S-002.

The current version of NORSOK S-002 states that if the WCI is above a certain threshold (> 1600 W/m2), no outdoor work is permitted. Figure 4-11 shows that in the winter months December – March there can be a substantial portion of the days (up to 20% in SE Barents Sea in January) where there will be periods where no outdoor work is permitted given the current requirements in NORSOK S-002. It can be noted that neither NORSOK S-002 nor ISO 11079 addresses the need for training or the effects of competence and experience. Working in arctic conditions is a competence in itself, a competence which should not be underestimated when it comes to carrying out arctic operations. Requirements for such competence are for instance described in the IMO Polar code for safe navigation.

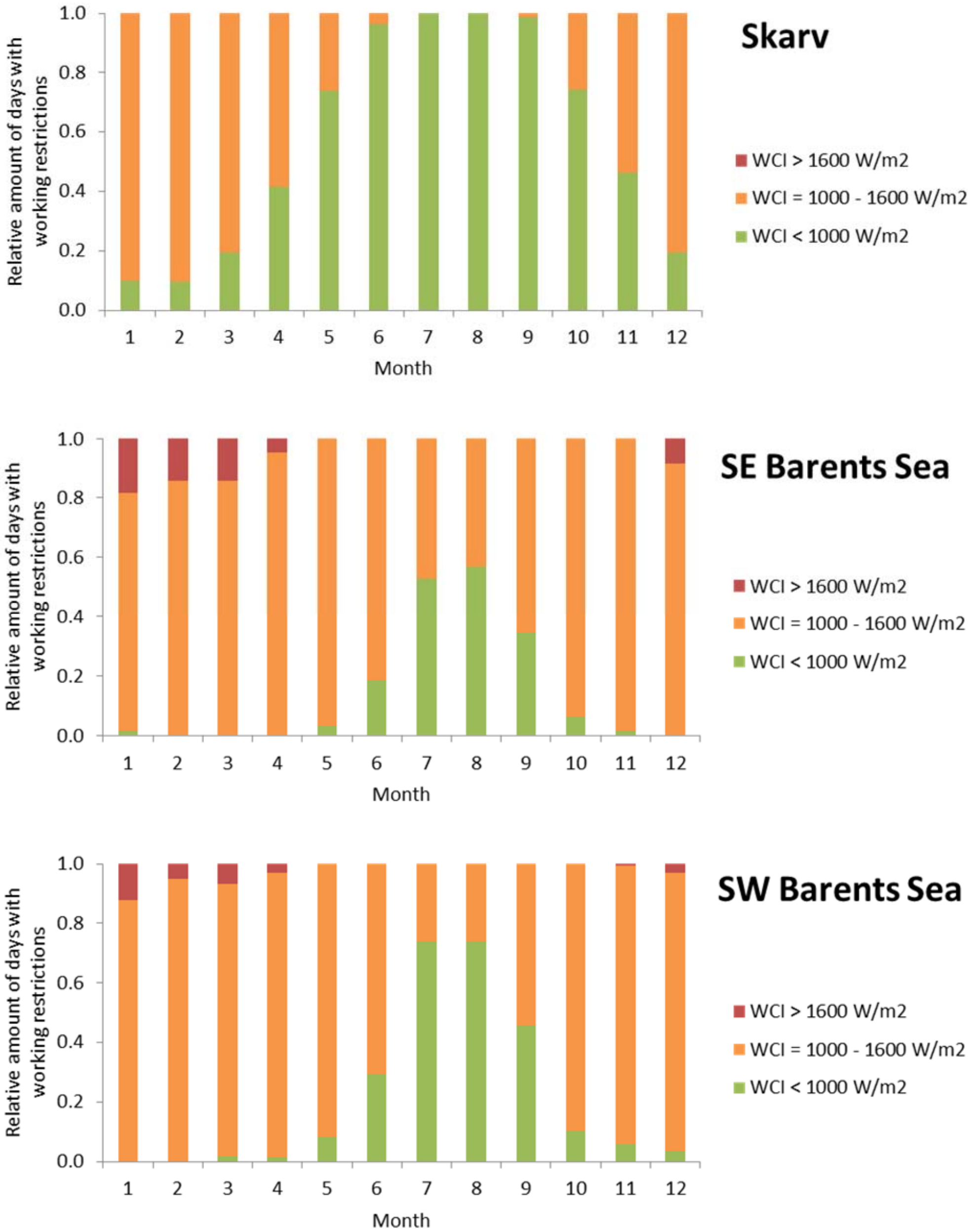


Figure 4-11: Relative amount of days through the year wind chill temperature with working restrictions using the categorisation in NORSOK S-002.

Sea ice and icebergs

The Barents Sea is dominated by first-year ice, which forms during late-autumn, grows during the winter and melts or drifts away during spring and summer. Remnants of multi-year ice have also been observed. The time frame for maximum southernmost extent of sea ice varies from year to year. Figure 4-12 shows the maximum extent in the month of April for the period 2001 to 2011.

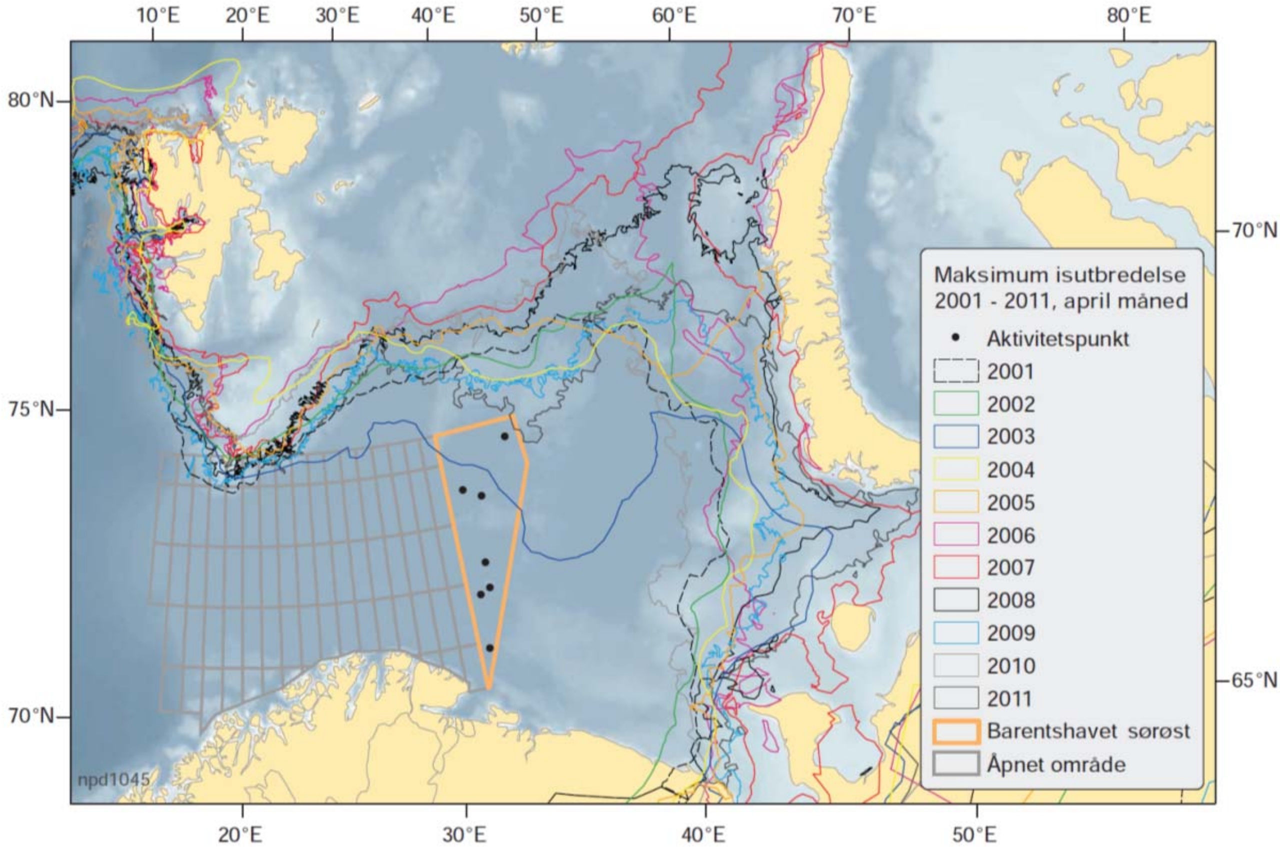


Figure 4-12: Maximum ice extent in April in the period 2001-2011 (Meld.St. 36).

Daily satellite data from University of Bremen was used to analyse the ice cover at the locations (DNV GL, 2014a). High resolution data with a spatial resolution of 6.25 km was used and the data covers the time period 2003-2014. Figure 4-13 shows the average amount of time (time when ice was present divided by duration of observation period) when the sea ice concentration was exceeding 10% (open water defined as less than 10% areal coverage of ice, WMO, 2014). Sea ice occurs more frequently on the eastern location than the western location. In the 12 year observation period, ice never reached the western location, while in the eastern location sea ice was present 2 out of 12 years (2003 and 2004). The analysis also shows that even though ice has not been observed on the western location in the period 2003-2014, it has been observed very close to this location. There are several years where the sea ice has been less than 50 km away. For the eastern location sea ice is present about 10-15% of the time in the months January – March, and slightly less in April – June and December. July – November has had open water conditions (i.e. less than 10% ice concentration) during the whole observation period.

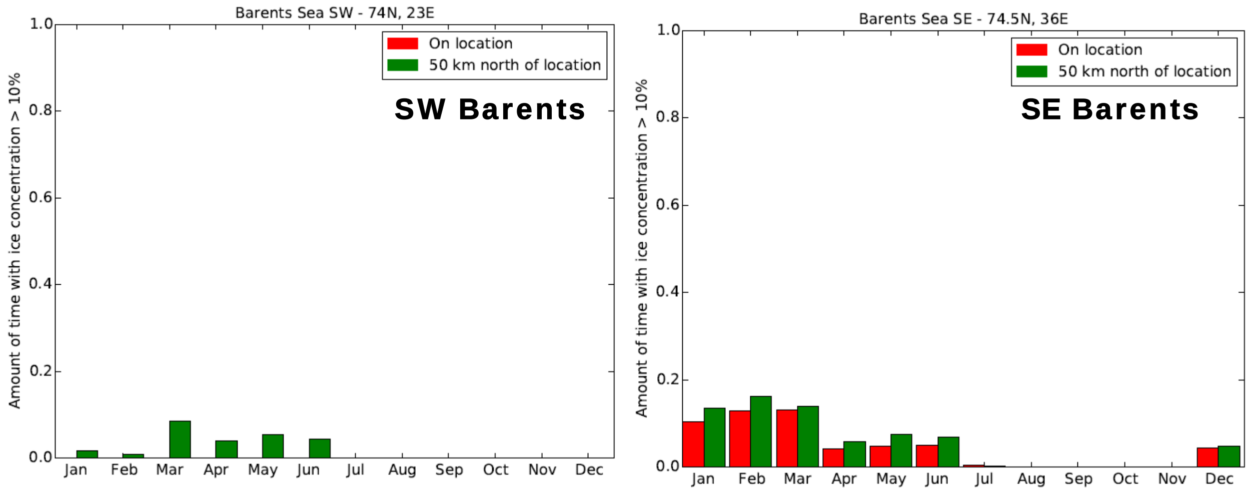


Figure 4-13: Amount of time during the year when the ice concentration is above 10% for the two locations and a point 50 km north of the locations.

In the years 2003 and 2004 the sea ice arrived (still sea ice concentration > 10%) at the eastern site 17 January 2003 and did not leave completely until 24 June the same year. It should be noted that sea ice was not present during this whole period, but moved further north and returned multiple times. The ice returned 16 December 2003 and ice was then present on the location until 21 March 2004. In the rest of the observation period there has not been any ice on the eastern location. The dates should be considered approximate as there is some uncertainties related to the accuracy of such satellite images when processing low ice concentrations. Figure 4-14 shows that when ice is present relatively high ice concentrations (i.e. the ocean is completely covered by ice) can be expected.

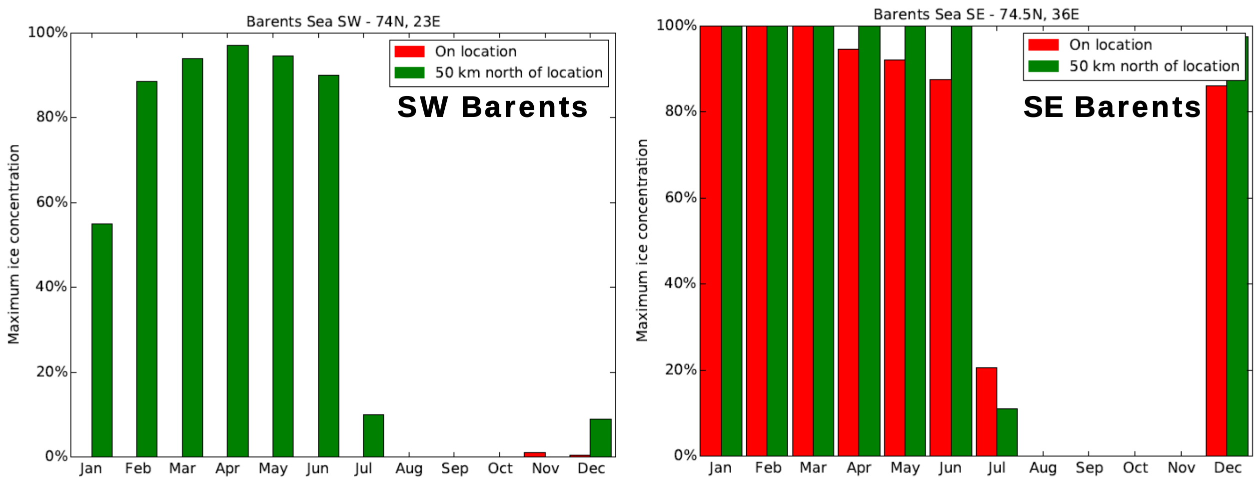


Figure 4-14: Maximum observed (2003-2014) sea ice concentration for the two locations and a point 50 km north of the locations.

