IMPACTS OF A BAN ON HEAVY FUEL OIL USE AND CARRIAGE AS FUEL BY SHIPS IN THE NORWEGIAN ARCTIC WATERS

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1 EXECUTIVE SUMMARY

The purpose of this study is to assess the effects on the Norwegian Arctic communities and industries of a ban on heavy fuel oil use by ships in the region. It also addresses associated costs and benefits of such a ban for the local industries, economies and the coastal and marine ecosystems of the Arctic. Finally, the report aims to assess whether the proposed HFO-ban fulfils its policy objective of reducing the environmental risks related to an HFO spill from shipping in the Norwegian Arctic waters both short and long term.

In order to provide the basis for this study, establishing an understanding of the demography on land as well as the shipping fleet populating the Norwegian Arctic is essential. The Norwegian communities in the Arctic are geographically spread between the islands Hopen, Bjørnøya, Jan Mayen and Svalbard, with Longyearbyen being the centre of activities. Since there are no indigenous populations within the Norwegian Arctic waters, the potential impact on such a population from a future ban of the use of heavy marine fuels is not discussed.

The vast majority of the vessels operating in the Norwegian Arctic waters are either just passing through or they are performing operations like fishing, research and fleet support not directly linked to the ports in the area. Amongst the vessels using HFO, the large intercontinental cargo vessels (tank, bulk and container) are dominating in number but none of these enter Norwegian Arctic ports. The HFO vessels visiting a Norwegian port (Longyearbyen) are predominantly cruise vessels apart from a few stray general cargo vessels and a bulk carrier exporting coal from Longyearbyen to Europe. This leads to the conclusion that tourism and coal exports are the only commercial activities connected to the Norwegian economy directly affected by an HFO ban in Norwegian Arctic waters.

Table 1-1 All vessels operating in Norwegian Arctic waters 2018.

Vessel type	All vessels	HFO-vessels	HFO-vessels in Nor. ports	Vessels with scrubbers
02 - Chemical tankers	20	16	0	0
03 - Gas tankers	15	15	0	0
04 - Bulk carriers	52	51	1	2
05 - General cargo ships	55	24	3	0
06 - Container ships	4	4	0	0
08 - Refrigerated cargo ships	18	9	0	0
10 - Offshore supply ships	21	0	0	0
11 - Other service offshore vessels	6	1	0	0
12 - Other activities	69	6	1	0
13 - Fishing vessels	278	12	0	0
14 - Crude oil tankers	15	15	0	0
15 - Oil product tankers	9	6	0	0
16 - Passenger ships	11	1	0	0
17 - Cruise ships	37	12	12	8
Grand Total	**610**	**172**	**17**	**10**

1.1 Effects of an HFO-ban

The quite dramatic changes in the marine fuel landscape introduced by the global sulphur cap from 2020, has been an important premise for this study. Consequently, a post-2020 setting is providing the baseline for the assessments. This introduces uncertainties regarding the fuel properties and the subsequent behaviour of the fuel oil in the case it is spilled to sea. This is because the new low sulphur blends developed to meet the sulphur cap, are still not fully understood in terms of their properties when spilled to cold water.

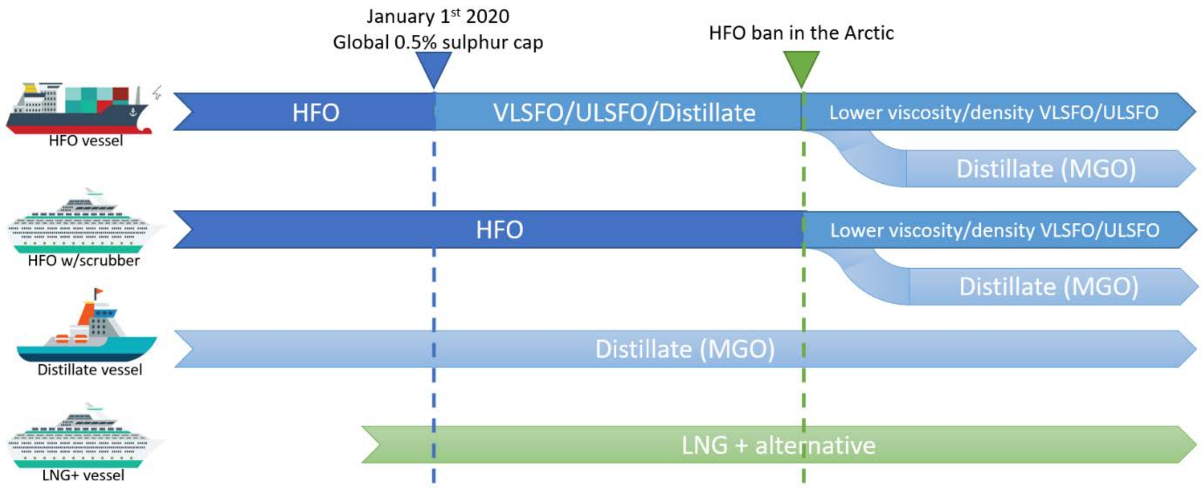


Figure 1-1 Main fuel alternatives in the Norwegian Arctic.

The figure above shows the main fuel alternatives represented in the Norwegian Arctic waters, and how these are affected by the 2020 0.5% sulphur cap and a potential Arctic HFO ban. This can be outlined:

- The vessels traditionally using HFO must regardless of an HFO-ban, comply with the global 0.5% sulphur cap from 2020. These vessels must therefore switch to low sulphur fuels (LSFO) or distillate fuels in order to meet the sulphur cap. In case of an introduction of the HFO ban, additional fuel requirements will also apply regarding density (below 900 kg/m^3) or a viscosity below 180 mm^2/s.
- It is likely that vessels using HFO will change to VLSFO/ULSFO qualities in compliance with the HFO ban if these are commercially available. This is because they likely will come at a lower cost than distillate fuels.
- The Arctic vessels using scrubber technology to comply with the sulphur requirements must also ensure that the criteria under the HFO ban is met. These vessels will most likely adopt the same alternative fuel strategy as the traditional HFO vessels without scrubbers.
- The majority of the current vessels in the Norwegian Arctic waters are already using distillate fuels (compliant with any current and proposed regulations in the Arctic) pertinent to the already introduced residual ban (since 2015) for the national parks at Svalbard. For current, and future vessels switching to distillate fuels from 2020 due to the global sulphur cap, the HFO ban will not influence the risk picture.

An important premise for actual and significant reduction of environmental risk from a future ban of the use of heavy fuel oil in the Arctic, is that the ban actually targets the relevant oil qualities representing particularly high environmental risks. Hence, that the risks are substantially reduced compared to a baseline scenario where a ban is not implemented.

The key question is then how different the weathering properties and behaviour will be for the emerging hybrid oils, as they will be having "similar" weathering properties as HFOs', and in addition could solidify on the sea surface at low temperatures?

There are large uncertainties related to the environmental risks from accidental spills of the new low sulphur fuel alternatives. Few studies have been carried out in order to investigate the weathering properties of these new blends, and this is particularly so for their behaviour and fate in cold water. Recently published information is highlighting challenges reported for the low sulphur hybrid fuels related to low evaporation, risk for solidification at low temperatures, and low oil spill response effectiveness.

Figure 1-2 Environmental risks with available fuel alternatives in the Arctic relative to the up-coming regulations.

The associated marine fuel risk picture (both with and without a ban) may become very different, compared to the situation from which the original heavy fuel oil ban was developed due to the sulphur cap. Some of the new 0.5% low sulphur fuels may be permitted under the proposed ban's HFO definition, even if these qualities still have environmental risk properties in line with traditional heavy fuel oils, especially in case of spills under Arctic environmental conditions.

