Offshore vessel design for Barents Sea operations

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ABSTRACT

High oil and gas prices are raising the level of interest in the exploration of Arctic oil and gas resources. Forty-three companies applied for licences in the 21st round for the Norwegian Continental Shelf (NCS), and 24 licences were approved in April 2011 (12 in the Norwegian Sea and 12 in the Barents Sea). In the 22nd round, 37 companies applied for 228 blocks, 181 of which were in the Barents Sea. This rising interest is linked to discoveries in the western part of the Barents Sea (Skrugard and Havis) as well as knowledge of locations with major gas resources in the Russian part of the Barents Sea. This paper summarises design considerations, numerical and physical studies and simulations of operational characteristics of a 120 m offshore intervention vessel for the Barents Sea. Ice performance of the vessel is discussed briefly as that will be the main topic of another paper by Su et.al (2013).

INTRODUCTION

The offshore industry is moving north. Future operations will be required to have low environmental footprints. Emissions during normal operations must be kept low and the probability of accidents leading to oil or chemical spills extremely low, as the consequences of a spill in the Arctic would be extremely serious. In collaboration with research and industrial partners in Norway and Finland, MARINTEK ran an R&D project to investigate important design parameters for an offshore intervention vessel for Barents Sea operations. As the operating conditions there change with location and season, the project partners agreed to develop a business case as the basis for the design of the vessel. More information about the business case is given in the next section. The starting point for the development of the vessel was a present design with proven good qualities for operations in harsh open-sea conditions. As installation work will take place in the summer, the open-sea season in the Norwegian sector, this approach was approved by the project partners. When the field is in production it must be possible to do unplanned repair operations on an all-year basis. The vessel thus must be designed for operation in medium-thick first year ice. The project took operation in 0.7m level ice thickness as a design criterion.

VESSEL DESIGN INPUT

A number of offshore vessels are designed for world-wide operations to enable shipowners to move vessels to regions of high activity and dayrate. Such vessels are not suitable for operations in Arctic waters. The growing concern of international maritime bodies (and governments of Arctic countries) related to the normal operation environmental footprint of vessels sailing and working in Arctic waters, and their influence on the greying of sea ice (due to carbon deposits) will have implications for the selection of engine types and fuel characteristics. The lack of resources to handle accidental spills in Arctic waters will need to be considered during vessel design, in order to minimise the probability of such spills through design modifications. For the project described here we agreed to base the vessel design on a defined business case. Equipment producers and engineering companies with Arctic experience were invited to workshops at which critical tasks for a light construction and intervention vessel were discussed. The capacities of various types of equipment for particular tasks were discussed. Later on the operational limits for specific operations were investigated, and it was agreed that current criteria based on significant wave height as a parameter were inadequate, as they do not take the vessel dynamics into account, since the vessel response in waves is also highly dependent on *wave period*. Wave direction and vessel speed also influence vessel performance. The business case was defined as referring to a point in the future when oil and gas activities will have started in Norwegian waters in the Barents Sea east of Svalbard (Figure 1). The primary operating region would be in the Olga Basin, which lies in the Marginal Ice Zone (MIZ). A number of potential locations for shore bases were proposed (Hammerfest, Kirkenes and Longyearbyen). It was decided to use Hammerfest for this study. This was the best position for the vessel's secondary area of operation in the northern Norwegian Sea ("Southern route" in Figure 1). It was specified that vessel would initially perform summer season operations related to the installation of subsea production system structures and components in the Olga Basin. When the field entered the production phase, the vessel should be able to perform unplanned repair and maintenance tasks on the subsea system on a year-round basis. For such operations the vessel would be supported by dedicated ice-breakers that would perform ice management so that the intervention vessel could stay on station using an advanced dynamic positioning (DP) system adapted to operation in managed ice.

The business case specified an operating profile. For the main mission (Olga Basin) the profile was:

- At shore base 20%
- In transit 20%
- At work site 60%

The distance to the primary work-site was approximately 485 nm; 1 day and 8 hours cruising at15 knots, which was specified as the normal transit speed. The distance to shore might require a modified logistics system compared to operational sites closer to the coastline. This would also require a vessel with longer endurance than required for operations closer to onshore infrastructure. Once the work site and tasks had been specified, the next step was to collect data for specification of the environment parameter design base for the vessel. A review of the available meteorological, oceanographic and ice data for the Olga Basin revealed generally poor data availability.