Figure 4-15 shows the annual probability of exceedance limits for sea ice and icebergs as given in NORSOK N-003. Based on visual inspection, the contour lines for sea ice correspond well with the satellite data.

When it comes to the presence of icebergs there is a major lack of data to quantify the number of icebergs in the Barents Sea. The major sources of icebergs are the glaciers on Franz Josefs Land, Novaya Zemlya and to some smaller extent Nordaustlandet. In general there are more icebergs in the northern and eastern parts of the Barents Sea (Abramov, 1996) than in the western parts. The limits given in NORSOK N-003 (right on Figure 4-15) should be considered indicative, however it is evident that the two locations are north of the 10^{-4} contour line, possibly also north of the 10^{-2} contour line. This means that icebergs need to be considered for structural design and operations of installations at the considered locations.

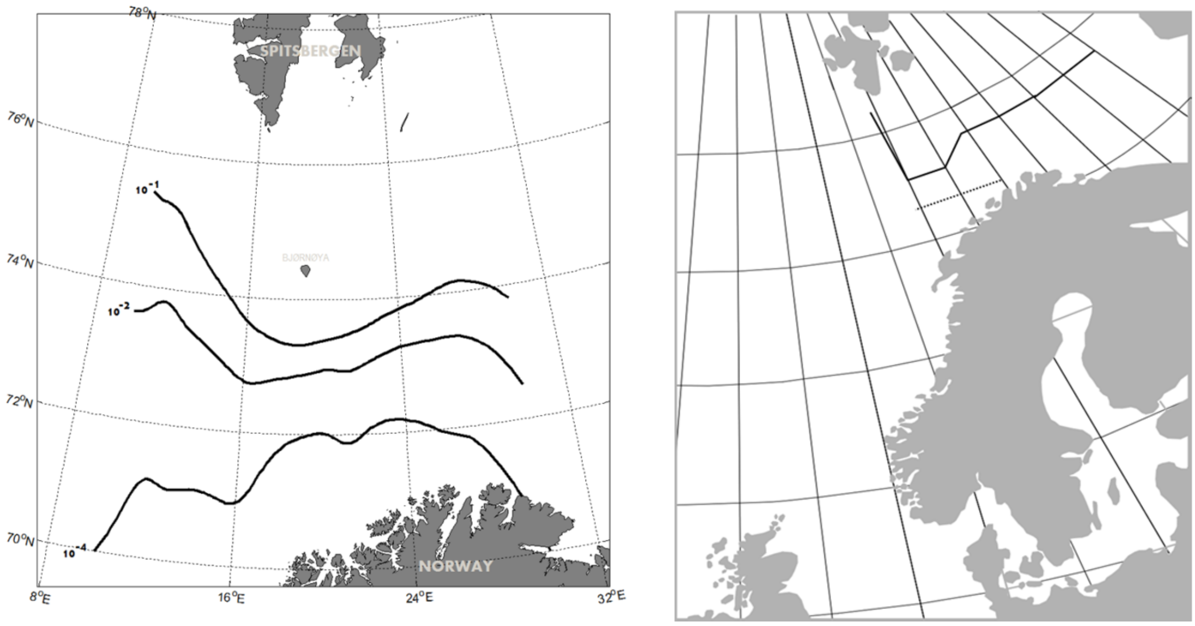


Figure 4-15: Annual probability of exceedance limits for sea ice (left) and icebergs (right) as given in NORSOK N-003. On the right figure the solid black and grey lines are for annual probability of exceedance of 10^{-2} and 10^{-4}, respectively.

4.5 Sensitive biological resources

The Barents Sea is an important area for birds, fish and marine mammals. The current assessment of sensitive biological resources in the two areas of interest has been performed based on information derived from the Havmiljø.no portal (http://havmiljø.no). Only species with the highest environmental values are described here. For a more extensive description of the regional environmental resources, it is referred to:

- ”Miljø- og ressursbeskrivelse av området Lofoten – Barentshavet” (Føyn et al., 2002)
- “Helhetlig forvaltningsplan for Lofoten og Barentshavet” (Havforskningsinstituttet, 2010)
- “Kunnskap om marine ressurser i Barentshavet sørøst” (Havforskningsinstituttet, 2012).

Havmiljø.no is a map-based portal presenting marine areas with high environmental values along the coast and sea outside of Norway and Svalbard. In addition to environmental values, the web site also provides information about vulnerability relative to acute oil pollution, in addition to tables showing the vulnerability of various species to other impact factors. Information about uncertainties in data and analyses are given in separate maps. The portal is developed in collaboration between the Norwegian Environment Agency, Norwegian Institute for Nature Research, Institute of Marine Research, The Norwegian Polar Institute, Norges Geologiske Undersøkelser and DNV GL.

The current analysis will mainly be based on the environmental values of the occurring resources within the respective areas in combination with an uncertainty estimate (high, medium, low or none). The uncertainty estimate indicates the level of detail and reliability in the information, and limitations in the data and knowledge available.

Environmental values describe the importance of a specific area for the ecosystem as a whole and are based on how important habitats for birds, fish, benthic organisms / ecosystems and marine mammals are distributed over the year. A set of seven criteria, the Ecologically and Biologically Significant Area (EBSA) criteria, is used by Havmiljø to identify areas considered important for the life-history stages of species in the sea (Table 4-4). The EBSA criteria have been adopted by the UN Convention on Biological Diversity (CBP COP 9 Decision IX/20) and are in general similar to the IMO Criteria for Particularly Sensitive Sea Areas (IMO, 2002).

EBSA Criterion 2, especially important areas for life-history stages of species, is forming the basis for the environmental value system in Havmiljø. These are areas where many animals congregate in particular life-history stages, meaning that evenly distributed species will not be highlighted in the analyses.

Table 4-4: Criteria for assigning environmental values.

Id	Description of criteria
K1	Rarity or uniqueness
K2	Important area for life-history stages
K3	Threatened, vulnerable or declining species and habitats
K4	Fragility , sensitivity or low recovery capability
K5	Importance for biological productivity
K6	Biological diversity
K7	Naturalness

In Havmiljø.no the assessments have been made for each species occurring in 10x10 km grid according to criteria listed in Table 4-5. The maximum values for each group can be summarized to an overall environmental value for an area.

Table 4-5: Criteria for assigning environmental values according to Havmiljø.no

Seabirds	**Fish**	**Marine mammals**
Assessment basis for each species: - important areas and periods for life-history stages - proportion of national population - Red List status Species with the highest value (max. value) represents the group as a whole	Assessment basis for each species: - uniqueness/key species - areas and periods that are important for life-history stages - density - importance for productivity Species with the highest value (max. value) represents the group as a whole	Assessment basis for each species: - areas and periods that are important for life-history stages - density - Red List status Species with the highest value (max. value) represents the group as a whole

The environmental sensitivity for i.e. oil pollution or noise can be determined by combining the environmental values with species-specific vulnerability towards a certain impact factor.

Results from analyses carried out by Havmiljø.no of environmental values in the two areas of interest over the year are summarized in Table 4-6 and illustrated in Figure 4-16. Sensitive biological resources at Bear Island (classified as particularly vulnerable area, PVA-area) are also included because of the proximity to the SW location and because a large oil spill from the SW location most likely will affect the biological resources in this area.

The uncertainty assigned to the distribution data forming the basis for Havmiljø.no are considered high, so both percentages of environmental values and species distribution over time must be read/interpreted as indicative estimates only.

By looking at the results from the Havmiljø analyses (Table 4-6 and Figure 4-16) it is evident that the locations have quite different vulnerability profiles for all groups of organisms. Whereas the location in the SE part of the Barents Sea is an important habitat for seabirds, marine mammals and fish, the location in the SW part of the Barents Sea is mainly overlapping with an important sea bird area. The overall environmental vulnerability is higher for the SE Barents Sea but because of the SW locations proximity to the Bear Island, industrial activity in the area could have significant negative effects on a wider range of biological resources than those having a distribution pattern overlapping the exact SE location.

Both locations are in proximity to the polar front (important seabird foraging area) and during years of extreme southward ice extension both locations could also be overlapping with the marginal ice zone and associated vulnerable ecosystem components (harp seal, ringed seal, polar bear, seabirds i.e. ivory gull and polar cod). This issue is most relevant for the SE locations as shown under section 4.4.

As already mentioned, the presented results are based on environmental values. In order to gain information about the environmental risk of oil spill (not relevant for the SW Barents Sea location) or the environmental impact of other industrial activities related to the proposed activities (increased ship traffic, drill cuttings and noise), more detailed analyses must be undertaken.

Table 4-6: Occurrence and temporal distribution of the species for the two locations including the Bear Island.

Group	Location	Species	Month 1	2	3	4	5	6	7	8	9	10	11	12
SE Barents	Seabirds	Brunnich's guillemot				X	X	X	X	X	X	X	X	
		Black legged kittiwake								X	X	X	X	
	Marine mammals	Harp Seal				X	X							
	Fish (larvae and 0-group)	Capelin									X	X	X	X
		North East Arctic Cod									X	X	X	X
		Norwegian Spring Spawning Herring									X	X	X	X
SW Barents	Seabirds	Brunnich's guillemot				X	X	X	X					
		Black legged kittiwake				X	X	X	X					
		Northern Fulmar	X	X	X									
Bear Island	Seabirds	Brunnich's guillemot				X	X	X	X	X				
		Black legged kittiwake				X	X	X	X	X				
		Northern Fulmar				X	X	X	X					
		Razor Bill				X	X	X	X					
		Little Auk				X	X	X	X					
		Common Guillemot				X	X	X	X	X				
		Glaoucous Gull				X	X	X	X	X			X	
	Marine mammals	Polar bear		X	X									
		Harp seal				X	X							
		Humpback whale					X	X	X					
		Common Minke Whale					X	X						
		White Whale					X	X	X	X	X			
	Fish (larvae and 0-group)	Capelin						X	X	X	X	X	X	X
		North East Arctic Cod								X	X	X	X	X
		Norwegian Spring Spawning Herring								X	X	X	X	X

Quality of existing data on sensitive biological resources in the Barents Sea and implications for risk assessments

Regarding seabirds, marine mammals and fish, the Havmiljø portal is built on the best available data for these resource groups, but as indicated above, the data are not very precise and are associated with uncertainty. Data with a higher resolution in time and space is needed in order to decrease the uncertainty in our assessments. Monitoring data, for instance logger data on seabirds from the SEATRACK project and satellite tracking data on marine mammals (cetaceans and pinnipeds) in addition to more data on the spatio-temporal distribution of marine resources collected at surveys are examples of information that would make risk assessments more precise. High resolution species distribution data should be matched with relevant ice and metocean data in more dynamic modelling approaches for better risk estimates. There is also a need to better understand the acute and chronic exposure scenarios (relevant for risk assessments of oil pollution) in the areas with a cold climate, large seasonal differences in air temperature and ice coverage, lack of light in long periods, complex ice/oil interaction and the patchiness in species distribution. More knowledge is also needed regarding the sensitivity of species towards different stressors (e.g. noise and oil). The sensitivity should also be evaluated in a climate change perspective – as many ice dependent species is already subject to pressure from declining ice coverage.