1.2 The potential cost and savings for the Norwegian society related to an HFO ban in the Norwegian Arctic

1.2.1 Costs related to an HFO ban

The analysis of the potential additional operating costs and onetime costs associated with an HFO-ban, relates to the number of vessels affected and their role in the economy. Out of the 172 ships in the Norwegian Arctic waters that used HFO in 2018, only 13 of them were identified as having any direct significance for the Norwegian Arctic economy. The reason that so few vessels are identified as such, is because the settlements within the Norwegian Arctic waters is nearly 100% served by vessels using distillate fuels and will not be affected by an HFO ban. The 13 identified vessels consist of the following:

- 8 large cruise vessels with scrubbers on a round-trip involving Longyearbyen
- 4 large cruise vessels without scrubbers on a round-trip involving Longyearbyen
- 1 bulk carrier transporting coal to the continent

Not knowing the strategies selected by the vessels to comply with an HFO ban, three different alternatives for compliance with an HFO ban were assessed; Use VLSFO, ULSFO or use distillate fuel. The implications of this is that in total, an HFO-ban for the marine traffic will constitute an estimated annual added cost for the Norwegian Arctic area of between 350 000 USD and 760 000 USD.

1.2.2 Potential benefits to the society and the environment

The costs and damages that accrue in case of an oil spill are highly dependent on the actual circumstances. Relevant factors include the oil type spilled, the amount of oil spilled, the geographic location of the spill (proximity to the shoreline and sensitive resources), the local response capacity and the clean-up technologies used, as well as weather and sea conditions. Hence, estimating the cost related to such spills introduces many uncertainties, not at least the fact that little information about the clean-up cost of bunker fuel in Arctic waters is published. We know that remoteness, temperature, ice and weather conditions all add to the expected complexity of an Artic clean-up operation and thus, to the cost. Therefore, the uncertainties in such assumptions are huge, mainly because there is little data and experience from tests and accidents to draw on, but also due to the fact the properties of the new hybrid low sulphur fuels may vary considerably.

Based on available literature, it was for this study assumed a cost difference between clean-up of distillate spill to be 22 500 US$/ton less than that of an HFO spill. Further, it was assumed that a spill clean-up cost per ton of ULSFO or VLSFO is the same as for HFO.

In order to exemplify the potential reduction in magnitude of possible accident scenarios, 3 possible cases with different HFO vessels currently populating the area were calculated and tabulated Table 1-2.

Table 1-2 Potential cost reduction with fuel alternatives to HFO

Vessel type	Fuel spill (ton HFO)	Clean-up cost reduction with VLSFO / ULSFO (US$)	Clean-up cost reduction with distillate (US$)
Bulk carrier	160	-	3.6 mill
Reefer	160	-	3.6 mill
Cruise	1 700	-	38.0 mill

1.2.3 Potential changes in oil recovery contingency

The Norwegian Coastal Administration (NCA) is responsible for any oil recovery contingency for Norwegian sea and land areas. Oil booms dedicated for Arctic climate are currently stationed onboard the coastguard vessel MV Svalbard as well as in storage in Vadsø and Horten. With the emerging new LSFO oils, NCA is adamant that this will require additional investments for research and testing in order to better understand the behaviour and fate of these oil qualities in cold climate and ice. This will apply to the use of skimmers, pumps, dispersants as well as booms.

With this in mind, an increased need for investment in oil recovery contingency may be expected in the near future. Following interviews with representatives from the NCA, they consider it unlikely that this will change with a future HFO ban in the Arctic waters provided the hybrid LSFO oils are potentially accepted under the ban.

1.3 Incident study – HFO vessels versus distillate vessels drifting in Norwegian waters

DNV GL has been requested to perform an additional task to what is defined in the IMO document PPR 6/20/Add.1 Annex 16. This is to evaluate the available statistics on drifting vessels in Norwegian waters collected by the Norwegian Coastal Administration as part of their VTS-service and determine if any relationships can be established between recorded engine failures and the use of residual fuel versus distillate fuel.

Looking into the statistical material, it was investigated whether an HFO fuelled vessel will likely experience engine failure with subsequent drifting more frequently than a vessel using distillate fuels.

However, several steps in the analysis include assumptions that carry uncertainties such as a lack of details in the statistical material to establish if the machine failure is fuel related or related to other causes. Neither is it possible to be sure on the actual fuel type used at the time of failure as most vessels will be switching fuels relative to regulatory area.

Based on the available data, DNV GL do not find it possible to conclude that ships using HFO as fuel experience engine problems more frequently than vessels using distillate fuels.

1.4 Conclusions

Depending on price differentials amongst the new fuel blends introduced with the upcoming 0.5% sulphur cap (January 1st, 2020), and consequently their market penetration, we may end up with a fuel mix with similar, or worse, environmental implications in case of an accident spill to sea. Therefore, in DNV GL's view, it is uncertain whether the proposed ban's definition of heavy fuel oil (as defined under the IMO/MARPOL for Antarctica) is well suited to ensure an actual and significant reduction in the environmental risk, compared with the baseline scenario from 2020 without a ban. It is therefore important to closely monitor the development and uptake of the new fuel blends in order to identify the residual fuel definition that not only fulfil the goals an Arctic HFO-ban, but also limit emissions to air and the risks posed by oil spills to the Arctic waters.

If the ban includes all residual fuel blends, as imposed from 2015 in the national parks at Svalbard, a significant environmental risk reduction may be expected.

Taking into account the cost of adapting some of the vessels to alternatives to HFO, expected added direct fuel cost and the subsequent effect of increased prices for cruise passengers, an HFO ban will still likely only have minor economic effects on the Norwegian regional economy. This is mainly so because of the very few HFO vessels found to be trading with the Norwegian communities in the Arctic

Following the new fuel situation in 2020, an increased need for investment in oil recovery contingency may be expected in the coming years due to requirements for research and development of new abatement technologies. This is particularly so for oil spill in polar waters. It is considered unlikely that this situation will change with a future HFO ban in the Arctic waters, provided the hybrid LSFO oils are potentially accepted and used under the ban. Hence, it may be concluded that it is unlikely that an HFO ban in the Arctic waters in the form currently proposed will reduce the oil recovery contingency cost in the near future.

2 INTRODUCTION

This report is commissioned by The Norwegian Maritime Authority in response to an invitation from the IMO sub-committee Pollution Prevention and Response (PPR). It has been financed by the Arctic funds from the Norwegian Ministry of Foreign Affairs.

The International Maritime Organization (IMO) has identified that the risks of possible fuel oil spills by ships that use and carry heavy fuel oil (HFO) for use as fuel in the Arctic waters is a significant threat to the Arctic Marine environment. Future ship traffic in Arctic waters is projected to rise, thus increasing the likelihood of oil spills and associated impacts on the Arctic environments, indigenous and local communities, industries and economies. As HFO is more persistent than other fuels when spilled, it poses an increased hazard to the Arctic environment and is more challenging and costly to clean up.

To mitigate the risks of such harmful spills, a ban on HFO use and carriage as fuel by ships in Arctic waters, has been proposed. The IMO intends to assess several possible measures to meet these objectives, both in terms of economic, societal and environmental impact, but also how well they meet the policy objective.

The report attempts to analyse and give an overview of the economic and environmental consequences of a ban on HFO fuels in the Norwegian Arctic waters. The report also examines the effects of a potential oil spill in the Norwegian Arctic waters.

Chapter 1 summarizes the findings and conclusions in an executive summary. Chapter 2 introduces the problem and the topic for the report, whilst Chapter 3 outlines the method, scope and assumptions for the analysis. Chapter 4 gives an introduction to the implications of the regulations that enter in to force in 2020. It also includes an overview over relevant existing HFO regulations. Chapter 5 describes the ports, communities and vessel demography in the Norwegian Arctic. This includes an analysis of data on which vessels that operate in the Norwegian Arctic waters and what fuel they run on. Chapter 6 identifies and estimates the additional costs related to an HFO-ban in the Norwegian Arctic area, and Chapter 7 identifies and discusses the potential benefits to communities and the ecosystems of an HFO-ban. An oil spill risk assessment and an evaluation of the environmental effects of an oil spill in the Norwegian Arctic waters is also part of Chapter 7. Chapter 8 gives a short conclusion based on the discussions and findings in the report.