Sea-ice thickness was measured by the Norwegian Polar Institute (NPI) using Upward-Looking Sonar (ULS) during the winters of 1994-95 and 1995-96. These are the only long-term recordings of ice thickness in the entire Barents Sea. The sampling intervals were relatively long (4-5 minutes) thus the recorded data can only be considered as statistical samples of ice draughts. The ice topography under individual features such as ice ridges would not be resolved. The Tromsø office of the Norwegian Meteorological Institute (NMI) has prepared ice maps for Norwegian waters. These maps only show the extent and concentration of ice. Seasonal variations for the last 15 years are illustrated in Figure 2 (data for 2011 is until the end of October). For a site-specific design of a vessel the thickness and variation in ice characteristics ought to be known. For the business case it was decided to use 0.7 m level ice as a design requirement.

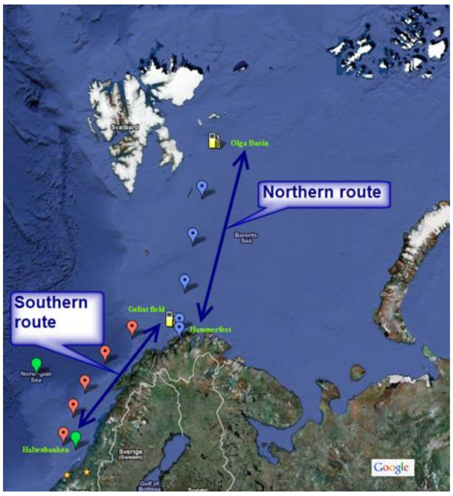

Figure 1. Operational area for the study

Currents were measured by NPI using an Aanderaa RCM current meter at 135 m water depth from August 1993 to August 1995 and at 99 m from August 1995 to August 1996. Due to the depths at which the measurements were made, these data are thought to be of little relevance for a construction vessel operating on the surface. However, they may be relevant to operations that involve cables, umbilicals etc. in the water column. No data sources for surface currents have been found.

Due to the lack of long site-specific of wind and wave time series, it was decided to use the new hindcast database developed by NMI as design data for this study. Wind and wave data for the Olga Basin are based on hindcast data produced by the Norwegian Meteorological Institute – WAM grid point 77.92°N, 28.4°E (figure 3). The data cover the period September 1957 – December 2008. It should be noted that in periods when the location has been covered with sea ice, no wind or wave data are available. All data correspond to winds averaged over one hour, and at 10 m elevation. Wave data correspond to three-hour sea states.

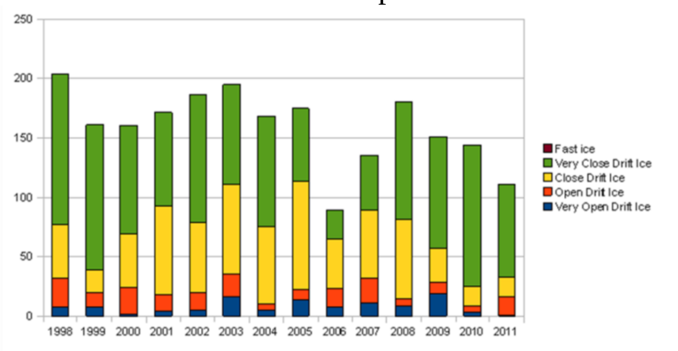

Figure 2. Ice concentrations at 78°N, 28°E; NMI 2011

As some marine operations may involve several vessels, there will be visibility limits for performing such operations. No data existed for visibility distribution. It was discussed whether data from the NMI observation station at Hopen could be used to get a preliminary estimate of visibility parameters. Finally, operations in the Barents Sea might be influenced by intensive Polar Lows (PL). A map produced by NMI (figure 4) shows the birth locations for PLs. The previous sections make it clear that the environmental parameter design base for vessels operating in the eastern Barents Sea is insufficient. New measurement campaigns need to be launched to collect more metocean and ice information prior to the start of oil and gas activities in the Norwegian part of the eastern Barents Sea.