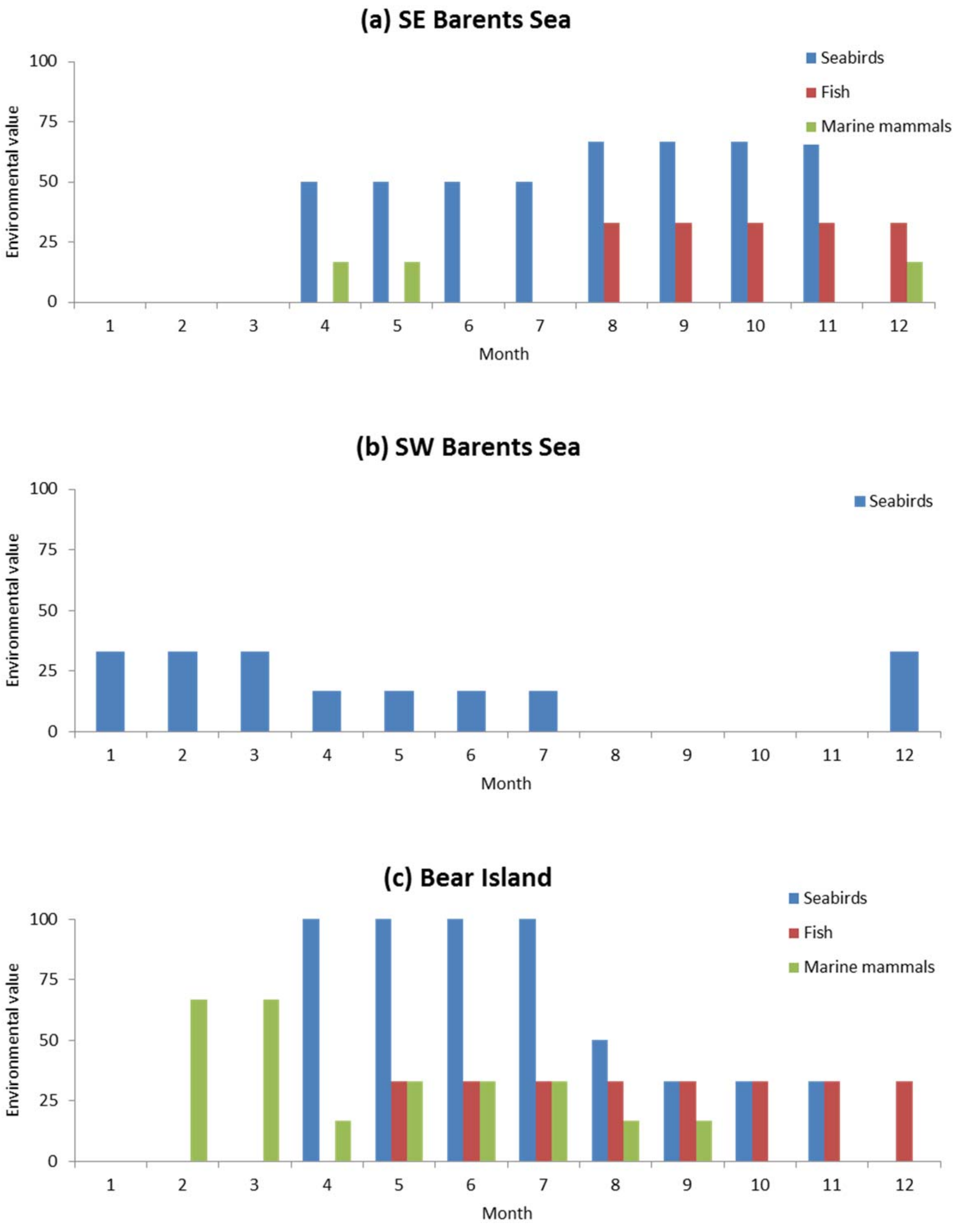


Figure 4-16: Environmental values for the locations SE (a) and SW (b) in addition to Bear Island (c) analysed at Havmiljø.no. Values are presented as % of the total value.

5 THREE EXAMPLES OF POSSIBLE FIELD DEVELOPMENTS AT 74°N

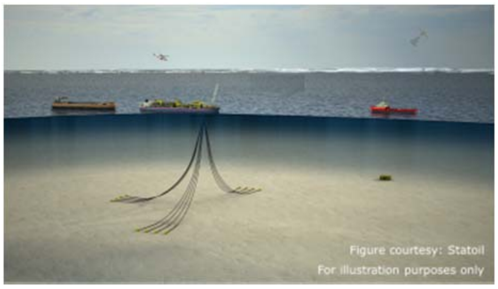
5.1 Introduction

Three examples of possible field developments at two different locations are used in order to more specifically discuss the technology challenges for oil and gas production on 74°N in the Barents Sea. The examples have been used as an instrument in this project and should not be seen as a proposal on how such fields should be developed, but rather as some out of many different field development solutions. There might be several alternative ways to develop a specific field at the chosen locations, and the examples themselves are not the main importance. The main results of this study are the identified technology challenges related to the solutions presented in section 6 and further discussed in section 7.

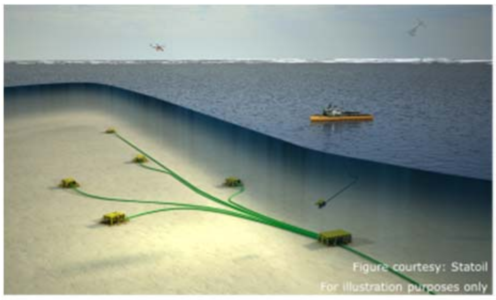
The field development examples were developed in close cooperation with the TTA groups in OG21 and are thought to be representative for relevant field development solutions. It should however be noted that the three examples were chosen to represent a wider spread in technology challenges for oil and gas production in this area, meaning that when looking at one individual field a different solution than the chosen one could be more optimal. Further, the field economics have not been assessed.

The three chosen field development examples are:

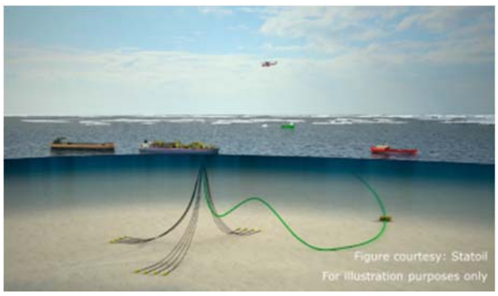
Oil production from a FPSO in the SW Barents Sea



Subsea oil production in the SW Barents Sea



Gas production from a FPSO in the SE Barents Sea



For all cases it has been assumed that seismic and drilling activities are conducted in the open water season.

5.2 Example 1: Oil production from a FPSO in SW Barents Sea

For the first example the oil field is located approximately at 74°N and 23°E. The water depth in this location is approximately 450 m, deepening to the south as the location is on the north side of Bjørnøyrenna.

It is assumed that the reservoir is of medium size with 100 MSm^3 with 30-60 MSm^3 recoverable. The reservoir depth is thought to be at 700 m below the mudline. The following reservoir characteristics have been defined by OG21:

- Pressure: 75 bar
- Temperature: 25°C
- API gravity: 20
- Gas to oil ratio: 25 Sm^3 / Sm^3
- Viscosity:4 cP

The offshore facilities of this field (Figure 5-1) consist mainly of:

- Subsea production system, including umbilicals, flowlines and risers
- A moored and disconnectable floating production, storage and offloading unit

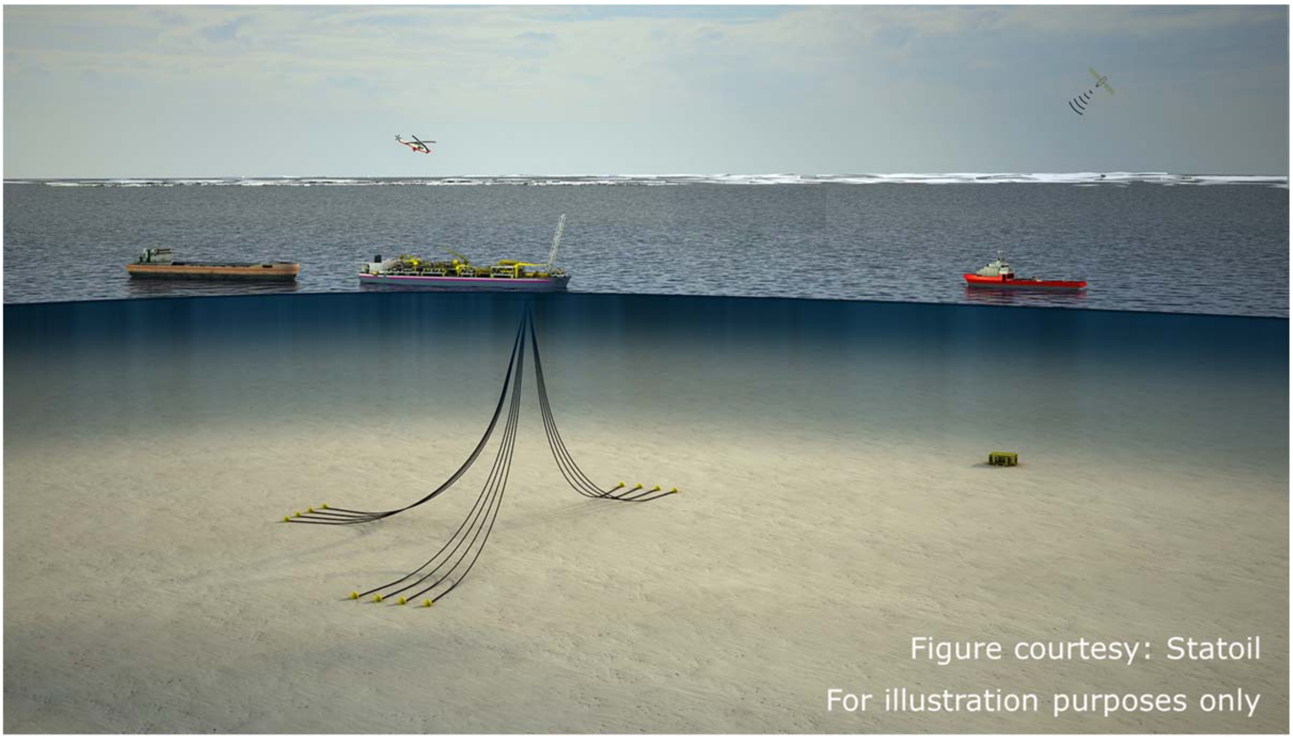


Figure 5-1: A possible field development solution for an oil field at 74°N.

The facility will support oil production and processing and a premise for this example is that there are no nearby facilities to which it would be possible to do a tie-in.

For the purpose of this report a ship-shaped hull concept have been assumed, however a thorough concept evaluation and selection process have not been carried out. Due to the possible presence of sea ice, the hull needs to be ice strengthened. Further, due to the possibility of encountering icebergs (to which there is great uncertainty due to the lack of data) it was chosen to include a disconnection system for the facility. For a specific project, especially for a location were the probability for icebergs are sufficiently low, but however not negligible, one would through design and operation optimization compare the full set of consequences (i.e. economic, operational, design etc.) of including a disconnection system towards the consequences of having more ice strengthening. One possibility for this example would be to use ice surveillance as a measure to know when to disconnect, while not planning to conduct ice handling (i.e. not tow icebergs, break sea ice etc.).

Due to the lack of nearby fields in production, the facility will need to support storage and offloading. The location is so far away from shore that a pipeline to shore (370 km) would not be feasible with today's technologies. The exact size of the storage depends on production profile, shuttle tanker operations, location of onshore process plant etc., but a 1 mmbbl storage capacity has been assumed. Direct offshore tandem offloading is used for similar facilities in comparable locations (e.g. Sea Rose FPSO on the Grand Banks).

It is assumed that production well drilling and well maintenance can be carried out in the open water season through the service life time of the field. As ice is not present every winter (see section 4.4) it should be expected that in many years, ice will not be a limiting factor for conducting all-year drilling operations. It will however, still be required to closely observe the ice conditions. The infrequent presence of sea ice would support such a strategy. It could also be assumed that all offloading operations can be performed when there is no sea ice.

Due to the low gas to oil ratio (GOR) it might not be possible to solely rely on conventional gas turbines for this field. The field is 370 km from shore, stretching the existing technology for subsea power transmission from Finnmark (assuming capacity exists in Finnmark). Alternative to power transmission from land, it has for this case been assumed that an electro-chemical fuel cell conversion technology is developed and can be implemented. This would enable an efficiency of 80% or more, utilizing the small amounts of gas available.

For such a field there will be large amounts of produced water which is assumed to be reinjected in a nearby aquifer.

5.3 Example 2: Subsea oil production in SW Barents Sea

The second example is also an oil field at the same location as in the first example. The principal difference to the first example is that it is assumed that there are other fields in production nearby with established export infrastructure. This enables a tie-in to that facility. Today the closest fields in production are the Snøhvit field with its subsea gas production and the Goliat field with oil production, storage and offloading. None of those options are viable for this example.

Similar reservoir characteristics are assumed for this example as in the first example.

The offshore facilities of this field (Figure 5-2) consist mainly of:

- Subsea production system
- Flowlines to tie-in to a neighbouring existing facility

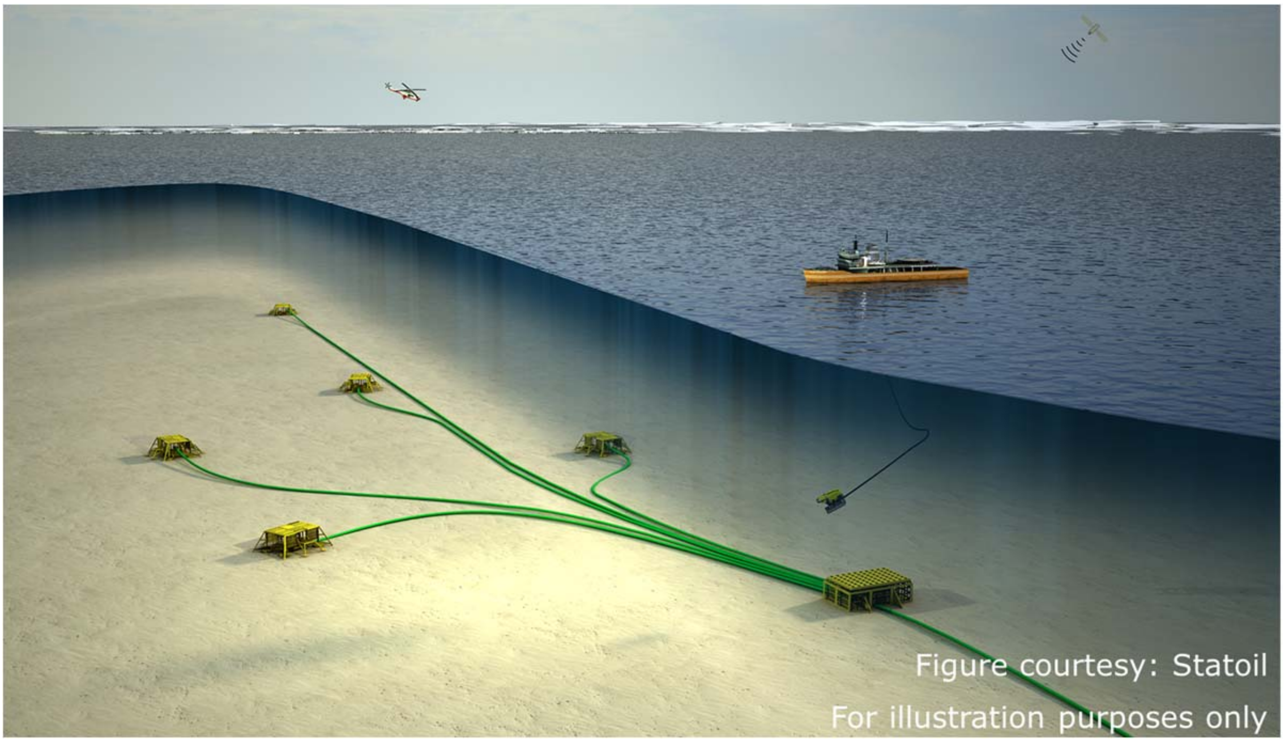


Figure 5-2: A possible field development solution for an oil field at 74°N.