3 SCOPE, METHOD AND ASSUMPTIONS

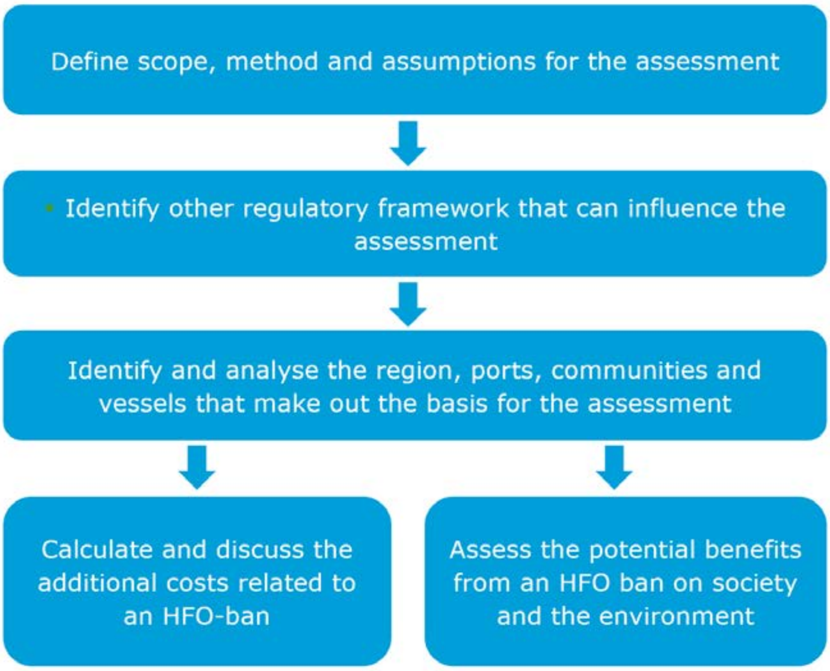
The report follows the methodology and the structure described in the IMO document PPR 6/20/Add.1 Annex 16. The purpose of the report is to estimate the effects on Norwegian Arctic communities and industries of a ban on heavy fuel oil use by ships in Arctic waters and the associated costs and benefits of an HFO ban to indigenous and local communities, industries, economies and the coastal and marine ecosystems of the Arctic. The report also aims to assess whether an HFO-ban will fulfil its policy aim.

Based on the identified maritime activities in the region, an economic and environmental impact analysis is performed to identify the potential costs and benefits of an HFO-ban. Such an analysis assesses the effects of a measure or an initiative compared to a baseline scenario. This report uses 2020 as the baseline scenario. This implies that the HFO-ban is analysed and compared to a 2020 situation without an HFO-ban. Costs, regulations and activities in the baseline scenario therefore follow the projected prices and regulations that are expected to be in effect in 2020. This includes the global 0.5 % sulphur cap and fuel prices that are in line with expected 2020 prices.

This report only estimates the immediate short-term effects of an HFO-ban in 2020. This is because most of the effects of a ban will be transitional and temporary. Stakeholders and parties in the Norwegian Arctic area can, and would gradually adapt to, an HFO ban and other regulation and market developments.

The four steps in the prescribed methodology are outlined as follows: Step 1 determines the area and demography that this report focuses on. It also includes a short introduction to the implications associated with the global sulphur cap that will enter into force 1st January 2020. Step 2 and 3 assess the additional costs and potential benefits related to a sulphur cap and the HFO-ban and whether the HFO-ban fulfils its policy objective of reducing the risk of an HFO spill from ships in the Norwegian Arctic waters as well as reducing the environmental risk in the fragile Arctic environments. Step 4 includes options for postponements of the HFO ban implementation given criteria not relevant for Norway, and this section is consequently not considered further. The structure of the report is illustrated in Figure 3-1.

Figure 3-1 Structure of the report.



3.1 Step 1 – Determining the area and demography

3.1.1 Scope

This study encompasses the Norwegian Arctic area. This includes the islands and archipelagos of Svalbard, Jan Mayen, Bjørnøya, Hopen and the part of the Barents Sea which falls within the IMO Polar Code definition of the Arctic as shown in Figure 5-1. Within this area the existing ports, their role in the local community as well as the traffic in and out of these ports are identified.

3.1.2 Method

In order to establish information of the population and economy at Svalbard, data from Statistics Norway was acquired and processed.

In order to establish a picture of the traffic in and out of the ports, the ship demography in the region is identified based on AIS data from 2018. These datapoints are connected to a multitude of different data sets in order to establish as complete a picture as possible including identifying the vessels with their parameters and the vessels which are using HFO as fuel. This includes using flag state databases, Class data, Safe Sea Net (Norwegian Coastal Administration, 2019), machinery data for each individual vessel as well as contacting the operators of a specific vessel whenever relevant.

The HFO vessels are categorized into vessels mainly using HFO and vessels with scrubber installed (allowing for HFO use also after the global 0.5% sulphur cap). The HFO vessels are categorized based on a methodology developed in conjunction with earlier studies carried out for PAME, (Martinsen, Endresen, & Mjelde, Alternative fuels in the Arctic, 2019) and (Martinsen, HFO in the Arctic - Phase II, 2013). This is further addressed in Chapter 5.

3.1.3 Assumptions

Only ports facilitating HFO ships are followed up with further analyses with respect to the economic impact of a ban. Any local bunkering facilities will also be discussed with respect to implications of a future HFO ban. In order to assess this, it is considered pertinent to use the new fuel situation introduced January 1st, 2020 with the global 0.5% sulphur cap, as the baseline scenario to compare a future HFO ban to. This means that the emerging fuel situation will be instrumental for how a future HFO ban is addressed in this study. Since there are no indigenous populations within the Norwegian Arctic, the potential impact on such population from ship traffic as well as their communities and industries are not discussed.

3.2 Step 2 – Assessing additional costs from an HFO-ban

For each identified community, potentially affected by a an HFO ban identified in Step 1, it is evaluated whether, and to what degree, the local economy is affected.

3.2.1 Scope

Whether the local economy is affected by an HFO-ban is directly tied to what extent they currently rely upon HFO-fuelled ships or facilities in the community. Introducing an HFO-ban for the vessels serving the community with transport of goods and general services, can involve additional costs if the vessel is forced to use more costly fuel types. This part of the study uses data from the Step 1 to assess the additional costs associated with an HFO-ban wherever relevant.

3.2.2 Method

The likely additional costs associated with an HFO ban, such as additional fuel costs, one-time costs as a result of alterations to ships and infrastructure and cost associated with de-bunkering, are identified and evaluated in terms of how they will affect local expenses, pricing of goods and other economic activity such as imports and exports. Potential modal shifts (e.g. from sea to air) are also considered.

The costs associated with an HFO ban is compared to a baseline scenario as described above. The costs are given in 2020 NOKs, and currency rates from the Norwegian central bank are used when necessary. The 0.5% sulphur cap implemented in 2020 will make a big impact on the global fuel market and introduces huge uncertainties regarding fuel qualities as well as pricing at the time of writing of this report. Three different sensitivities with different fuel switches are therefore included to illustrate the width of possible outcomes associated with an HFO-ban that is implemented after the 2020 sulphur cap is included.

3.2.3 Assumptions

The costs are given in 2020 USDs, and currency rates from the Norwegian central bank are used when necessary. Since the spot and future prices of different types of fuel have fluctuated a lot over the last months, a monthly average of September 2019 Rotterdam prices for the relevant fuels are used in the assessment. These assessments are addressed in Chapter 6.

3.3 Step 3 – Assessment of potential benefits to the society and the environment

The main driver behind introducing a ban on the use of HFO in the Arctic is the assumption that the society and the environment will benefit from a reduced risk of heavy oil spill to sea in the vulnerable Arctic communities and nature. Step 3 assesses whether this is a likely outcome of an HFO-ban.