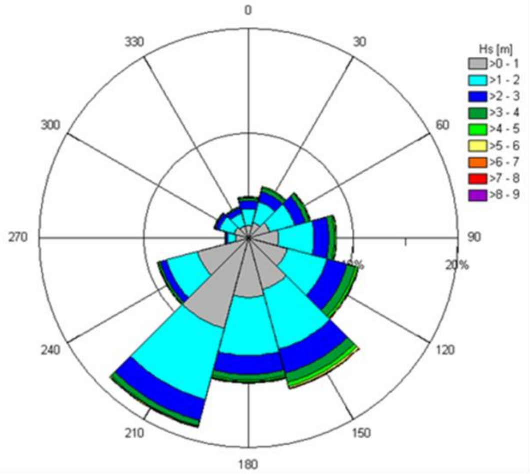

Figure 3. Wave distribution; direction and wave height (all year).
WAM grid point (77.92N, 28.4E). Hindcast data produced by the NMI

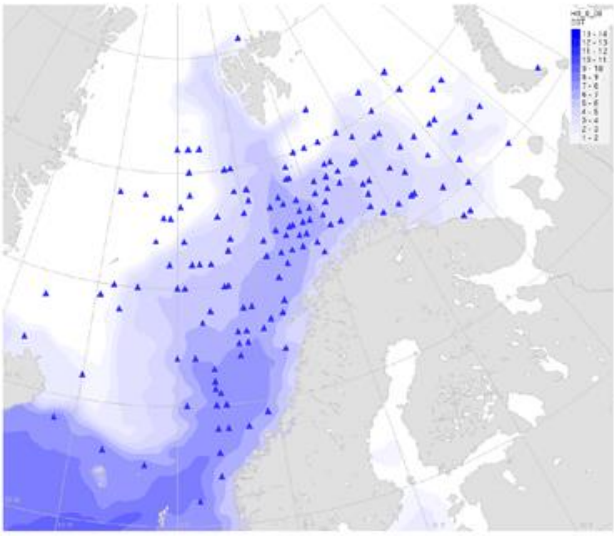

Figure 4. Formation areas of polar lows 2000-2012 (NMI)

VESSEL DESIGN STUDY

The agreed case study concerned the design of an intervention vessel, with particular focus on the east side of Svalbard, the Olga Basin. The basic focus was on prolonging the season for the installation and maintenance of subsea oil and gas facilities, as well as a comparison with existing OSV's (Offshore Specialized Vessels). The vessel is not intended for heavy installation work since such tasks will be performed in any case during the summer season, using specialized vessels for such work. During summer season the vessel will perform typical tasks such as interventions in which equipment and structures can be launched and retrieved over the side, stern or through the moonpool. During the winter season the corresponding tasks could be unplanned intervention tasks in the Norwegian part of the Barents Sea. For ice-free periods the vessel needs to be capable of operating as a stand-alone vessel (without support vessel(s)). In periods with thin seasonal ice the vessel needs to be supported by a first-line ice management vessel. Under such working conditions, equipment and modules can only be launched and retrieved through a moonpool.

Analysis of available metocean and ice data

A study was performed to compare metocean data from the Norwegian Sea with Barents Sea data. Hindcast data from NMI using the WAM-model was made available to the project through Statoil. A general observation was that the waves in the Barents Sea are shorter than the waves in the Norwegian Sea. Some wave information is provided in Figures 5 and 6.

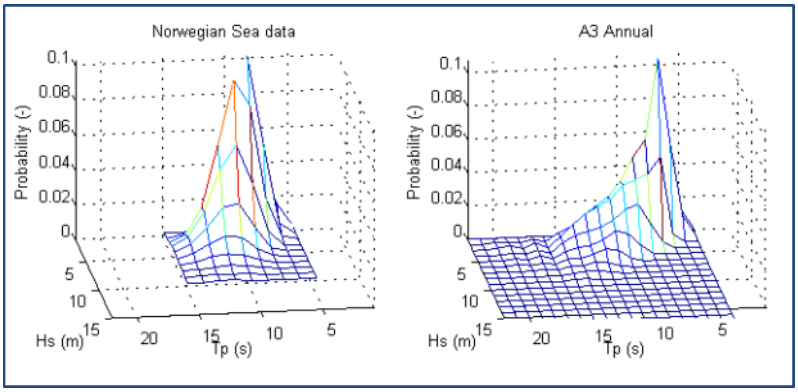

Figure 5 Left: Overview CIVARCTIC operational area (Google Maps). Right: Comparison of metocean data for the Norwegian Sea and Area 3 (72.79 North, 24.41 East).