A subsea concept can to some extent simplify parts of the field development. There will for instance be no permanent surface facilities, effectively avoiding drifting sea ice and icebergs. Drilling units and well intervention vessels would naturally need to relate to wind, wave and ice conditions, however as in other offshore areas, operations can be planned for periods with suitable conditions.

Adequate intermediate treatment of the well flow will be conducted at the location in order to transport it to the nearby facility. Heating of the pipeline or the use of chemical inhibitors might be needed to prevent hydrate formation. Produced water and associated gas will be reinjected in either the reservoir or in a nearby aquifer.

One of the main challenges for this solution will be the power supply. Although the nearby facility has process, storage and offloading capacity it is not given that an adequate surplus of power exists. Thus, it is assumed that power needs to be transmitted from shore and that adequate power supply can be provided from mainland Finnmark. Alternative in-field power generation should be evaluated.

5.4 Example 3: Gas production in SE Barents Sea

The third example is further east, located at approximately 74° 30'N and 36°E and is assumed to be a gas field. The water depth on this location is about 240 m, also deepening to the south.

The reservoir is assumed to be 500 GSm^3 with 200-250 GSm^3 recoverable. The reservoir depth is thought to be at 700 m below the mudline and the following reservoir characteristics have been defined by OG21:

- Pressure: 75 bar
- Temperature: 25°C
- Gas to oil ratio: 6000 Sm^3 / Sm^3
- 1/Bg: 50 Sm^3 / m^3

The offshore facilities of this field (Figure 5-3) consist mainly of:

- Subsea production system, including umbilicals, flowlines and risers
- A moored and disconnectable floating production, storage and offloading unit
- Single line pipe to export gas to for instance Melkøya

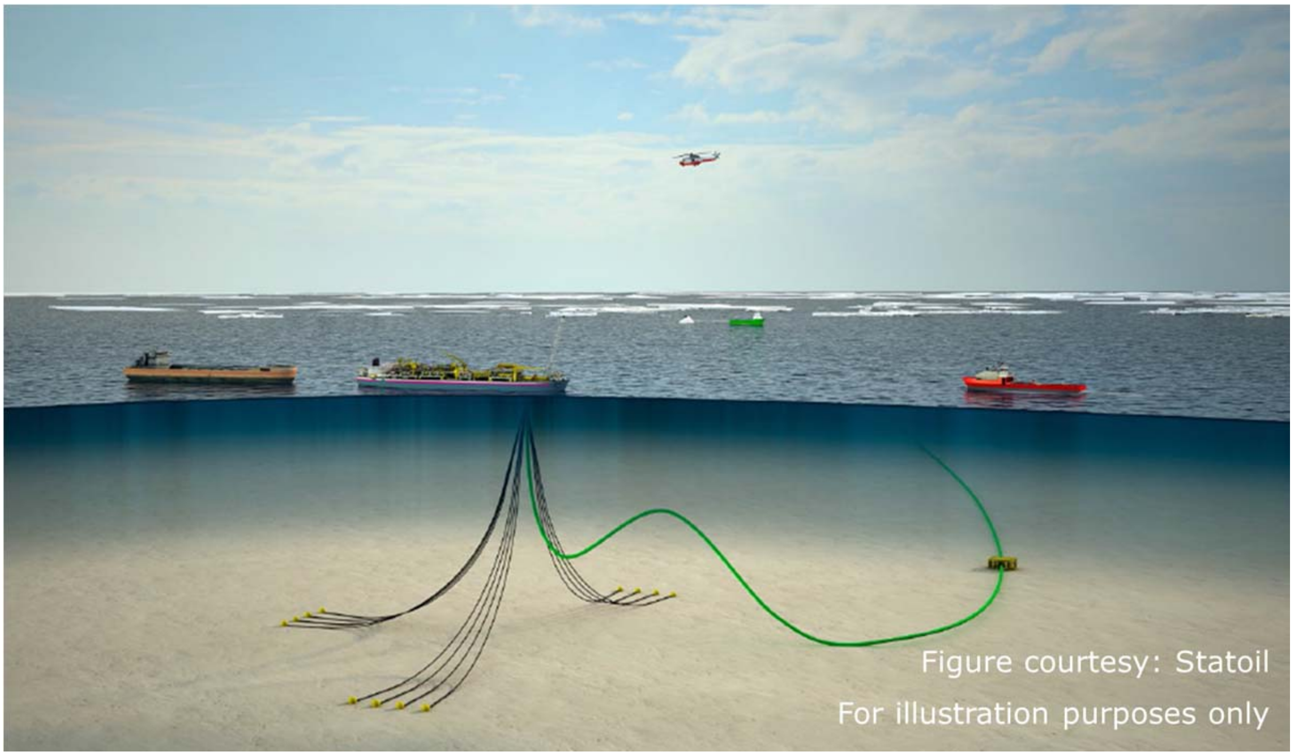


Figure 5-3: A possible field development solution for a gas field at 74°N.

Similar to the first example, the production and process will be conducted on an FPSO. However, for this location sea ice will be present more often and the probability for encountering iceberg is also larger as more icebergs are encountered in the eastern part of the Barents Sea (Abramov, 1996). A disconnection system is also proposed here, but since ice occurs more frequent a physical ice management system (i.e. vessels capable of handling ice) would be a measure to reduce downtime and disconnections.

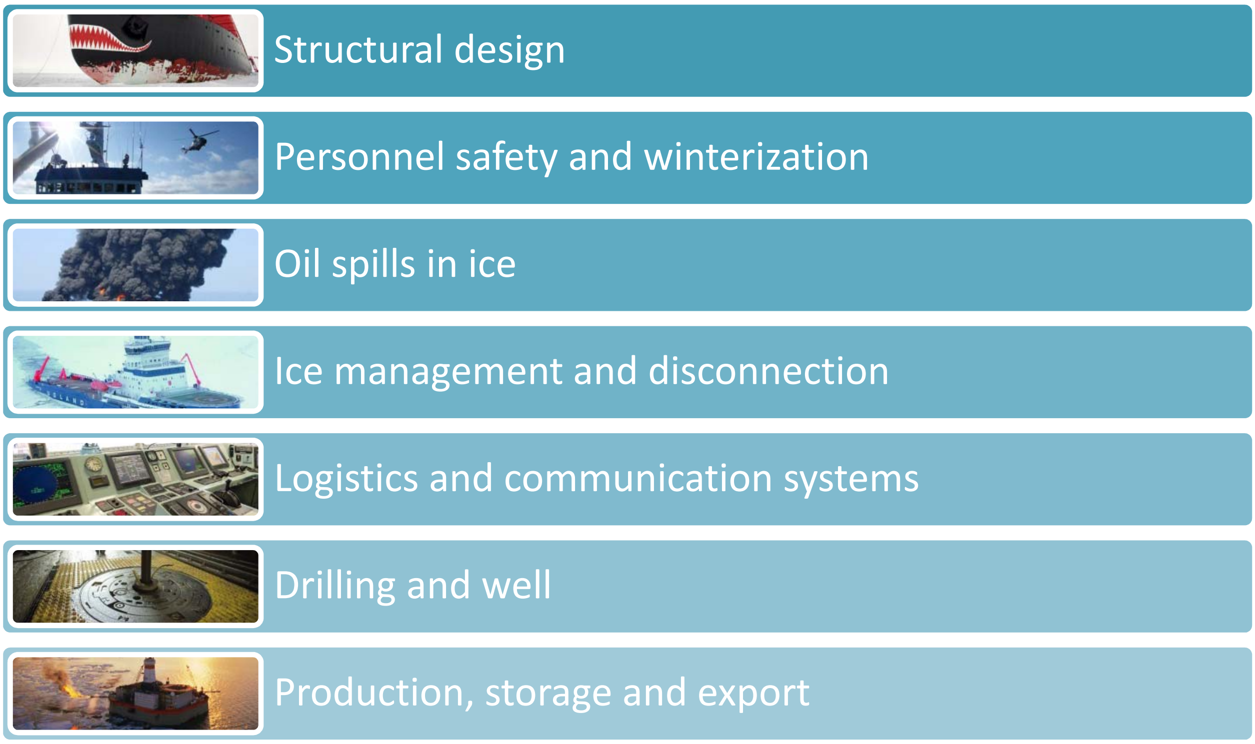
The process facility will separate gas, condensate and water. Gas is to be transported by single line pipe to mainland Norway (i.e. Melkøya as there is no other gas infrastructure in the region), while condensate will be stored on-board and offloaded to shuttle tankers. If the volume of condensate would support, another pipeline could be an alternative. The produced water is to be cleaned and released to sea.

As this location is about 610 km from shore providing power from the mainland is deemed unfeasible, given the time frame considered in this project. Alternatively, a hybrid solution with gas turbines in combination with batteries is proposed. Other alternative in-field power generation solutions should be evaluated.

As highlighted in the introduction to this section, the field development examples are mainly used to represent a wider spread in challenges. This specific example (a large remote gas field) can be developed in several different ways than what has been outlined above. For instance a subsea tie-back to a production unit further south would be another possibility. However the examples in this report were chosen to identify technology challenges related to design and operation in an artic environment.

6 TECHNOLOGY CHALLENGES

DNV GL has identified a number of arctic technology challenges related to oil and gas production. A workshop was organised as a part of the project where some the latest relevant projects and activities provided useful input to the identification of some of the most relevant challenges. This was supplemented with a literature study. This section contains a brief description of some of the most important challenges. Only arctic specific challenges are described and they have been divided into the groups shown below:



6.1 Structural design

Hull design

New concept designs for production, drilling, well operations as well as marine operations are needed for the Barents Sea. The concepts need to address the challenges of operating in the arctic and site specific environmental conditions and far from established onshore infrastructure:

- The concept designs for both locations need to be capable of operating in the sea ice conditions with hulls designed to withstand the loads from impact with sea ice and potentially drifting icebergs (INTSOK, 2014a, 2014b). The extent of hull strengthening depends on the amount of ice, but also to which extent ice handling is used.
- Vessel concepts for marine operations should reflect the lack of existing offshore infrastructure and the long distance to established onshore infrastructure. New vessels should be able operate in ice covered waters and perform multiple functions (INTSOK, 2014c, 2014a, 2014d).

In contrast to ships operating in ice covered waters, there is limited experience with floating offshore structures in ice. The Sea Rose and Terra Nova FPSOs have been designed for the subarctic environment off the east coast of Canada, mainly with the iceberg threat in mind, but both FPSO's are reinforced to sustain loads form sea ice. On the Grand Banks sea ice occurs in average about every second year when considering the last 30 years, however ice appear more frequent in the 80's and 90's compared to recent years (C-CORE, 2015).

The lack of fit-for-purpose concept designs can cause an increase in costs as the adaption of existing concepts to the prevailing in the conditions in the Barents Sea might be suboptimal.

Ice load prediction models

Ice load prediction models play an important role in understanding the global, local and dynamic loads resulting from ice-structure interaction. A number of issues reflect the need for new and improved ice load prediction models:

- There is still a need for improving the understanding of the effect of ice loads on structures (INTSOK, 2014b).
- Results from ice basin testing cannot be directly applied to different ice features and may not replicate the full scale ice environment (INTSOK, 2014a, 2014b, 2014e).
- Knowledge regarding the loading effects from sea ice, especially in combination with other environmental loads such as wind and waves, is limited (INTSOK, 2014a, 2014e).
- Predictability of ice loads has to be improved in order to design station keeping systems, mooring lines and DP systems (Arctic Operations Handbook JIP, 2013; CARD, 2012).
- While ice management systems can be used to reduce ice features and as such also the resulting loads, their effect on ice actions and design loads has not yet been validated (INTSOK, 2014a).

Ice-strengthening of marine structures is generally considered to be a cost-driver. Improved ice load prediction models can help reducing conservatism in the estimated design loads and as such have a cost-reducing effect, mainly for example 1 and 3 where FPSO's are assumed.