3.3.1 Scope

This report assesses both the potential monetary and non-monetary benefits from having non-HFO spills rather than HFO spills in line with a baseline and HFO-ban scenario. In addition, it is assessed how low sulphur fuel oils, hybrid fuel oils and MGOs compare in this context. This relates to the assumed reduced clean-up costs in case of an accident with HFO spills, reduced emergency response readiness requirements as well as the potential loss of natural resources and impact on local activities.

3.3.2 Method

The global sulphur cap will result in a dramatic change in the fuel composition, also for Arctic shipping. Instrumental for this analysis is how the new VLSFO and ULSFO fuel types, resulting from the sulphur caps, perform when spilled to cold Arctic waters. Little research has been carried out regarding this, but the few studies done, will drive the conclusions in this part of the study.

The maritime AIS-based risk analysis system AISyRisk is used to establish the risk of ship accidents based on the 2018 traffic in the region. This will highlight the areas at risk. One possible scenario with a ship accident leading to an HFO oil spill is also assessed with respect to differences in abatement cost and oil contingency services.

Step 3 assesses whether an HFO-ban will have an effect on the potential risks and costs associated with marine accidents in the Norwegian Arctic waters. As in step 2, the baseline scenario is 2020 with a global sulphur cap that has entered in to force. As in Step 2, the HFO-ban is assessed in light of what fuel switches the fleet in the Norwegian Arctic waters make. This is further addressed in Chapter 7.

3.3.3 Assumptions

Challenges related to indigenous populations and cultures are not relevant for the Norwegian Arctic as there are no indigenous populations living in the area.

3.4 Step 4 – Other factors

In the methodology described in the IMO document PPR 6/20/Add.1 Annex 16, there is a Step 4 related to other factors indicating potentials for states to delay the implementation of a ban for vessels fulfilling certain criteria. In case of Norway, none of this is considered to be of relevance because there are no Norwegian vessels in regular traffic using HFO, and no critical supply chains are dependent on HFO ships. Finally, there are fuel alternatives to HFO readily available.

4 REGULATORY INFLUENCES ON FUEL

What the baseline situation for fuel will be when a future HFO ban is introduced in the Arctic region is likely dramatically different from the current situation. This is due to the IMO-imposed sulphur cap introduced in 2020. Hence, when introducing a future HFO ban in the Arctic (MARPOL Annex I Regulation 43), this will have to be compared to a new baseline situation bringing a series of uncertainties.

4.1 Future fuel types

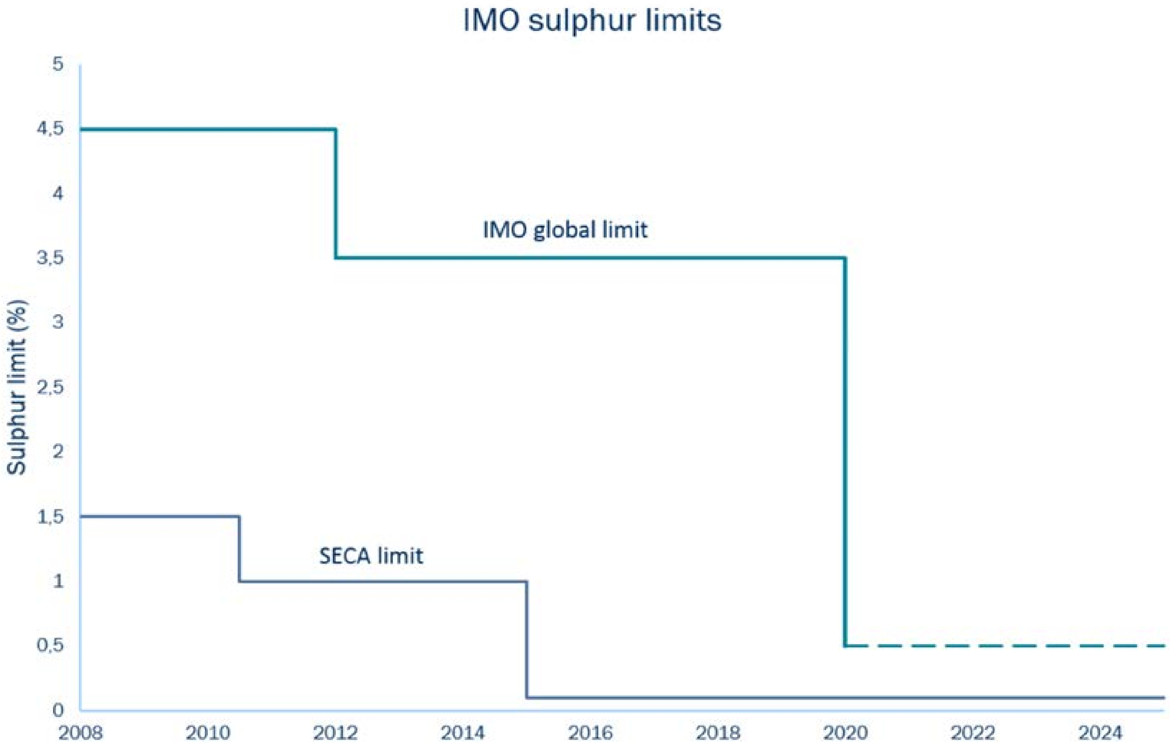


Figure 4-1 - Sulphur limits introduced by IMO according to MARPOL Annex V (WIN GD, 2019)).

Following the introduction of the Emission Control Area (ECA) sulphur cap of 0.1% in 2015, the fuel suppliers quickly responded with a residual fuel blend complying with the new sulphur limit typically referred to as ULSFO. As of 1st January 2020, a global 0.5 % sulphur cap for marine fuel oil will enter into force, as shown in Figure 4.1 above.

- VLSFO up to 0.50 % S content; and
- HSFO for scrubber operation with a sulphur content up to 3.50 % (or even higher).

Most fuels used in the market after 1st January 2020 will be VLSFO, as only a small percentage of the fleet is expected to be equipped with scrubbers and therefore able to operate on HSFO as before. Based on world order reserve less than 4 000 vessels with scrubber are projected in 2023[1].

The scrubber systems have been developed and employed to treat exhaust from engines, auxiliary engines and boilers, onshore and onboard marine vessels, to ensure that a vessel will remain in compliance with the MARPOL Convention introducing a sulphur cap of 0.5% after January 1st, 2020.

[1] https://afi.dnvgl.com/Statistics?repId=2

The switch to VLSFO will affect refineries production as it is unlikely that HFO products in use today will simply be desulphurised to create compliant fuels. Instead, VLSFO will consist of blends of fuels produced from different refineries' streams. These blends are expected to contain higher fractions of paraffinic products, which will affect the properties of VLSFO and also potentially problematic qualities when spilled to the sea (Fritt-Rasmussen, Wegeberg, Gustavsson, & Sørheim, 2018).

Table 4-1 under shows a naming convention which has been used by the industry to describe the new fuel alternatives entering the market in 2020. Figure 4-2 shows how the different fuels are a result of the distillation process.

Table 4-1 – fuel type and naming convention after January 1st 2020.