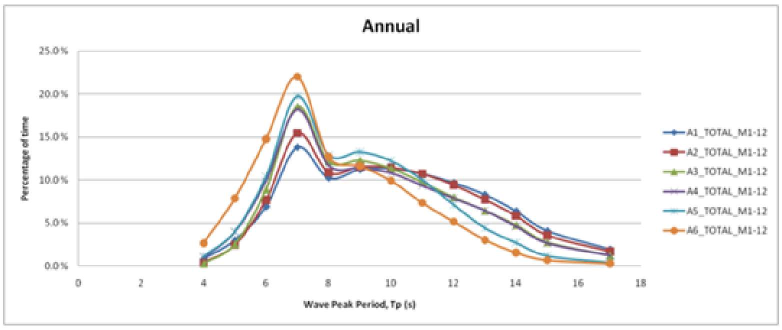

Figure 6. Annual distribution of wave peak periods on the voyage from Hammerfest to the Olga Basin in the Eastern Barents Sea (NMI)

Single purpose versus multipurpose vessels

By definition, single-purpose vessels cannot perform as wide a range of tasks as a multipurpose vessel. However, multipurpose vessels are often a compromise among several vessel characteristics. In the Arctic, the ultimate goal is to minimize the environmental footprint, so single-purpose vessels are of the essence to optimize vessel performance. However, secondary tasks that do not reduce the availability and reliability of the vessel in performing the primary intervention tasks should be integrated into the final vessel design. Secondary tasks of interest are oil spill containment/handling, fire fighting, and search and rescue.

Operational experience in Arctic waters is limited, and there is a generation issue as many experienced navigators from fishing and sealing/whaling hunting have retired or are on the brink of retiring. Their views on topics such as superstructure icing, is of importance for the design of new vessels. It will be essential to incorporate these aspects in the design spiral. This must be done through close collaboration between designers and by utilising the experience of the above-mentioned personnel.

At present, metocean data are generally speaking affected by significant uncertainties for the Arctic regions. The quality of forecast tools at high latitudes is also poor, resulting in uncertainties from a designer's point of view. High-quality studies are of the utmost

importance in the Artic in order to minimize vessel footprints, so campaigns to acquire essential missing metocean data are needed.
Some of the most important characteristics of a typical offshore vessel can be deduced from the following equations:

$$\omega_{03} = \sqrt{\frac{\rho g A_W}{M + A_{33}}} \qquad \Leftrightarrow \qquad T_{03} = \frac{2\pi}{\omega_{03}} = 2\pi\sqrt{\frac{M + A_{33}}{\rho g A_W}}$$

$$\omega_{04} = \sqrt{\frac{\rho g\, GM_T}{M r_{44}^2 + A_{44}}} \qquad \Leftrightarrow \qquad T_{04} = \frac{2\pi}{\omega_{04}} = 2\pi\sqrt{\frac{M r_{44}^2 + A_{44}}{\rho g\, GM_T}}$$

$$\omega_{05} = \sqrt{\frac{\rho g \nabla GM_L}{M r_{55}^2 + A_{55}}} \qquad \Leftrightarrow \qquad T_{05} = \frac{2\pi}{\omega_{05}} = 2\pi\sqrt{\frac{M r_{55}^2 + A_{55}}{\rho g \nabla GM_L}}$$

For example, the natural periods for a generic offshore vessel with a length over all of 120 m, 24 m beam and 6 m draft will be approximately:
T_{03} = 7 sec, head sea, zero speed
T_{04} = 12-17 sec, beam sea, zero speed, an important parameter is GM_T (related to vertical centre of gravity)
T_{05} = 6 sec

As we can see, the natural frequencies in heave and pitch are rather close to the maximum occurrence of peak periods shown in Figure 6. It is important to take this into account when designing a vessel for operation in such waters. The most important way of modifying the effect of this is by adjusting main parameters, i.e. during the early design stage. Knowledge of metocean data at this stage is therefore important. Figure 7 illustrates a typical heave RAO (Response Amplitude Operator) for the generic vessel used as an example.