Moorings & appendages

Moorings and appendages need to be designed for withstanding the environmental loads in the Barents Sea or need to be protected from them. The following challenges for moorings and appendages have been emphasized:

- Only first-year ice loads (~20' MT, light ice conditions) on moorings can be handled, while multi-year ice loads (~75'-100' MT) cannot be dealt with economically (IMVPA, 2008).
- Currently, ice-breaking thrusters on production facilities cannot be fully serviced or replaced in the field (INTSOK, 2014a).
- The hull has to be designed such that it prevents ice from flowing under the hull of a floating production platform with risers underneath (INTSOK, 2014a).
- Interaction with trawl wires has led to mooring line failures on the NCS, in particular for fiber rope moorings (PSA, 2014; Kvitrud et al., 2006). Possible increased risk due to increased pelagic trawling in areas with floating moored structures should be investigated.

The challenges related to moorings and appendages need to be addressed in the design stage of the structure. There will also be differences in how to address the challenges when designing a rig for exploration drilling or a production platform. As drilling activities are assumed to occur during the open water season, development of stronger or more cost-efficient mooring systems will mainly benefit field development example 1 and 3.

Materials

Steel and concrete have both been used as material for constructing facilities exposed to arctic conditions. Other materials such as composite materials or alloys may require technology qualification before being available for use in the Barents Sea.

The following issues regarding materials for arctic conditions have been raised:

- The selected materials need to uphold their mechanical properties also in low temperatures (Gudmestad and Quale, 2011; INTSOK, 2014e). There is a lack of a concise set of definitions, rules and standards for steel material selection for cold climate offshore areas (Horn et al., 2012)
- Further research regarding the reduction of corrosion and erosion effects is needed (INTSOK, 2014a).
- There is a need for further development of elastomeric materials which do not suffer from brittleness in cold climate during storage and reeling (INTSOK, 2014d).
- Further development of low temperature polymeric materials for insulation purposes in flowlines and risers. (INTSOK, 2014d)
- There is a knowledge gap related the fatigue properties of elastomeric and polymeric materials at low temperatures (INTSOK, 2014d).

There is limited long-term experience with floating structures in Arctic waters. In addition, temperature requirements for materials used for offshore structures in the Barents Sea are still considered to be uncertain, and constitute as such a challenge for all three field development examples.

6.2 Personnel safety and winterization of installations

Personal protection and emergency equipment

Personal protection and emergency equipment covers a wide range of equipment, from protective clothing for performing outdoor operations to apparel suitable for survival actions. Two major topics have been highlighted:

- Survival suits require insulation against cold temperature for several hours. They also need to prevent leakages and serve as floatation help (THELMA, 2010).
- Clothing for outdoor operations needs to provide thermal protection while maintaining functionality (e.g. thick gloves vs. ability to handle small parts) (Gudmestad and Quale, 2011; THELMA, 2010).

Providing necessary protection from cold temperatures will be a requirement for being allowed to operate in the Barents Sea. Improved protective clothing might also lead to improved uptime as outdoor operations might be performed under harsher climatic conditions than today.

Winterization solutions

The purpose of winterization is to ensure that a vessel or installation is *"suitably prepared for operations in cold climates"* (DNV-OS-A201, 2013). This includes measures to avoid or mitigate the negative effects of low temperatures, snow, freezing and icing on the installation, personnel, functionality of equipment and safety of the installation or vessel.

The following challenges regarding winterization have been highlighted in various reports:

- A general need of addressing the effects of snow and icing on the functionality and operability of equipment has been identified (Gudmestad and Quale, 2011), (INTSOK, 2014e).
- The risks from accreted ice, e.g. falling ice, slippery work areas and access ways, need to be properly addressed. The ability to predict icing as well as to evaluate prevention and is needed. (Gudmestad and Quale, 2011).
- Loading systems need to be winterized. This applies to both buoy loading and ship-to-ship systems (e.g. oil, condensate, LNG) (Gudmestad and Quale, 2011).
- Offloading systems, e.g hoses and hawsers, require proper winterization and may have to be protected from water and ice. Additional testing and inspection might become necessary (Arctic Operations Handbook JIP, 2013).
- Special fluid additives may be needed to prevent freezing of pipes (INTSOK, 2014e).
- Hydrophobic coating can be used as an anti-icing measure, however there are still challenges with respect to the durability of such coatings.

Properly winterized offshore structures are a requirement for operating in the Barents Sea. By selecting suitable technologies and by dimensioning the systems correctly, addressing winterization challenges can have a positive effect on both CAPEX and OPEX. This might not only be the case for the examples where surface installations are proposed, but also supporting vessels and drilling rigs needs to be winterized.

Further development and implementation of automatic and autonomous systems might replace some of the need for personnel and outdoor work. Such systems also need to be winterized, but can possibly be a way to reduce work in exposed areas where adequate sheltering is possible. Automatic condition monitoring systems may reduce the need for manual inspection for instance detection of ice build-up, freezing of deluge systems etc.

Enclosed topsides and explosion risk

Enclosing the topsides and sheltering the process plants on the FPSO's in example 1 and 3 can protect workers and equipment from the arctic environment. Enclosed topsides can have a positive contribution to the uptime and the energy consumption of an offshore installation. Still, a potential increase in explosion risk has to be considered as the ventilation of the process modules will be affected by the enclosement. Thus, some of the aspects needed to be taken into account when designing offshore structures are:

- There is a need to reduce human exposure to open air, especially due to the wind chill effect (INTSOK, 2014c).
- Alternative and more energy efficient solution for keeping exposed areas free of snow and ice need to be developed (INTSOK, 2014a).

- Encapsulating exposed areas to reduce challenges from cold temperatures, snow or icing might increase the risk for explosion, e.g. due to reduced ventilation (Gudmestad and Quale, 2011; THELMA, 2010; Rambøll, 2012).
- Optimal design of winterization measures for areas exposed to explosion risks requires additional work. Simulations models reflecting arctic conditions are not yet fully developed (INTSOK, 2014a).
- Qualification programs for systems and equipment not previously used in the Arctic, e.g. active weather panels, should be developed (INTSOK, 2014a). The effect of ice on release systems for such panels should be investigated including the pressure levels in case the release systems do not work as intended (for instance due to ice freezing on sensors or the release mechanism).

Infrastructure for safe Escape, Evacuation and Rescue (EER)

In contrast to the well-established areas further south on the Norwegian Continental Shelf (NCS), there is currently limited *supporting* offshore EER infrastructure in the Barents Sea. The distance from shore to locations at 74°N exceeds 300 km, giving rise to the following challenges:

- Long distances between offshore operations and supporting onshore infrastructure are a challenge for the range of AWSAR helicopters currently in use on the NCS. Strategically located refuelling depots as well as the next generation of Norwegian AWSAR helicopters are expected to help addressing this challenge (INTSOK, 2014c). Alternative evacuation measures, such as extended use of on-site supply vessels equipped to handle effective personnel transfer in case of emergencies and down-manning could be considered to supplement helicopters.
- Darkness has a negative effect on the time needed to rescue a person from the sea, considerably reducing the available rescue capacity during the polar night (see Figure 4-1 for the effect of different rescue times on the rescue capacity and Preventor, 2012 for more discussion on this matter). Seasonal darkness and the risk of low visibility weather conditions will have to be addressed, for example through the use of advanced technology such as night vision goggles (INTSOK, 2014e).
- Forward support bases that can serve as safe havens have been discussed as a risk-reducing measure. Further development of the concept is needed. (INTSOK, 2014a).

Sufficient EER infrastructure should be established for offshore operations in the Barents Sea, and especially for the eastern part which is more remote than the western part. The concept of strategic multipurpose hubs in the Barents Sea might have to be investigated further for reducing the distance between potential accident sites and safe havens. NOROG (2015) provides a good systematic overview of the needs and ongoing work related to helicopter preparedness.

EER technology

Norwegian petroleum regulation (§44 of the Facilities Regulations in combination with §77 of the Activities Regulations) stipulates that it must be possible to evacuate and rescue all personnel on board an offshore installation at all times and under all weather conditions. Failing to meet the requirements can lead to precautionary downmanning and even shutdown of production or operations.

The following issues have been highlighted:

- Sea ice can threaten the operability of evacuation resources (Gudmestad and Quale, 2011).
- Systems for evacuation large numbers of personnel off an offshore structure in ice are currently only available for the mildest Arctic conditions and need to be developed (INTSOK, 2014a, 2014e).
- Lifeboats need to be developed that can be deployed and operated in sea ice. Freefall lifeboats may have to be reconsidered as secondary means of evacuation in areas where sea ice can be present (INTSOK, 2014a).
- Alternative solutions such as the Personnel Evacuation Bridge can also have limited operability with respect to sea state and sea ice conditions (INTSOK, 2014a).

Solutions for evacuation under sub-arctic conditions have been implemented for offshore activities at the east coast of Canada, however the solutions (davit launched lifeboats) are capable of operating only in light ice conditions.

6.3 Oil spills in ice

Forecasting and modelling of oil in and under ice

In order to apply the correct oil spill response technologies, oil drift and weathering in and under ice needs to be correctly modelled. This challenge, and the next two (technology for oil spill response and detection and monitoring of oil spills) are naturally more relevant for the two field development examples where oil reservoirs are assumed.

The following challenges have been identified:

- Existing modelling capabilities have to be improved with respect to the fate and transport of oil in and under ice (INTSOK, 2014e, 2014f; Dragsund, 2015).
- Oil spill contingency models need to incorporate the characteristics of shallow and deep water areas in the High Arctic (INTSOK, 2014f).
- Proper data on hydrodynamics and meteorology is required for reliable oil spill modelling (INTSOK, 2014f).
- Already available data needs to be collected while data availability is further improved by collecting new data (INTSOK, 2014f).

Technology for oil spill response (OSR)

There is currently no single oil spill response technology that can be applied under all conditions in the Arctic. This is also reflected by the following issues:

- Arctic challenges such as low temperatures, sea ice, icing, etc., affect ability to combat oil spills (ACE, 2014).
- More investigation of different alternatives and combinations of the different OSR measures is needed. Mechanical recovery has been the preferred option, whereas in-situ burning is not currently in use (INTSOK, 2014e).
- The effectiveness of mechanical recovery, use of dispersants and in situ burning needs to be improved further (INTSOK, 2014e).
- OSR technologies need to be improved to reduce the negative effects of sea ice, waves and remoteness (INTSOK, 2014e; Bjørnbom, 2015).

Sufficient oil spill response capabilities are a requirement for operating in the Barents Sea. Multiple OSR technologies should be present on-site to provide the operator with the flexibility to choose the technologies that will have the highest success rates under the prevailing environmental conditions (DNV GL, 2014b).

Detection and monitoring of oil in and under ice

Oil spill detection and monitoring capabilities are a prerequisite for a successful oil spill response system. In the Barents Sea, seasonal darkness, periods with low visibility and the presence of sea ice present a challenge for the development of reliable detection and monitoring systems.

The following challenges and technology gaps have been identified:

- There is a need for improved remote sensing solutions for oil spill detection in and under ice (CARD, 2012; INTSOK, 2014e; Sand, 2015; Bjørnbom, 2015)
- Airborne-based Ground Penetrating Radar (GPR) for detecting oil covered by snow or ice is currently developed, but more work is required for to account for varying ice conditions and validation of the technology for operational use (INTSOK, 2014f).
- The efficiency and accuracy of airborne Nuclear Magnetic Resonance (NMR) technology should be improved. Validation of a full-scale prototype and arctic field testing are expected within the next years. (INTSOK, 2014f)
- Unmanned Underwater Vehicles (UUV) and Autonomous Underwater Vehicles (AUV) are considered promising technologies as they can be deployed in a range of ice and weather conditions. Their sensors will also have a direct view of oil trapped beneath the ice (INTSOK, 2014f).
- Stand-alone subsea leak detection systems based on physical, chemical and biological sensors able to transmit signals in water need to be further developed.
- Both existing technologies (satellite, radar, IR-camera) and alternative methods such as sensors on mobile subsea units (AUV, ROV, gliders etc.) and stationary sensors mounted on the sea bed or subsea installations need to be improved in order to detect oil in and under ice. (INTSOK, 2014e)
- As of today, no single sensor is able to cover all aspects of detection and monitoring oil spills in and under ice. Combining different sensors into an effective oil spill surveillance system is therefore becoming more important (INTSOK, 2014f; Bjørnbom, 2015).

Oil spill detection and monitoring is an important part of the oil spill contingency system. As such it has to be considered as an enabling technology for operations in the Barents Sea.

Environmental risk modelling

The Arctic and the marginal ice zone in particular, are considered to be ecologically vulnerable. In order to properly assess this vulnerability, environmental risk models have to be improved (valid for all three examples). The following issues have been raised:

- The available data for environmental risk assessments needs to be improved (INTSOK, 2014e; Bjørnbom, 2015).
- Long term environmental monitoring programs should be established (INTSOK, 2014e).
- For certain areas, there is a need to define the key elements in the ecosystem and establish their response to different anthropogenic impacts (INTSOK, 2014e).

Improved environmental risk assessments will help reduce the uncertainty regarding the vulnerability of the ecosystem. This will help to properly dimension the oil spill response system.

6.4 Ice management and disconnection

Disconnection and reconnection systems

For a floating structure (such as the two FPSO's proposed for field development example 1 and 3), temporarily disconnecting from moorings and risers and moving off-site is one way of avoiding excessive ice loads. After ice conditions have improved sufficiently, the structure can move back and reconnect in order to resume production.