Sulphur content	HFO / IFO (RM-fuel)	Sulphur content	HFO / IFO (RM-fuel)
$S \leqslant 0.10$ %	ULSFO RM	ULSFO DM	$S \leqslant 0.10$ %
$0.10 \% < S \leqslant 0.50$ %	VLSFO RM	VLSFO DM	$0.10 \% < S \leqslant 0.50$ %
$0.50 \% < S$	HSFO RM	HSFO DM	$0.50 \% < S$

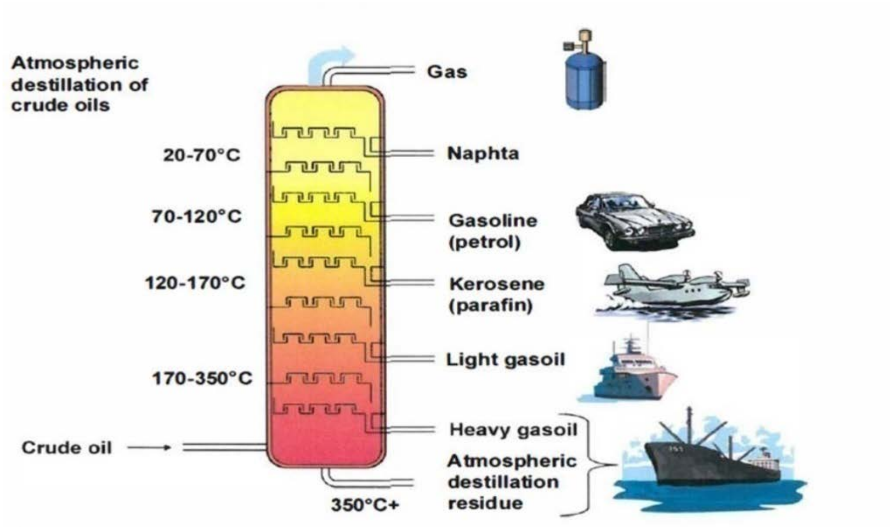


Figure 4-2 – Example of a distillation process of crude oil including non-distillable residue (WIN GD, 2019).

4.1.1 Compliance of future fuel types with an HFO ban

There are a lot of uncertainties linked to the properties of the currently available hybrid fuels such as VLSFO and ULSFO, and what kind of fuels will be offered in the future. VLSFO fuels will generally have properties that make them non-compliant with an HFO-ban as per the current MARPOL regulations for Antarctica. Refineries can however blend a VLSFO which is compliant, should there be a marked for it. This is already the case for some HFO-ban compliant ULSFO qualities. There are however large uncertainties related to both the availability and cost for these fuels.

One consequence of these uncertainties is that some vessels might choose to switch fuels directly to MGO with the introduction of the sulphur cap or an HFO-ban. MGO has several preferred properties to hybrid fuels, and it is only marginally more expensive. In the analysis in Chapter 7 of the additional costs related to a potential HFO-ban, it is however assumed that the vessel operators choose the cheapest available fuel both in the 2020 baseline and the HFO-ban scenario.

4.1.2 The future prices of the fuel alternatives available

The sulphur cap is expected to have significant effects on the global fuel markets, both in terms of prices and the kind of fuels that are offered.

Table 4-2 shows the prices of different types of fuel that are used to estimate costs of a fuel ban in Chapter 7. The prices are based on the September 2019 monthly average of spot prices on the different fuel types in Rotterdam.

Table 4-2 Fuel price comparison.

Fuel type	Price (USD/ton)
HFO	338
VLSFO	527
ULSFO	553
MGO	633

Source: (Ship and Bunker, 2019), (Shipping Intelligence Network, 2019).

This monthly average is used since the future prices for 2020 and the differences between them (spreads) fluctuate a lot. These fluctuations are present because it is expected that demand for MGO will increase considerably, and demand for HFO will fall (KECH, 2019). Both will be used to blend new hybrid fuels, but it is not yet certain how quickly the markets will react and adapt to the sulphur cap. Towards 2021, the markets and spreads stabilise at a level which is relatively close to what they are today. Due to the expected development in demand, it may be that the HFO-price could have been somewhat lower and the VLSFO-price higher, but the purpose of these prices is predominantly to give an indication of what the long-term differences between the fuel types will be.

4.1.3 LNG as an alternative

In the study called "Alternative fuels in the Arctic" (Martinsen, Endresen, & Mjelde, Alternative fuels in the Arctic, 2019) DNV GL ranked 11 different fuel alternatives with respect to their environmental performance as well as economic and scalability potential. The study ended up ranking LNG as best suited fuel for Arctic operation. Currently, 32 LNG cruise vessels are on order[2], and it is reasonable to expect that within a few years, this fleet of vessels will make an impact on the Svalbard cruise traffic too. Even if LNG in itself eliminates oil spill risk, most LNG installations for larger vessels (including cruise vessels) are dual-fuel systems. Thus, the fact that they may operate on LNG does not rule out the possibility for carrying and using oil-based fuel and hence still posing an environmental treat in case of an accident.

4.2 Environmental considerations

The switch to VLSFO will affect refineries' production as it is unlikely that HFO products in use today will simply be desulphurised to create compliant fuels. Instead, VLSFO will consist of blends of fuels produced from different refineries' streams which will affect the properties of VLSFO. It is important to state that VLSFO must be compliant with ISO 8217:2017 (ISO, 2017) and fit within the same RM grades as used before 2020. However, fuels of the same ISO grade may show a high variability in other characteristics such as viscosity and specific density. This variation is potentially instrumental for the evaluation of the environmental impact of a future HFO ban. This is because it implies that the HFO definition proposed used for the HFO regulation in the Arctic (like for the Antarctica in MARPOL) will not

[2] https://afi.dnvgl.com/Statistics?repId=1

necessarily limit the use of residual fuel qualities, with potentially equally problematic qualities as HFO when spilled to the Arctic water (Fritt-Rasmussen, Wegeberg, Gustavsson, & Sørheim, 2018).

4.3 Other relevant fuel regulations

4.3.1 The Antarctic HFO fuel ban

Since 2010 IMO regulates the use of HFO fuel in the Antarctic through MARPOL Annex I Regulation 43 that prohibits the use of residual fuels. Residual fuels being defined as follows:

- Crude oils having a density at 15°C; higher than 900 kg/m3;
- Oils, other than crude oils, having a density at 15°C higher than 900 kg/m3, or a kinematic viscosity at 50°C higher than 180 mm2/s; or
- Bitumen, tar and their emulsions.

In connection with the ban in the Arctic, the second bullet in the list above is also the working definition used. The IMO sub-committee on Pollution Prevention and Response (PPR) is instructed to propose a final definition, but this work is currently not completed.

4.3.2 The current ban in the National Parks of Svalbard

Svalbard and the Norwegian Arctic regions as defined in the IMO Polar Code are today regulated by a Heavy Fuel Oil (HFO) ban within certain controlled areas as governed under Norwegian regulations *FOR-2014-04-04-337*.

The National parks are included under the current ban including (marked green in Figure 4-3) Sør-Spitsbergen nasjonalpark, Forlandet nasjonalpark and Nordvest-Spitsbergen nasjonalpark.

Ships entering the national parks shall not use or carry fuel other than DMA compliant fuel (distillate) in accordance with ISO 8217:2017 standard, see (ISO, 2017). This restriction does not apply for the shortest route possible through the following areas:

- The north-western most part of Sør-Spitsbergen nasjonalpark to- and from Sveagruva.
- The northern most part of Forlandet nasjonalpark and the southernmost part of Nordvest-Spitsbergen nasjonalpark to- and from Ny-Ålesund until 1. January 2015.
- Nordvest-Spitsbergen nasjonalpark to- and from Magdalenefjorden until 1. January 2015.

The Nature reserves under the current ban include (marked red in Figure 4-3):

- Nordaust-Svalbard naturreservat
- Søraust-Svalbard naturreservat

In addition, ships entering the reserves shall not use or bring onboard fuel other than DMA compliant fuel in accordance with ISO 8217 standard (see Appendix A). Further, ships in these reserves shall not carry more than 200 passengers onboard.