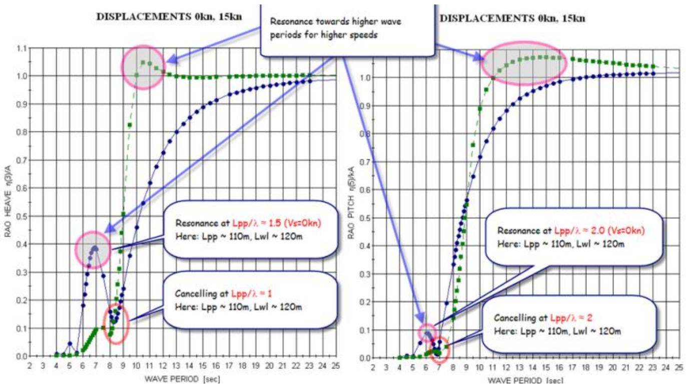

Figure 7. Typical heave response amplitude operator (RAO) for a 120 m long OSV

Design guidelines
Three main areas have been focused on in the design of the vessel:

- Icebreaking capabilities
- Long distance from base – Efforts to optimize open-water performance
- Design for Barents Sea – Added value for operations in the Norwegian Sea

Designing the best compromise between open water characteristics and icebreaker capabilities was the most important design topic. The expertise of designers of icebreakers and traditional offshore vessel produced a good compromise. Models of two designs were tested for power consumption in MARINTEK's towing tank. The original design was intended to have good icebreaker capabilities. However, its energy consumption was high, so a new design of the after part of the ship that would retain its icebreaking capability but offer reduced resistance was needed. Before the model of the final design was tested it was also subjected to optimization of the aft ship design using CFD, for the final detail analysis. This offered a reduction in power requirements of close to 15% compared to the original design, which is a significant reduction. A comparison with a comparable offshore vessel (without any ice-breaking capabilities) showed that the final design was close to it in performance. Seakeeping and stationkeeping model tests were then carried out in MARINTEK's ocean basin and used as input to a numerical study of seakeeping capabilities. The vessel design proved to be comparable with an existing offshore vessel, for operations in the Norwegian Sea, so the trade-off between open water- and icebreaker capabilities seemed to be a success. The final design is shown in figure 8 and it satisfies PC-5, Winterized Cold requirements.

Figure 8. Proposed vessel design

A design guide based on the findings of the project was then established and the main considerations are summarized as follows:

- Calm-water performance
    - Low **resistance**
    - Optimizing **propulsion** characteristics - a compromise between the actual aft ship hull design and the propeller design.
- Seakeeping performance
    - **Main dimensions** such as B/L-ratio, T/L-ratio, C_{WF} – forward water-plane area coefficient and GM_T – Transverse metacentric height.
    - **Rolldamping devices**.
    - **Added resistance** in waves is dependent on good bow design for short waves (less than the ship length).
    - **Slamming** exposed areas.
- Ice performance – important parameters
    - Bow form (stem and waterline angle), bulbous bow
    - Waterline area and frame angles at waterline, beam
    - Appendages, roll damping
    - Bollard pull vs design speed propeller optimization, Bollard pull/Beam ratio
    - Displacement

BRIEF PRESENTATION OF ICE PERFORMANCE STUDIES

A numerical model validated by field measurements was employed to investigate the level-ice performance of the CIVARCTIC vessel. The simulations were conducted at first on model scale for a direct comparison with the ice-model tests carried out in the Aker Arctic ice tank. The simulation results agreed well with the model tests , and concluded that the ice-going capacity of this vessel was much better going astern than ahead in level ice. The test results also showed that the vessel does not turn very well in 0.50 m-thick level ice. The simulation results indicated even poorer turning performance under these conditions. But if a heeling angle of 2° was considered, the simulation and test results compared well. The ice-property values obtained from full-scale tests with the Norwegian Coast Guard icebreaker KV Svalbard (Table 1) were then employed in a full-scale case study (Su, 2012). The estimated maximum speeds that the CIVARCTIC vessel can reach under these conditions are approximately: 5 m/s going ahead and 6 m/s astern. The estimated turning circle diameter of the vessel under these conditions is about 550 m, see Figure 9. It should be noted that this numerical model is based on the full-scale estimates of ice crushing pressure and ice bending failure; the size effect on the fracture of a floating ice sheet (fracture mechanics) was not considered in the model-scale simulations. The influence of instantaneous heave, roll and pitch motions on ship's performance was not considered in the comparison of simulation and test results. These issues remain for further analysis.