The following requirements have been identified:

- Disconnection might be required to avoid excessive ice loads or to reduce the collision risk with icebergs (Gudmestad and Quale, 2011).
- Disconnectable turrets need to be designed for regular disconnects, including high reliability and usage under heavy ice loads (CARD, 2012).
- There is a need to further develop efficient disconnect/reconnect systems for moorings and risers to provide operational flexibility in case production is disrupted by severe ice conditions (INTSOK, 2014b).
- The mooring system needs to be protected from sea ice and icebergs after disconnect (Arctic Operations Handbook JIP, 2013).
- Offshore installations need to reconnect after moving off-site. The reconnection procedure needs to address challenges related to: maneuvering, station keeping, support vessel operations, ROV operations, mooring retrieval (Arctic Operations Handbook JIP, 2013).
- Moored vessels operating in ice need the ability to disconnect under high lateral ice loads. Reconnection procedure may require improved methods for retrieval of mooring lines (CARD, 2012).

Disconnection can be a complex and time-consuming procedure. The trade-off between the probability of having to disconnect and designing against ice loads will have to be considered.

Detection, forecasting and surveillance

Sea ice and icebergs might be present in the Barents Sea, potentially threatening offshore installations (such as the FPSO's in field development example 1 and 3) and delaying marine operations. In order to avoid both damage due to excessive ice loads and unnecessary disconnection, it is important to install surveillance systems for monitoring and tracking ice. The deployment of ice handling resources and also the decision whether or not to disconnect depend on reliable information about the actual and expected ice conditions.

Numerous challenges related to the detection, monitoring and forecasting of ice have been identified:

- Ice floes may drift into areas that are usually ice-free (Gudmestad and Quale, 2011).
- Detection and monitoring technologies for of sea ice need to be developed further (CARD, 2012). In-field logistics are dependent on a surveillance system for continuous monitoring of ice movements (detection, tracking, and forecasting) (INTSOK, 2014c).
- Reliable and sufficient detection, forecasting and prediction systems need to be established and available in the area of operations (INTSOK, 2014a, 2014b; NOROG, 2015)

- Improved systems are required for detecting and monitoring so called "blue ice", a form of ice berg currently difficult to observe. (INTSOK, 2014a)
- A reliable surveillance system, combining large quantities data from different sources is needed (INTSOK, 2014e).
- Better knowledge of the behavior of drifting sea ice and icebergs is needed to improve forecasting and to provide design data e.g. for moorings. (INTSOK, 2014a, 2014e; Sand, 2015). The detection, monitoring and forecasting capability of iceberg (including growlers) drift should be improved (NOROG, 2015).
- The current in-field surveillance system for detection and tracking needs to be improved. New technology such as UAVs, upward looking sonars etc. should be included (INTSOK, 2014a, 2014e).
- Satellite based imaging and radar technology for detection of drifting ice objects require improvement; existing systems are not adequate (INTSOK, 2014a, 2014c).Forecasting models for sea ice drift (3-5 days) for tactical ice management in support of station keeping will be beneficial (CARD, 2012). NOROG (2015) also identified the need for an improved simulation model capturing the dynamics of ocean, sea ice and atmosphere.
- There is a need to develop improved weather forecasting models (INTSOK, 2014c) for instance for polar lows.

There is considerable experience on ice detection and forecasting from Canada. It is however unclear how much of the experience can be directly transferred to the Barents Sea as the ice conditions are different.

Ice handling systems

Ice handling systems are a possible mitigation strategy in areas that are exposed to sea ice and icebergs. They reduce the severity and probability of ice-structure interaction and can have a positive impact on the design ice loads. For instance, for the first field development example it is anticipated that sea ice and icebergs are so infrequent that it would not be economic feasible to charter vessels and train crew for conducting ice handling operations. In case severe ice approaches one would instead disconnect. However, for the third example, where sea ice and icebergs are more frequent vessels for ice handling operations would perhaps be justified in order to maximize the operability of the facility. Detailed studies are needed to reveal what the best option is for a specific field.

The following challenges regarding ice handling have been identified:

- More research is required to improve the system's capabilities of extending the structure's operating season. (CARD, 2012).
- Towing success rates and efficiencies need to be properly quantified for appropriate consideration (CARD, 2012).
- The reliability of ice handling systems should be enhanced through analytical and experimental verification (INTSOK, 2014e).

6.5 Logistics and communication systems

Logistics

The long distances from onshore supply bases combined with the environmental conditions can increase the probability of delays in transportation and supply services. The following issues have been highlighted:

- There is a need for more land based infrastructure to handle the increased transportation needs (INTSOK, 2014e)
- The logistics system needs to incorporate safety features, redundancies and operational system different from those in the North Sea in order to secure operational efficiency, security and safety in the Barents Sea (INTSOK, 2014c).
- For fields with long step outs, the availability of chemicals could be a challenge as this transport can be inefficient in a very long umbilical (could be a challenge for the second example, depending on where the tie-in is made). Being able to store chemicals subsea with a system for easy replacement of the chemicals can lead to a more efficient system design (INTSOK, 2014d).

It is worth noting that addressing the logistics challenges may not necessarily require new technology. There is however a potential for cost reduction if the system can optimized for the requirements in the Barents Sea. For instance floating refueling bases and multipurpose vessels might supplement onshore infrastructure (INTSOK, 2014c) and could make supply logistics more efficient.

Communication systems

Operations in the Barents Sea require reliable communication systems that both provide sufficient coverage and capacity. Needs for high bandwidth communication with the facility can be covered by subsea fibre optic cables, however this might not be sufficient for all communication needs. Several concerns have been raised with respect to the communication systems currently available:

- There is a need for a reliable satellite-based arctic communication system. Coverage of the current communication system is reduced when passing 72°N due to low elevation angles of the satellites (INTSOK, 2014e).
- More capacity in the communication system might be required for high bandwidth data transfer. While current capacity might be sufficient for day-to-day use, in case of an emergency large amounts of data will have to be exchanged between different rescue and communication centers (INTSOK, 2014c).
- In order to establish a high quality telemedicine system, a high bandwidth communication link and a geostationary satellite for covering the High North are required. (INTSOK, 2014e).
- Threat evaluation when monitoring a constantly changing environment requires that large amounts of data have to be exchanged. Small deficiencies in data gathering and exchange can have an effect on efficiency of the different operational systems, e.g. ice handling operations (INTSOK, 2014c).
- Atmospheric disturbance is common in the Arctic and affects both satellite communication and navigation (INTSOK, 2014c; Bekkadal, 2014; Sand, 2015). Better understanding of how space weather affects electronic communication and navigation systems, including how such disturbance can be mitigated should be developed.

Improving the coverage and bandwidth of communication systems for the High North might not require new technologies, but might need considerable investments in satellite technology.

Positioning systems

Reliable positioning systems are necessary for a variety of operations, e.g. dynamic positioning (DP) station keeping, and reconnection. Satellite-based systems such as GPS or GLONASS may at high latitudes be affected by the proximity to the magnetic and geographic poles. Magnetic storms due to polar activity can also have a negative impact on the quality of the signal (INTSOK, 2014b).

The following issues have been emphasized:

- Relative azimuth uncertainty increases at high latitudes. Technology addressing this issue is required, e.g. for the accurate positioning of wellbores (INTSOK, 2014b, 2014e).
- The position of drifting ice objects needs to be improved in order to evaluate the risk of collision (INTSOK, 2014g).

The potential limitations of satellite-based systems are well known. Sufficient ship traffic can to a certain degree complement satellite coverage. It is also possible to install a local positioning system for operations on-site, but this will add to the project's CAPEX.

6.6 Drilling and well

Drilling technology

Drilling technology for the Barents Sea has to be designed to cope with the metocean and ice conditions in the High North. For the two locations considered here, the drilling operations can be conducted when the ice is more than 50 km away, which is many years mean that all year drilling can be conducted, while continuous ice condition monitoring takes place. The drilling technology also has to contribute to reducing the cost of a producing well while at the same time maintaining well integrity. It is assumed that during normal operations, drilling will be conducted during the ice-free period of the year. However, ice interference should still be considered as an accidental scenario.

The following focus areas for the development of drilling technology haven been highlighted:

- Sea ice and icebergs need to be kept away from the risers. The hull geometry might prevent ice getting underneath or include protective features in the riser area (INTSOK, 2014a).
- Sea ice, icebergs and icing can interfere with station/course keeping operations and affect the operability of wires, etc. (INTSOK, 2014g).
- Excavation methods used in connection with the installation of subsea equipment should be improved, focusing on significantly reducing both duration and volume of discharge of silt/particles in environmentally sensitive areas (INTSOK, 2014d).
- The development of slender well technology (drilling, well and completion) can have a positive effect on the cost of establishing a ready producing well (INTSOK, 2014d).
- Technology that combines slender wells with large through bore capacity is seen as beneficial for the development of gas fields as the total number of wells required is reduced (INTSOK, 2014d).

Limiting drilling to the open water season will reduce the risk related ice loads on risers or during station keeping operations.

Combining slender wells with large bore capacity could potentially increase the risk of a large blowout. On the other hand, being able to use large bore wells can have a significant positive impact on the CAPEX of a gas field development.

Reservoir performance

Improved reservoir performance will contribute to a more cost effective development of fields in the Barents Sea. Still, there are a number of issues that need to be addressed:

- Shallow reservoirs may require artificial lift (Gudmestad and Quale, 2011).
- The number of wells that can be drilled from one location is limited due to shallow reservoirs (Gudmestad and Quale, 2011).
- Increased Oil Recovery (IOR) or Enhanced Oil Recovery (EOR) by injection of clean or treated sea water is considered as an area for future technology development (INTSOK, 2014d).

Shallow reservoirs do also exist outside the Arctic. Necessary technology development might be driven by projects in other areas, but these still provide experience that can be transferred to operations in the Barents Sea. Improving the cost-benefit of measures to increase the reservoir's performance will have a positive effect on developments in the Barents Sea.

Same season relief well drilling (SSRWD)

Drilling is currently limited by the length of the open water season. Being able to drill a same season relief well might therefore require completing the regular drilling campaign well ahead of the end of the open water season. For the two locations considered, the open water season is in most years lasting all year.

The following challenges regarding the drilling of same season relief wells have been highlighted:

- Year-round drilling in Arctic is currently not possible, challenging the drilling of same season relief wells (CARD, 2012).
- Drilling in ice might be required in case of relief well drilling. This requires developing solutions for e.g. station keeping or riser protection in ice (CARD, 2012).
- Same season relief well drilling technology needs to be developed for use in all arctic locations (INTSOK, 2014e).
- Remoteness of rigs capable of drilling relief wells needs to be considered when planning operations (INTSOK, 2014e).
- Technologies for breaking the well operations into multiple seasons can ensure that it is technically feasible to have SSRWD capability. (INTSOK, 2014b)

For areas further north than what have been considered there, the ability to drill same season relief wells will enable year-round operations in the Barents Sea. An effective ice handling system will be required both to ensure access to the location and to reduce ice loads to acceptable levels.

In relation to SSRWD the use of capping stacks could also be considered (NPC, 2015). The performance of capping stacks has not been assessed in this report.

6.7 Production, storage and export

Flow assurance

Long distances and cold temperatures in the Barents Sea are expected to be a challenge for flow assurance. Being able to accurately predict and manage multi-phase flows is considered critical for subsea developments in the Arctic (INTSOK, 2014d). Remote field developments may require transportation of well fluids over a long distance (>150 km). Subsea tieback solutions are becoming available for longer distances: oil tiebacks have reached 45 km (Tyrihans), gas tiebacks 143 km (Snøhvit) (DNV GL, 2015b). It is assumed that the tie-back for the second example is within reach when being developed. The multi-phase flow will be impacted by low temperature at the sea bottom, increasing the risk of hydrate formation (Gudmestad and Quale, 2011).

The following challenges have been emphasized:

- The modeling and prediction capabilities of existing multi-phase flow simulation systems are limited with respect to predicting the behavior of certain type of fluids, e.g. heavy oil. For long distance transport and larger diameter pipelines, this can cause significant errors in the flow prediction (INTSOK, 2014d).
- New/improved models for multiphase flow, with improved capabilities to predict flow instability, slugging, and liquid accumulation will facilitate development of remote field in the Arctic. (INTSOK, 2014d).
- The use of Low dosage hydrate inhibitors (LDHI) can be considered as a mean to reduce insulation. LDHI is one out of several methods to prevent hydrate formation. The technical solution for hydrate prevention must be holistic considering all aspects (for instance how it affects the product, cost and availability etc.).

Experience with heated long-distance multi-phase pipelines already exists. The distances that are currently technically feasible however, are still too short compared to the needs of remote field developments in the Barents Sea. Due to the long step-out more condition monitoring along the pipe will be needed (OG21, 2012).

Further technology development and increases in the range of multi-phase pipelines is to be expected for fields in other areas than in the Barents Sea. This to the benefit of future fields in the Barents Sea.

Power supply

Offshore installations require a lot of power under high regularity. Land-based power supply is often suggested as means to reduce the carbon footprint of the offshore activities. Long-distance, high-power transmission systems may be featuring higher voltage (up to 145 kV) and either low-frequency AC or DC transmission technology (INTSOK, 2014e). However, not all technology challenges have been overcome for installations located far from the coast. The following challenges have been emphasized for field developments in the Barents Sea:

- Long distance to site challenges power supply from land (Gudmestad and Quale, 2011). Step-out distances may be up to 600 km. Existing technology can cover distances in the range 200-350 km (INTSOK, 2014e) and more technology development is needed to supply for instance a field at the SW Barents Sea location will power from shore.