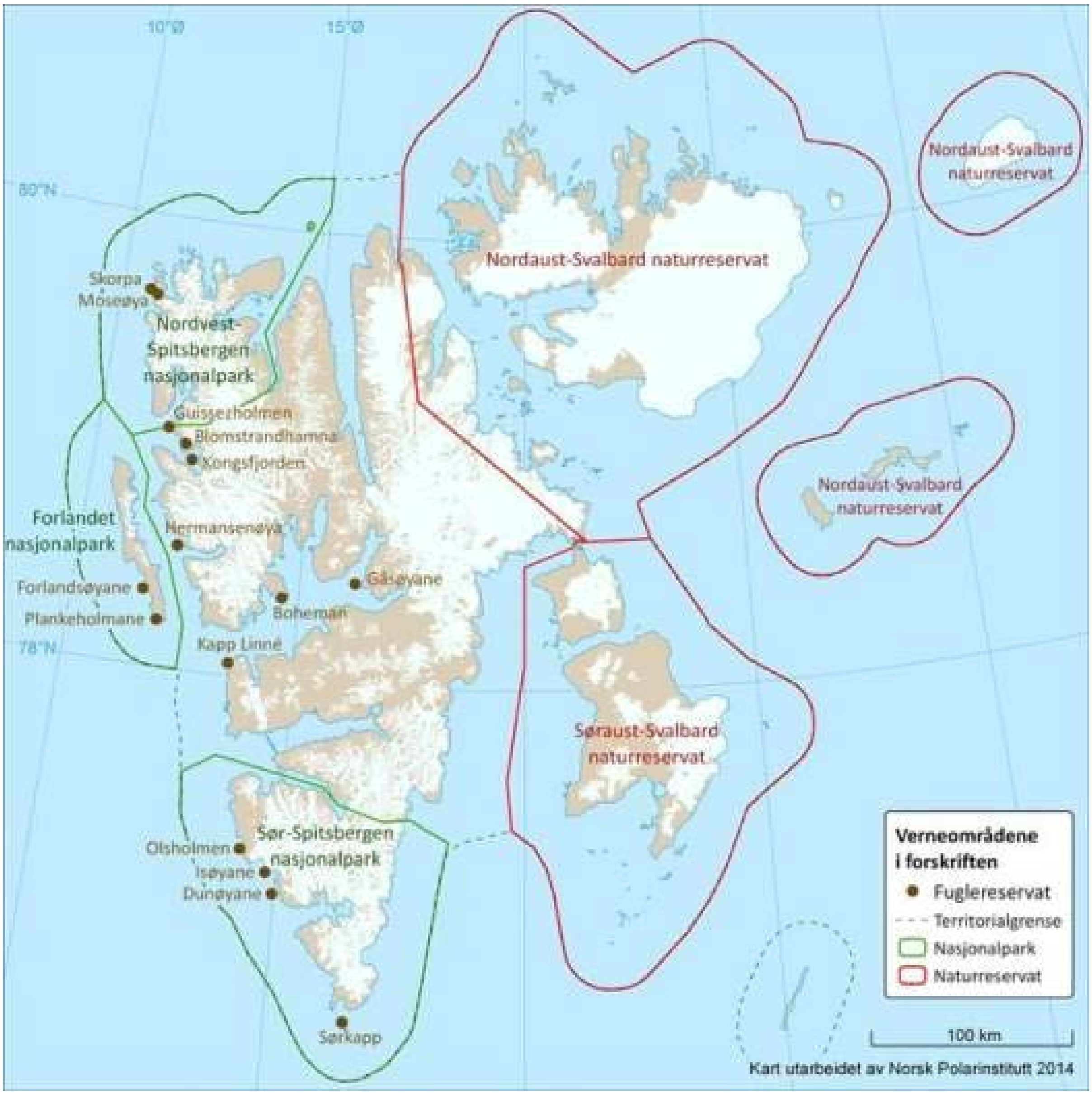


Figure 4-3 - The Svalbard special protection areas.

5 PORTS, COMMUNITIES AND VESSEL DEMOGRAPHY IN THE NORWEGIAN ARCTIC

5.1 Communities and ports in the Norwegian Arctic

Norwegian communities in the Arctic are geographically spread between the Islands Hopen, Bjørnøya, Jan Mayen and Svalbard, with only the latter being more than mere research stations. Hence, a diversified community is only found at Svalbard where Longyearbyen and Ny Ålesund are the main settlements. Figure 5-1 below shows the Norwegian Arctic area as defined in this study, as well as the ship density in the region. Since this data shows the the HFO vessels only enter Svalbard and the Port of Longyear, Bjørnøya, Hopen and Jan Mayen are not included in the analysis assessing the effects of an HDO ban. The economic effects for the ports and settlements in Ny-Ålesund and Barentsburg are only analysed through the maritime traffic to Port of Longyear.

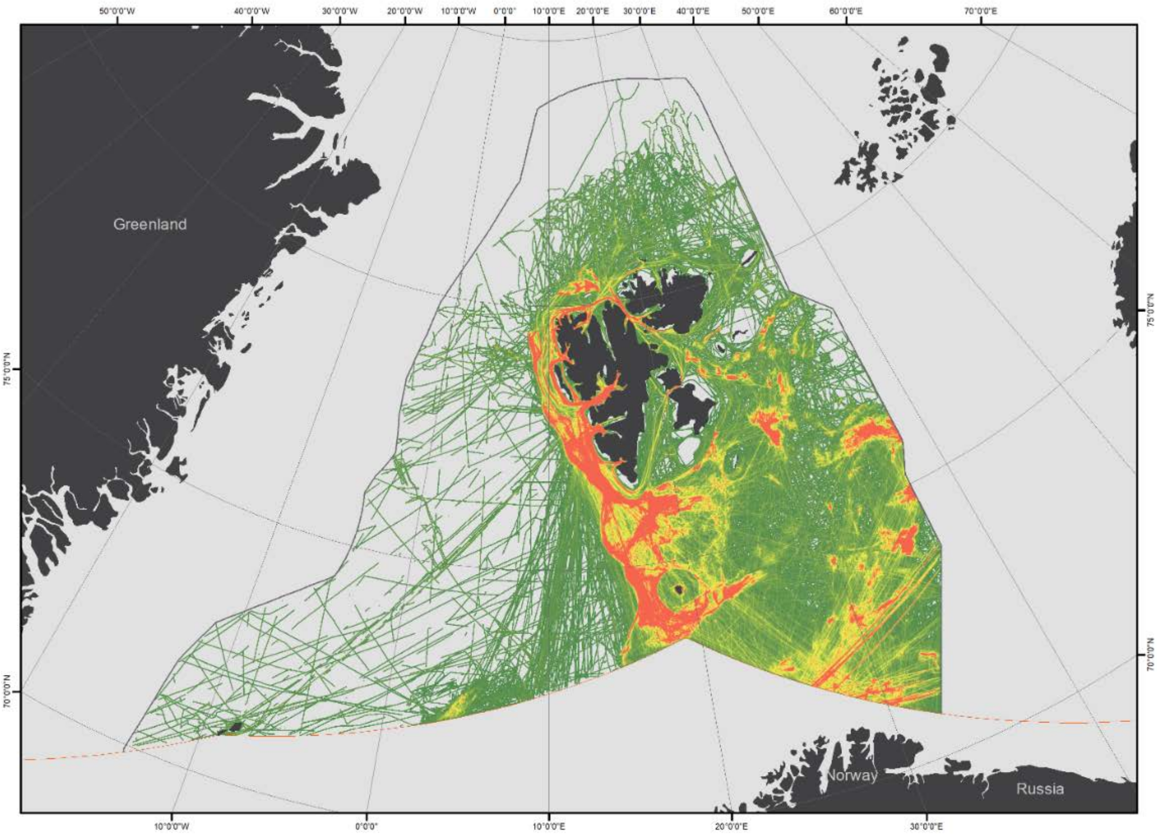


Figure 5-1 – The Norwegian Arctic area as defined for this study – showing ship density (fuel consumption) of all vessels in the Norwegian Arctic – 2018.

5.1.1 The Norwegian Arctic economy and Svalbard

Svalbard is a part of the Kingdom of Norway and its largest town and port is Longyearbyen. Most of Svalbard's Norwegian population lives here, and the vast majority of commerce, trade and economic activity is based in close proximity to Longyearbyen.

Svalbard has a special strategic and geopolitical position and is governed according to the Svalbard treaty. The treaty states that all signatories of the treaty can engage in commercial activities on the island. Currently, Norway and Russia exercise this right. Barentsburg is a Russian settlement in the Island and is assumed to be outside the scope of this analysis.