Table 1. Ice properties in a full-scale test with KV Svalbard
(Source: Lubbad and Løset, 2011)

Average ice thickness	0.33 m
Elastic modulus	2.0 GPa
Flexural strength	0.40 MPa
Crushing strength	1.50 MPa
Density	900 kg/m^3

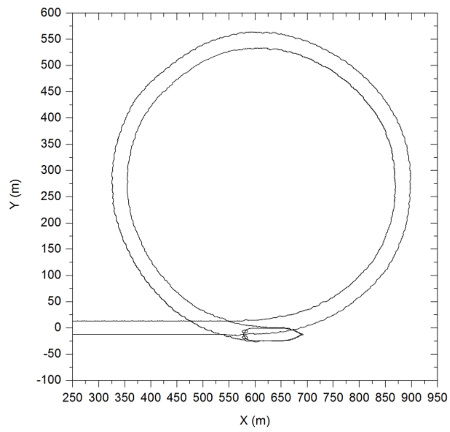

Figure 9. Simulated turning circle in 0.33 m thick level ice
(Power 100%, Azipod angle 35°, Heeling angle 2°)

MINIMIZING OPERATIONAL EMISSIONS

Engine system selection

One of the objectives of this study was to minimize the operational exhaust gas emissions of the vessel, taking into account the operational profile defined in the business case. The research question asked was whether the dual-fuel engines would offer a distinct advantage (emissions-wise) over conventional diesel engines in this vessel. The exhaust gas emissions of two design alternatives were compared. The main attributes taken into account in the environmental footprint calculation were fuel consumption and fuel-specific emission factors. The two engine options for the ship were:

1) four diesel engines Wärtsilä 12V32 (6 000 kW each), running on low-sulphur marine diesel oil (MDO) or

2) two diesel engines Wärtsilä 12V32 (6 000 kW each) and two dual-fuel engines Wärtsilä 12V34DF (5 400 kW each) that can burn liquefied natural gas (LNG) ignited by pilot fuel (MDO), but also capable of running entirely on diesel oil.

The emission calculations were performed under the assumption that all engines, including the dual fuel ones, are equipped with a selective catalytic reduction (SCR) to reduce NO_x emissions.

Fuels and emissions

The fuel consumption figures are derived from required power for different operating modes and are dependent on the engine loads, the optimum being somewhere near 80–85%. The specific fuel oil consumption (SFOC) figures were acquired from the manufacturer's engine-specific project guides. SFOC is usually given for a few engine loads; the other required power and respective engine loads between the given points have been interpolated from the curve. The required engine loads according to the operational profile for the project vessel are based on the model test results and metocean data from the Barents Sea.

The combustion process of the diesel engine produces compounds that in large amounts have negative environmental effects. The most common of these are carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur oxides (SO_x) and particles (PM). LNG, on the other hand, is mostly methane (CH_4). Methane emissions are highest during low-temperature combustion or incomplete combustion (US EPA, 1998). Natural gas has lower CO_2 emissions due to its low carbon to hydrogen ratio of fuel (1/4; gasoline has 1/2.25) and lower NO_x emissions thanks to the lean-burn concept (high air-fuel ratio). LNG engines produce almost zero SO_x emissions since sulphur is removed from the fuel when the gas is liquefied, while the particulate emissions of natural gas are also very low (US EPA, 1998). The fuel-specific emission factors used in the calculations have been selected from various references in co-operation with the engine manufacturers and project partners. Some of the emission factors (CH_4 in particular) are notably higher on low engine loads. When operating on very low loads, say under 10%, a dual-fuel engine is practically running in diesel mode. Although dual-fuel engines can be used in gas mode or diesel mode, they are optimised for gas operation.

Comparison of diesel and LNG

The method used in the comparison was life cycle impact assessment (LCIA) and it was narrowed to cover two impact categories in ship operation:

- global warming potential (GWP) and
- acidification potential (AP).

These two methods are appropriate for measuring emissions to the atmosphere. Calculating the global warming potential allows CO_2 and CH_4 emissions to be compared. Similarly, NO_x and SO_x emissions can be compared by calculating their acidification potential (Figure 10).

Impact assessment is necessary to compare the environmental impacts of air emissions from different type of engines using different fuels, since there is a considerable difference in impact potentials of greenhouse gases. In practice, the greenhouse gas in question is compared to carbon dioxide, whose GWP-value (characterization coefficient) is 1.0. The result is given as carbon dioxide equivalent (CO_2 eqv). The GWP value of methane is 25, which is to say that its potential impact is 25 times as large as that of carbon dioxide over a 100-year time-span.