- High-Voltage Direct Current (HVDC) and Low-Frequency Alternating Current (LFAC) power transmission systems to remote (>600 km) subsea fields require large-power static converters designed for subsea applications. Qualified concepts are currently unavailable (INTSOK, 2014d).
- Potential sub-sea processing requires more power (Sand, 2015).

Supplying offshore activities with electricity from land will not only require transmission solutions, but also access to power. Offshore power production might still be needed as available power might be limited.

The challenge with power supply can in the Barents Sea be even greater than further south due to low GOR in the oil reservoirs (such as the first field development example). This means traditional gas turbines might not be a viable option (such as the case with field development 1). Electro-chemical fuel cell conversion technology is promising to better utilize for instance the small amounts of gas in shallow oil reservoirs. Hybrid solutions with battery and gas turbines are also a way to run the gas turbines much more efficiently. Duel fuel burners also capable of using crude will also probably have to be considered.

Subsea facilities

One of the advantages of placing equipment on the sea bottom is that most ice related challenges can be avoided. This advantage is partly set off by reduced accessibility, especially if the area is covered with ice. The use of subsea facilities also requires highly reliable equipment, as access for maintenance and replacement is also limited.

The following challenges for the use of subsea facilities in the Barents Sea have been identified:

- There is a need to develop modular solutions, including components with reduced weight and size, to facilitate fast installation (INTSOK, 2014e).
- Autonomous systems as well as advanced condition and performance monitoring systems need to be developed due to time restricted accessibility (INTSOK, 2014e).
- Technologies and services increasing the application range of ROVs/AUVs/submarines should be improved, including the ability to operate under ice (INTSOK, 2014d).
- Subsea systems will require periodic maintenance. Ice-going support vessels and ROVs might have to be deployed in order to access the installations (IMVPA, 2008).
- Produced water should be separated and re-injected, requiring subsea separation from well stream and use of subsea pumps for reinjection (ACE, 2014; INTSOK, 2014d). Due to the shallow reservoirs overburden integrity should be monitored.
- Robust repair system solutions need to be developed for areas where damage caused by ice or denied IIMR (Inspection, Intervention, Maintenance, Repair) access will cause a significant reduction in the availability of the Subsea Production Systems (INTSOK, 2014d).
- Changing soil conditions, e.g. due to presence of relict seabed ice and gas hydrates melting, are considered to be a major challenge for subsea installations (INTSOK, 2014e).
- There is a need for new and innovative wellhead foundation solutions (including cement technology and instrumentation for monitoring) suitable for a seabed with changing properties (INTSOK, 2014d).

Subsea systems developed for and used in other areas might be readily applicable for the Barents Sea. Being able to deploy robust and reliable subsea equipment will have a positive effect on CAPEX.

Gas compression

Gas compression is used to maintain the production levels, once reservoir pressure in a gas field declines. A subsea compression system is expected to be the only technically feasible solution for areas where sea ice coverage is likely (INTSOK, 2014d).

The following technology gaps have been identified:

- By improving of liquid tolerance, the application range of dry gas compressors can be expanded (INTSOK, 2014d).
- Develop technologies enabling scale-up of wet gas compression systems to increase their unit power, flow rate, and differential pressure (INTSOK, 2014d).

Several components for subsea compression have already been qualified for use and the first subsea compression systems were installed this summer at Åsgard and Gullfaks. Gas compression technologies have a direct positive effect on CAPEX and IOR, improving the overall profitability of the project.

Pipelines

Pipelines will play an important role in the development of oil and gas fields in the Barents Sea (as assumed in the third example). Design, fabrication, installation, operation and maintenance of the pipeline will have to take into account the environmental conditions in the High North. The challenges below have been emphasized:

- Safe and cost-efficient methods for pipeline fabrication and installation need to be developed that satisfy the requirements of harsh environmental conditions, remoteness and lack of infrastructure (INTSOK, 2014d).
- Dredging and trenching technology for arctic conditions needs to be improved. Efforts should target a reduction of required burial depth, equipment to produce deeper trenches as well as a more efficient use of the operational window (CARD, 2012; INTSOK, 2014d).
- The stability of pipelines is challenged by disappearing permafrost and erosion (Gudmestad and Quale, 2011)

Speeding up the installation process will have a positive effect on the costs of the pipeline. The material costs of the pipeline also affect the total pipeline costs.

7 EVALUATION OF TECHNOLOGY CHALLENGES

New technology is often introduced as value adding technologies, to either reduce OPEX or CAPEX, or to increase recovery and production (Figure 7-1). These types of technologies can be referred to as enhancing technologies. There might also be cases where the technology itself is required for a specific field development, for instance due to compliance to requirements or long step outs. This latter category of technologies is referred to as enabling technologies.

When assessing new technologies it is important to understand the "risk/ reward" ratio. New technology may increase the expected value of an investment, but the risk of loss will also be increasing as capital is spent on technology development and qualification. To prioritize technical challenges identified in the previous section, a qualitative assessment based on added value and cost of developing the technology was made. This was done based on consensus in a one-day workshop facilitated by DNV GL with representatives from OG21 Technology Area groups.

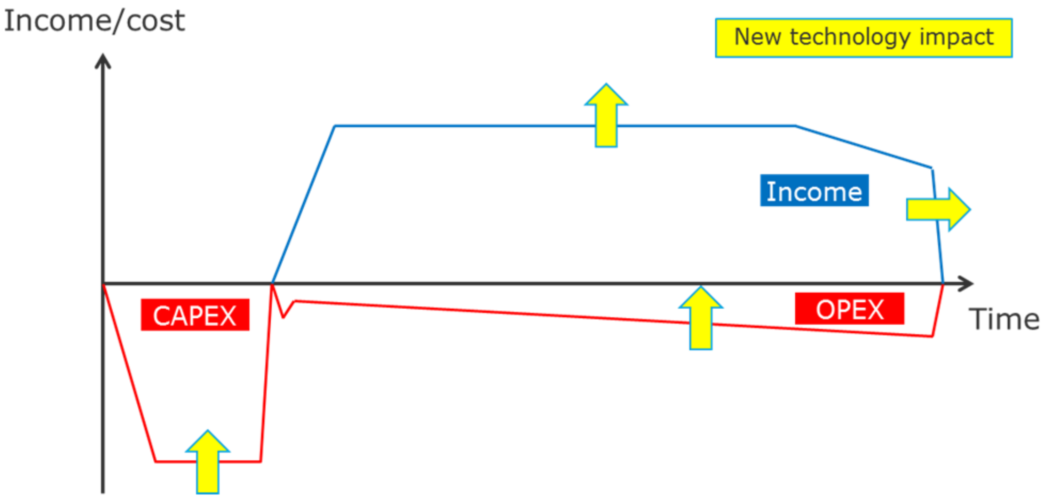


Figure 7-1: A simplification to how new technology might impact a development (DNV, 2009).

7.1 Methodology

The evaluation of the technology challenges consisted of four main parts, as shown in Figure 7-2, where the first part was only to confirm the base cases and technology needs identified. In the second part cost to mature technology was evaluated by combining an assessment of Technology Readiness Level (TRL) and Technical Risk / Complexity, before the added value of each technology was ranked. Added value was a proxy for the expected value, and differentiated between the impact a technology would have on OPEX, CAPEX or production. The final prioritization was made by weighing the added value with the cost.

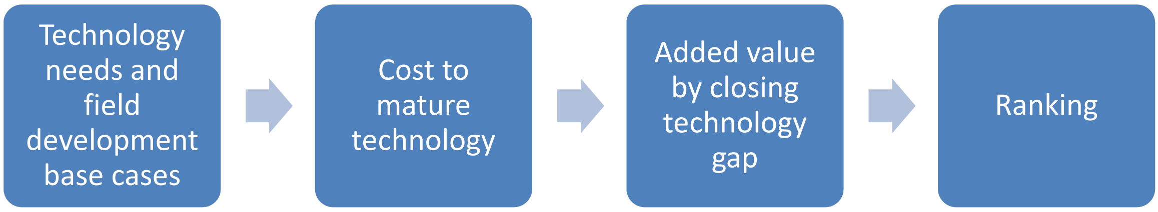


Figure 7-2: Assessment methodology in brief.

Cost to mature technology

TRL is a way to grade the readiness for implementation of a new technology. It was initially developed by NASA, and is today used by several governmental agencies and widely implemented in the oil and gas industry by several operators. Normative references can be found in both DNV-RP-A203 and API 17N. API 17N corresponds closely to the operator's internal procedures, and is therefore used as basis for a simplified version will fewer categories (Table 7-1) that was used in this project.

Table 7-1: Simplified application for TRL screening (based on API 17N).

TRL range	Description
0	Unproven. Paper concept
1 – 2	Early concept development. R&D needed to define concept.
3 – 5	Engineering and prototype stages. Concept proved. Maturing technology solution.
6 – 7	Field qualification. Operational experience being gained.

TRL alone is not a sufficient proxy for cost. For instance personnel safety equipment and multi-phase flow might be evaluated to be at the same TRL level, however the remaining gap to fully develop, test and implement those two technologies might be very different with respect to time and resources. Technical risk was therefore introduced to assess how large and complex the remaining gap for a technology at a given TRL was. Based on API 17N the categories given in Table 7-2 were used to categorize both technical and environmental risk. Please note that *environmental risk* refers here to the *physical environment* and not the ecological environment.

Table 7-2: Remaining gap for a technology at a given TRL.

Rating	Technical risk	Physical environmental risk
Very high	Very high technical risk, very high technology complexity. Novel design or technology. Configuration not been previously applied by supplier.	Concept is pushing environmental boundaries such as pressure, temperature, new part of world, severe meteorological conditions or hostile on land test location.
High	High technical risk, high technology complexity. Known technology with major modifications such as material changes, conceptual modifications, manufacturing changes, or upgrades.	Many changes noted; extended and/or aggressive operating environment; risk requires additional review.
Medium	Medium technical risk, Medium technology complexity. Existing suppliers providing a copy of previous equipment with minor modifications such as dimensions or design life	Same as a previous project or no major environmental risks have been identified.
Low	Low technical risk, Low technology complexity. Known supplier providing equipment of identical specification, manufactured at same location	Same as recent project.

The combination of TRL and technical risk was then used as a proxy for the development cost related to a mature technology (Figure 7-3).

Figure 7-3: Development cost related to mature technology.

The TRL and technical risk/complexity for each technology was combined according to the matrix in Table 7-3. Very mature technologies (high TRL) are generally almost ready to be used. Immature technologies and especially novel technologies with high complexity would need significant development costs before they can be used in an offshore development project. Table 7-4 briefly explains the result of combining TRL and technical complexity.

Table 7-3: Combination TRL and complexity.

Complexity / Technical risk		Technology Readiness Level			
	Very high	N.A	4	4	4
	High	N.A	3	4	4
	Medium	N.A	2	3	4
	Low	1	2	3	4
		7 – 6	5 – 3	2 – 1	0

Table 7-4: The combination of TRL and complexity can be used to indicate remaining development cost.

Rating	Remaining development cost
1	Ready for use, still implementation cost
2	Some development cost required, prototypes established
3	Moderate development cost required before proceeding to the next stage (some uncertainties unclear)
4	Significant development cost required. Candidate for further R&D

Added value to the operator

The reward of developing and using new technology will be the effect on ROE (return on equity) of the investment. High value technology investments will contribute to reduced CAPEX or OPEX or increased recovery or production. At 74°N in the Barents Sea some technologies will also be a prerequisite to start production (an enabling factor). Other technologies again may represent a "ticket to trade" with a negative impact on CAPEX and OPEX. The value of the technologies identified was therefore divided into the categories described in Table 7-5.

Table 7-5: Simple categorisation for how the new technology might impact the cash flow of the project.

Rating	Added value
High positive	No alternatives available, key technology (enabling). Scalable technical solution. Direct and high positive impact on CAPEX/OPEX/production.
Moderate positive	No/few alternatives available. Scalable technical solution. Moderate positive impact on CAPEX/OPEX/production.
Low positive	Alternatives available (enhancing). Unclear contribution to CAPEX/OPEX/production.
Unclear / negative	Unique technical solution. High cost for technology development. Unclear and possible negative contribution to CAPEX/OPEX/production

7.2 Ranking

Based on the methodology described above, the technical challenges listed in section 5 were assessed and ranked accordingly. Table 7-6 describes the TRL and complexity evaluation for each of the identified technology needs. The results of the evaluation were agreed in a workshop with the OG21 TTA leaders.

Table 7-7 shows the result of the combination of TRL and complexity as well as the possible added value for developing the various technologies. In the upper part of the table the enabling technologies are listed, while the enhancing technologies are in the lower part. With respect to the priorities in Table 7-7, all the enabling technologies are ranked with higher priority than technologies which address the business case of the field (where often alternative more costly technology alternatives exist). The technologies are prioritized firstly by added value (high added value given more priority than low added value), secondly by development cost (high development cost given more priority than low development cost). In other words, technologies considered as '*low hanging fruits*', are given priority, while technologies where alternatives already exist combined with a large remaining development cost is considered of less importance. The priority should not be understood as to how critical that particular technology gap is. For a specific field development a more detailed technology screening and assessment is normally conducted in order to both satisfy regulatory safety an environmental requirements and financial requirements for the investment.