Maintaining Norwegian civilian settlements in Svalbard is an important political objective for the Norwegian government. Economic activity is important to fulfil this objective. In 2019, the population in the Svalbard archipelago counted 2 258 people.

In 2018, the Svalbard area had a total turnover of almost 3.6 billion NOK employing over 1 600 full time equivalents. The largest industries in terms of employment are within public administration and services, the service and retail sector, construction, cultural activities and mining. During the last decade the economy of Svalbard has seen a development towards reduced mining activity and a shift towards tourism, culture and research and development which these statistics demonstrate.

Table 5-1 Turnover and full-time equivalent employment in Svalbard, 2018.

Sector	Turnover (NOK 1 000)	Full time equivalents
Svalbard total	**3 589 525**	**1 625**
Mining and quarrying	161 067	113
Manufacturing	204 808	59
Construction	588 538	182
Wholesale and retail trade: repair of motor vehicles	381 008	110
Transportation and storage	303 837	96
Accommodation and food service activities	415 556	274
Information and communication	615 074	61
Real estate activities	85 650	11
Professional, scientific and technical activities	36 541	64
Administrative and support service activities	413 126	180
Public administration and defence	197 158	120
Education	61 962	166
Human health and social work activities	13 196	60
Arts, entertainment and recreation	106 704	119
Other service activities	5 300	9

Source: Statistics Norway, 2018 [3]

Historically, coal mining has been the main occupation in the area, but as the political support and business case for coal mining is fading, this development is encouraged by the Norwegian state. In November 2019, a new strategy for innovation and business development was published by the Norwegian Ministry of Industries and Fisheries. This strategy confirms the long-term goals for the Svalbard policy, but also points in what direction the economy in Svalbard can develop.

The strategy highlights that the Norwegian government will facilitate a development towards a society in Svalbard with more activity and business that leads to a diversified, knowledge-based and sustainable economy. Business development in Svalbard should preferably be focused around stable, all-year round activity, that is economically viable and that maintains the natural values in the area without straining the available infrastructure and services. New areas of economic activity could be within innovation and

[3] https://www.regjeringen.no/globalassets/departementene/nfd/dokumenter/strategier/innovasjon-og-naringsutvikling-pa-svalbard.pdf
https://www.ssb.no/en/virksomheter-foretak-og-regnskap/statistikker/sts
https://www.nav.no/en/Home/Benefits+and+services/Relatert+informasjon/work-and-residence-on-svalbard

knowledge-based development in cooperation with existing businesses in Svalbard or in mainland Norway, digitalization and testing of new technologies and products, aerospace industries and communications as well as growth in sustainable tourism.

5.1.2 Local fuelling facilities

Longyearbyen port only has fuelling facilities for MGO. However, there are numerous ships that perform ship-to-ship (STS) operations in the region. This includes product tankers that offer both distillate and HFO fuels for refuelling. These services mostly take place in Bellsundet, which is in Isfjorden close to Longyearbyen, but also takes place in other areas in the region.

5.2 The current fleet populating the region

When going through the available AIS-data for the Norwegian Arctic from 2018, Table 5-2 and Figure 5-2 clearly shows that amongst the 610 registered vessels, the relatively smaller vessels are dominating, and fishing vessels in particular.

Table 5-2 Vessels in the Norwegian Arctic – 2018.

Row Labels	1. < 1000 GT	2. 1000 - 4999 GT	3. 5000 - 9999 GT	4. 10000 - 24999 GT	5. 25000 - 49999 GT	6. 50000 - 99999 GT	7. >= 100000 GT	Grand Total
02 - Chemical tankers		5		10	5			20
03 - Gas tankers		1					14	15
04 - Bulk carriers				24	24	4		52
05 - General cargo ships	3	23	14	9	6			55
06 - Container ships				1	2	1		4
08 - Refrigerated cargo ships		10	8					18
10 - Offshore supply ships	1	11	9					21
11 - Other service offshore vessels	2	2	1				1	6
12 - Other activities	27	23	13	4	2			69
13 - Fishing vessels	104	166	8					278
14 - Crude oil tankers					3	11	1	15
15 - Oil product tankers		5	1	3				9
16 - Passenger ships	7	3			1			11
17 - Cruise ships	5	6	5	5	10	5	1	37
Grand Total	149	255	59	56	53	21	17	610

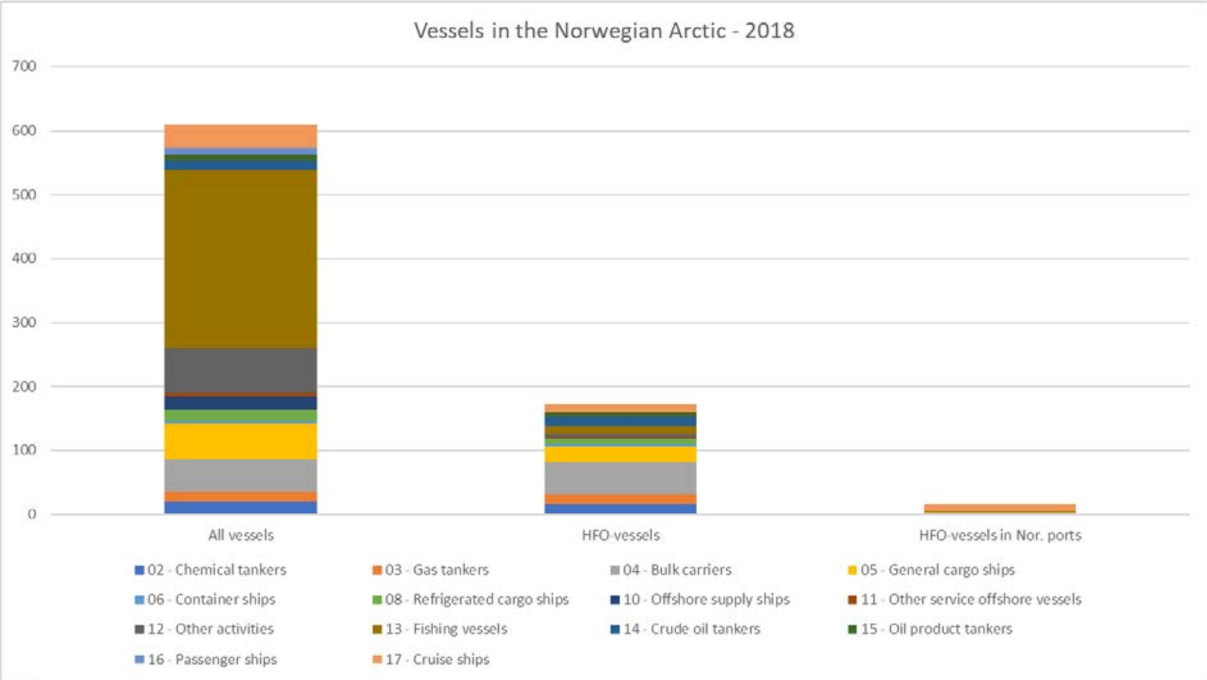


Figure 5-2 Number of unique vessels in the Norwegian Arctic 2018.