Dual-fuel engines operate in gas mode in transit. At the worksite four engines are always running, since power requirements vary greatly with the different tasks involved and changes in environmental conditions. The calculations have been performed for a single typical operating mode "on-site". Gas is not used when operating with DP, so the dual-fuel engines run on diesel "on-site". In the emissions inventory, the most outstanding difference between the alternatives studied in the project is in methane emissions. The diesel option has minimal CH_4 emissions compared to the dual-fuel option. The dual-fuel version of the project vessel produces lower CO_2, PM, SO_x and N_2O emissions that diesel. A life cycle impact assessment will have to be performed to complete the comparison process. In this case study, the results are slightly in favour of the dual-fuel engine option over conventional diesel engines. The difference in the GWP between MDO and dual-fuel is very small, perhaps irrelevant. The GWP from dual-fuel operation appears to be 98% of GWP from the MDO option. AP from dual fuel turned out to be 91.5% of AP from diesel operation. These results are case-specific and should not be generalized to other diesel and dual-fuel option comparison.

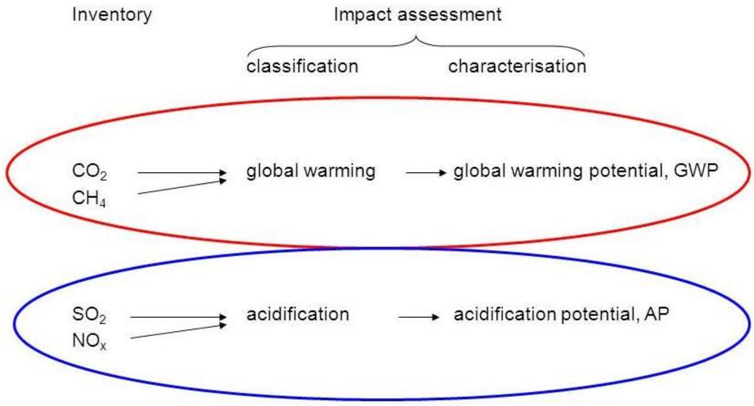

Figure 10. The impact assessment restricted to global warming potential (GWP) and acidification potential (AP).

CONCLUSIONS AND RECOMMENDATIONS

The study highlighted the lack of qualified metocean and ice design data for the eastern part of the Barents Sea. Petroleum sector stakeholders need to cooperate in collecting and sharing new metocean and ice data for the Barents Sea. Starting with a vessel with good open-sea performance, it is possible through design modification and optimized operational procedures to obtain good performance figures for the vessel in thin to moderate first-year ice.

No clear benefit emerged from the selection of dual-fuel engines, primarily due to the operational profile of the ship and the fact that LNG cannot be used when operating on DP. It is important to notice that the environmental footprint results presented here are case-specific and should not be generalized to other diesel and dual-fuel comparisons.

ACKNOWLEDGEMENTS

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ABBREVIATIONS

Abbreviation	Definition
AP	Acidification Potential
CFD	Computational Fluid Dynamics
CH_4	Methane
CO_2	Carbon Dioxide
DF	Dual Fuel
DP	Dynamic Positioning
ekW	Effective kiloWatt
GWP	Global Warming Potential
kW	KiloWatt
LCIA	Life Cycle Impact Assessment
LNG	Liquefied Natural Gas
MDO	Marine Diesel Oil
MIZ	Marginal Ice Zone
NCS	Norwegian Continental Shelf
nm	Nautical mile
NMI	Norwegian Meteorological Institute
NO_x	Nitrogen Oxides
OSV	Offshore Service Vessel
PL	Polar Low
PM	Particulate Matter
R&D	Research and Development
RAO	Response Amplitude Operator
SCR	Selective Catalytic Reduction
SO_x	Sulphur Oxides
ULS	Upward-Looking Sonar
WAM	Wave model

SYMBOL LIST

Symbol	Definition
A_{ii}	Added mass/moment of inertia, i= 3 Heave, i=4 Roll, i=5 Pitch
A_W	Waterplane area
B	Ship beam
C_{WF}	Forward waterplane area coefficient
g	Gravitational acceleration
GM_L	Longitudinal Metacentric Height
GM_T	Transverse Metacentric Height
H_S	Significant wave height
L	Ship length
M	Ship mass
r_{ii}	Radius of gyration (i= 4,5,6)
T	Ship draught
T_{0i}	Natural period (i= 3,4,5)
T_p	Wave peak period
λ	Wave length
ρ	Water density
ω_{0i}	Natural frequency (i=3,4,5)