Technologies that may increase the operational uptime or operability of the facility are generally attractive options for development and implementation. Environmental events like approaching icebergs, polar lows, extended periods of fog, might affect the operability. The optimal balance between operability and CAPEX/OPEX is unique for each field. For instance for the first field development example with a relatively low probability for encountering icebergs (however the probability is large enough so icebergs shall be considered) the chosen solution to implement a disconnection system might not in all cases be the most cost-effective solution. A cost-benefit analysis might reveal for instance that it is a better solution is to maximize operability of the facility and rather strengthen the hull of the FPSO such that structural integrity is maintained after an iceberg impact. While for the SE Barents Sea location a closer examination of the iceberg conditions in that area would perhaps reveal that including a disconnection system is the most cost-effective solution. This might for instance be due to larger icebergs.

The ranking below does not differentiate between the three field development examples. For instance, pipelines are almost irrelevant for the first example, while crucial for the example with gas production and gas transport to shore.

Table 7-6: TRL and complexity assessment of technology challenges

Technology	TRL	Complexity (Technical risk)
Structural design		
Hull designs	6 - 7	Medium
Ice load prediction models	3 - 5	High
Mooring & Appendages	6 - 7	Medium
Materials	3 - 5	Low
Personnel safety and winterization		
Personal Protection and Emergency Equipment	3 - 5	Low
Winterization solutions	6 - 7	Low
Enclosed topsides and explosion risk	3 - 5	Medium
EER infrastructure	3 - 5	High
EER technology	6 - 7	Low
Oil spills in ice		
Forecasting models of oil in and under ice	3 - 5	Medium
Environmental risk models	3 - 5	Medium
OSR technology	3 - 5	High
Detection and monitoring technology of oil in and under ice	3 - 5	Medium
Ice management systems and disconnection		
Disconnection and reconnection systems	6 - 7	Medium
Ice detection, forecasting, surveillance systems	3 - 5	Medium
Ice handling systems	3 - 5	Low
Logistic and communication system		
Logistics		
Communication systems	6 - 7	Low
Positioning systems	6 - 7	Low
Drilling and well		
Drilling technology	6 - 7	Low
Reservoir performance	6 - 7	Low
Same season relief well capability	3 - 5	Medium
Production, storage and export		
Flow assurance	3 - 5	Medium
Power supply	3 - 5	High
Subsea facilities	3 - 5	Medium
Gas compression	6 - 7	Low
Pipelines	6 - 7	Low

Table 7-7: Ranking of technology challenges

#	Technology	Added value	Dev. cost	Case 1 Oil	Case 2 Subsea	Case 3 Gas
1	EER infrastructure*	High pos.	1	√		√
2	Environmental risk models*	High pos.	2	√	√	√
	Detection and monitoring technology of oil in and under ice*			√	√	
	Ice detection, forecasting, surveillance systems*			√	√	√
	Ice handling systems*					√
	Same season relief well capability*					√
3	Ice load prediction models*	High pos.	3	√		√
	EER technology*			√		√
	OSR technology*			√	√	
4	Personal Protection and Emergency Equipment**	Low pos.	1	√		√
5	Winterization solutions**	Low pos.	2	√		√
	*Key technology to enable production					
	**Required technology (compliance)					
6	Drilling Technology[1]	High pos.	1	√	√	√
	Reservoir performance			√	√	
	Drilling technology (large bore wells)					√
	Gas compression					√
7	Forecasting models of oil in and under ice	High pos.	2	√	√	
	Subsea facilities				√	
8	Power supply	High pos.	3	√	√	√
9	Hull designs	Moderate pos.	N/A	√		√
10	Communication systems	Moderate pos.	1	√	√	√
	Positioning systems			√		√
11	Flow assurance	Moderate pos.	2		√	
12	Enclosed topsides and explosion risk	Moderate pos.	3	√		√
13	Mooring & Appendages	Low pos.	N/A	√		√
	Disconnection and reconnection systems			√		√
14	Pipelines	Low pos.	1			√
15	Materials	Low pos.	2	√	√	√
16	Logistics	-	-	√	√	√

[1] Large bore wells only applicable to case 3

Of the 28 technologies identified and assessed by the TTA groups, 11 was identified as enabling technologies that needs to be in place for year-around production to take place (Table 7-7, #1-3). In addition, two technologies were identified as a requirement to be allowed to operate (Table 7-7, #4-5). Moving forward, these are the technologies that should receive the highest prioritization.

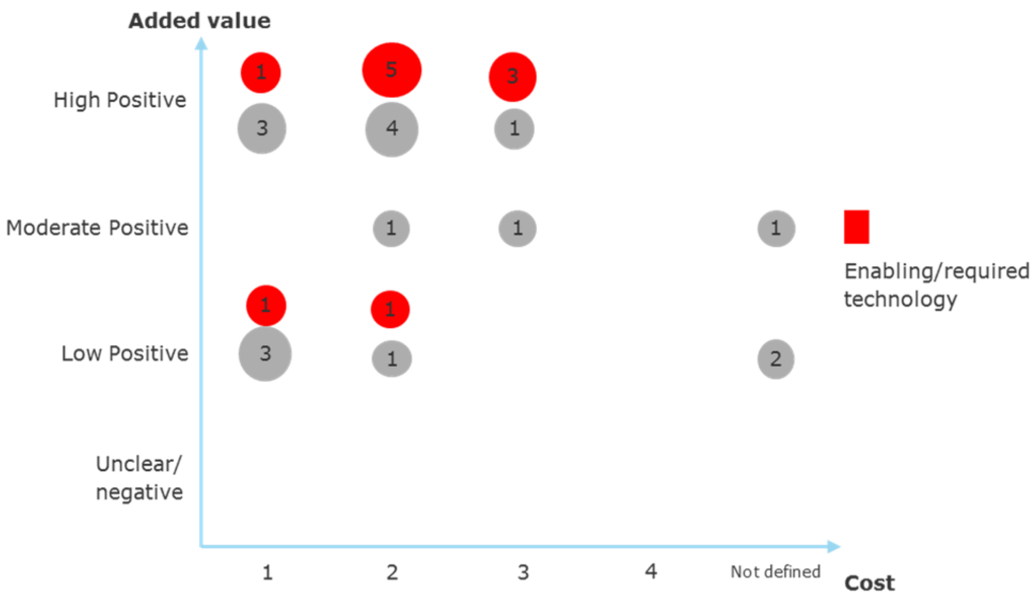


Figure 7-4: Value and remaining development cost distribution (number of technologies).

Looking at the TRL and complexity assessment, all the technologies are either at a maturing stage or ready for field qualification as shown in the figure below. This means that a 5 – 10 years perspective for field development at 74°N should be realistic. The actual time to develop the technologies to TRL 7 where full scale experience is gathered has not been assessed in this study. Such an assessment would have to include a more refined analysis of the state of the technology, which are the actors that can contribute to such technology development etc.

Judging by the amount of technologies relevant for each field development example, case 2 seem to need less undeveloped technology. However, for the second field development example it is assumed that it is possible to tie-in to a nearby facility. Presently, there are no such facilities in the vicinity of the SW Barents Sea location. The technology needs for the first and third example are widely similar except the need for oil spill related technologies for the first example. This is mainly due to similar facilities in those two examples.

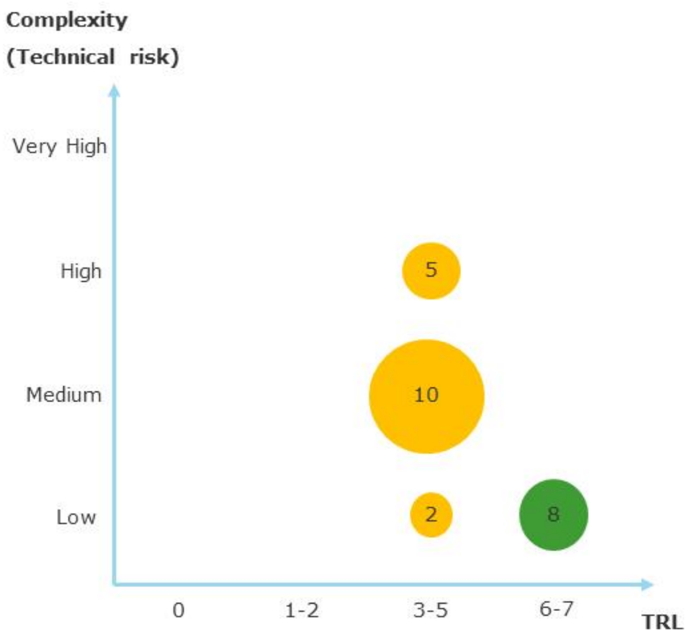


Figure 7-5: TRL and complexity distribution (number of technologies).

It is however important to remember that these are only technologies that contributes to the feasibility of a field development for the different cases. There might still be new innovative technologies not covered here, that might greatly improve the business case.

The current focus on costs on the NCS is highly relevant also for oil and gas developments in the Barents Sea. The industry is continuously searching for new innovative solutions throughout the value chain. Many of these solutions will also contribute to making oil and gas developments in the Barents Sea more commercially attractive.

8 CONCLUSIONS

DNV GL was given the task by OG21 to describe and prioritize the technology challenges for year-round oil and gas production on 74°N in the Norwegian part of the Barents Sea. The northernmost blocks in the 23rd licensing round are at 74°N and the physical environment in this area differs from other areas on the Norwegian Continental shelf where there is oil and gas production today.

There are identified eleven key technologies which are enabling year-round oil and gas production in the Barents Sea. These technologies (or in some cases knowledge areas) have no direct alternatives and can be considered as challenges the industry needs to find a solution to. Within all these areas, there are already extensive R&D and technology developments going on within both academia and the industry. The key technologies are:

- EER infrastructure
- Environmental risk models
- Detection and monitoring technology of oil in and under ice
- Ice detection, forecasting, surveillance systems
- Ice handling systems
- Same season relief well capability
- Ice load prediction models
- EER technology
- OSR technology
- Personal Protection and Emergency Equipment
- Winterization solutions

When it comes to key enhancing technologies, which are mainly affecting the business case of a development, alternative technologies exists today. A further development within these areas will lead to reduced development cost and increased production. Development of one or more of these technologies can also enabling a field development as one of the main barriers for field developments in the Barents Sea is the higher cost of production. The enhancing technologies with expected highest added value to a development project are:

- Drilling Technology
- Reservoir performance
- Drilling technology (large bore wells)
- Gas compression
- Forecasting models of oil in and under ice
- Subsea facilities
- Power supply

All evaluated technologies have a relatively high technology maturity level. This is related to that offshore oil and gas production is taking place in similar conditions (e.g. Sakhalin and Grand Banks), however as we do not have such experience on the NCS, adaptation of technologies should be expected.

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APPENDIX A WORKSHOP 1

Place and time: Norwegian Petroleum Directorate, Stavanger, 17 June 2015

Agenda

09:00 Introduction (OG21)

09:20 Background material and method (DNV GL)

09:40 Possible field development cases (DNV GL)

10:00 Break

10:20 Presentations of main findings from relevant studies part 1

11:30 Lunch

12:00 Presentations of main findings from relevant studies part 2

13:50 Discussions (DNV GL facilitator)

For the presented field development cases:

- What challenges is there agreement on?
- What challenges is there not agreement on?
- Which 2-3 field development cases covers the most important challenges? (to be used in the work moving forward to elaborate the challenges and sketch actions and solutions)

15:40 Summary and next steps

The participants of the workshop were:

Name	Company
Gunnar Lille	OG21
Arne Holhjem (partly)	NPD
Dag Breivik	OMV
Helge Skæveland	Shell
Øyvind Fevang	Statoil
Thor Christian Andvik	INTSOK
Egil Dragsund	NOROG
Gunnar Sand	SINTEF
Alfred Hansen	UiT
Erik Bjørnbom	ENI

Name	Company
Tor Langeland	CMR
Anne Minne Torkildsen	NPD
Joar Dalheim	LR
Trond Sagerup	Aker Solutions
Anne Grete Johnsen	Statoil
Øyvind Tuntland	PSA
Per Olav Moslet	DNV GL
Bente Leinum	DNV GL
Cecilie Kielland	DNV GL
Peter Schütz	DNV GL

APPENDIX B WORKSHOP 2

Place and time: The Norwegian Research Council, Lysaker, 2 September 2015

Agenda

10:00	Welcome by Gunnar Lille
10:00 - 10:15	Introductions
10:15 - 10:45	Presentation of method for the workshop
10:45 - 11:30	Discussion and ranking of technology needs for the oil case (case 1)
11:30 - 12:00	Lunch
12:00 - 13:45	Cont'd discussion and ranking of technology needs for the oil case (case 1)
13:45 - 14:15	Discussion and ranking of technology needs for the gas case (case 3)
	Note: Only the technology needs that are unique for the gas case and which have not been discussed earlier will be covered.
14:15 - 14:45	Discussion and ranking of technology needs for the subsea case (case 2)
	Note: Only the technology needs that are unique for the subsea case and which have not been discussed earlier will be covered.
14.45 - 15.45	Ranking added value
15:45 - 16:00	Summary of findings
16:00	End of workshop

The participants of the workshop were:

Name	Company
Gunnar Lille	OG21
Dag Breivik	OMV
Helge Skjæveland	Shell
Kjetil Skaugset (video)	Statoil
Øyvind Fevang	Statoil
Alfred Hansen	UiT, ARCex
Tor Langeland	CMR
Inge Alme	Lloyds Register

Name	Company
Anne Minne Torkildsen	NPD
Joar Dalheim	Lloyds Register
Øyvind Tuntland	PSA
Per Olav Moslet	DNV GL
Bente Leinum	DNV GL
Cecilie Kielland	DNV GL
Kjell Olav Skjølsvik	DNV GL

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