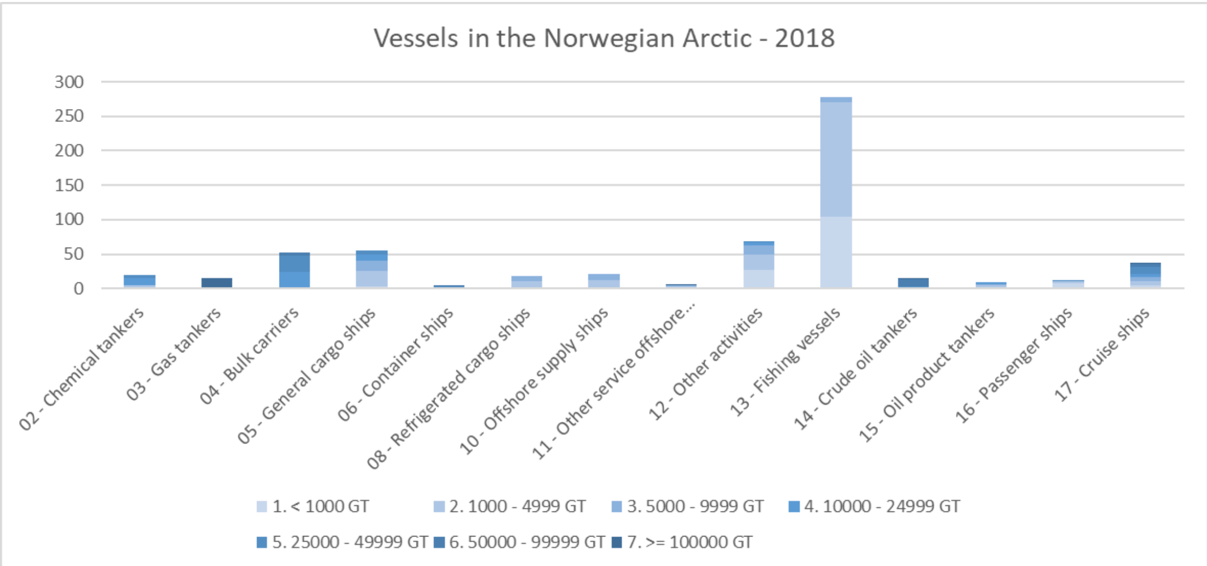


Figure 5-3 Vessels in the Norwegian Arctic – 2018.

5.2.1 HFO-vessels and their trading patterns

The vessels identified as HFO vessels in the material are, as opposed to the general fleet found in the region, consisting of the larger inter-continental cargo vessels (bulk, tank and container) mainly passing through the region in the south-east, see Figure 5-3.

As seen in Table 5-2 another major vessel group is the large cruise vessels visiting Isfjorden/Longyearbyen as part of a 14-16 days round-trip with a base in Germany or the UK. There are also a few reefers loading fish and bulk carriers shipping coal from Longyearbyen that use HFO as fuel. Figure 5-3 also shows that the HFO-vessels avoid the areas currently affected by the Svalbard HFO ban imposed in the national parks (see Section 4.3.1). None of the vessels identified as HFO vessels sail under Norwegian flag.

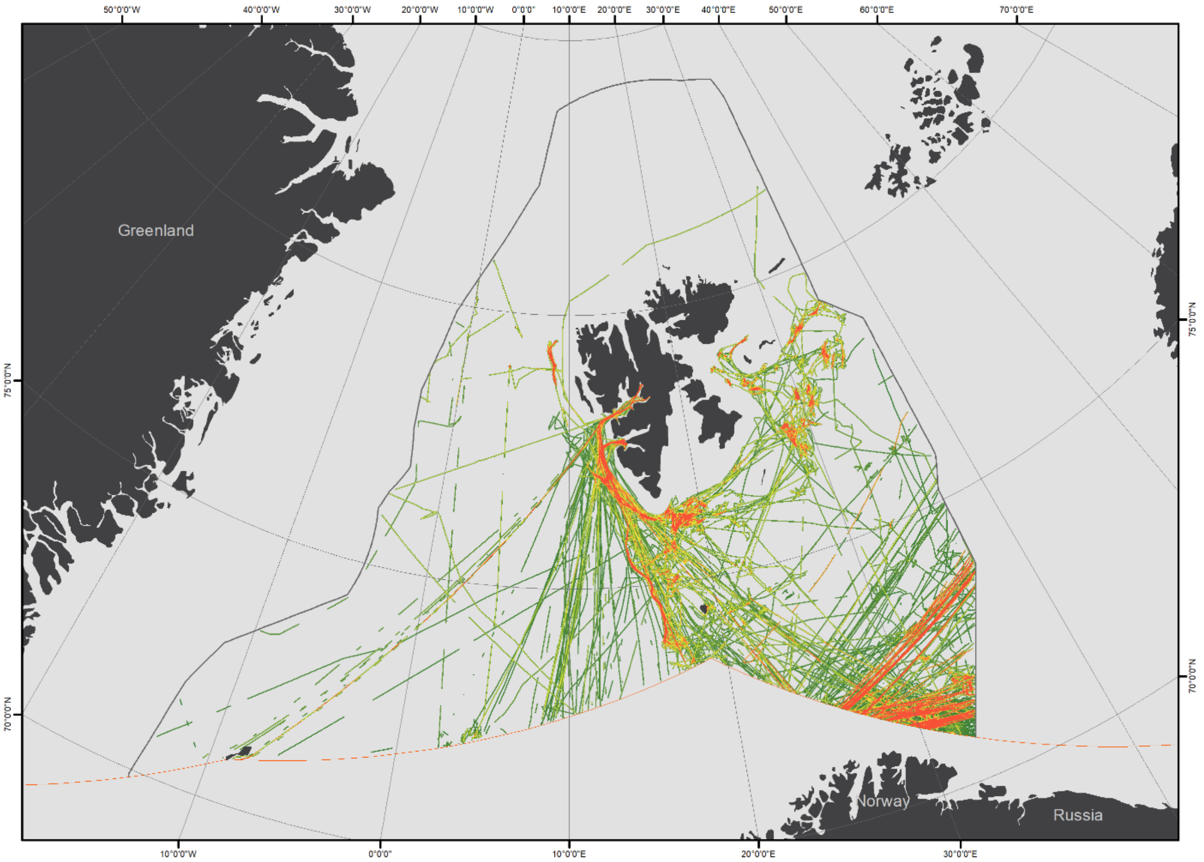


Figure 5-4 - Vessels operating on HFO in the Norwegian Arctic in 2018.

Table 5-3 Vessels in the Norwegian Arctic – fuel and trades - 2018.

Vessel type	All vessels	HFO-vessels	HFO-vessels in Nor. ports	Vessels with scrubbers
02 - Chemical tankers	20	16	0	0
03 - Gas tankers	15	15	0	0
04 - Bulk carriers	52	51	1	2
05 - General cargo ships	55	24	3	0
06 - Container ships	4	4	0	0
08 - Refrigerated cargo ships	18	9	0	0
10 - Offshore supply ships	21	0	0	0
11 - Other service offshore vessels	6	1	0	0
12 - Other activities	69	6	1	0
13 - Fishing vessels	278	12	0	0
14 - Crude oil tankers	15	15	0	0
15 - Oil product tankers	9	6	0	0
16 - Passenger ships	11	1	0	0
17 - Cruise ships	37	12	12	8
Grand Total	**610**	**172**	**17**	**10**

As illustrated in Table 5-3, only 17 HFO vessels enter Norwegian ports, and Longyearbyen is the only port visited. HFO vessels pass by Bjørnøya and Jan Mayen, and some of the HFO cruise vessels stop outside Jan Mayen. There are also signs of ship-to-ship operations outside Bjørnøya between HFO-reefers and product tankers and fishing vessels leeward of the island, but it is assumed that none of this is related to local trading and economy as there is no commercial activities based on the islands.

5.2.2 Vessels with scrubbers installed

According to the DNV GL operated database *Alternative Fuel Insight Platform* (DNV GL, 2019), ten of the identified vessels in the Norwegian Arctic waters are identified as vessels with scrubber installed. Two of these are relatively large bulk carriers passing through the south east corner of the Norwegian Arctic waters whereas the remaining eight are cruise vessels, all entering the Isfjord and Longyearbyen (see Table 5-3).

The fact that the identified vessels have installed scrubbers indicate that they are planning on continuing their use of traditional HFO after 2020, and not the "hybrid" low sulphur fuel (LSFO) that vessels without a scrubber will likely be using.

5.2.3 Fuel consumption and composition in the Norwegian Arctic 2018

Table 5-4 below shows how the fuel consumption within the region is distributed, and also how the fuel mix is shared between the different vessel types. The largest group of vessels in the Norwegian Arctic is with a good margin the fishing fleet. They also contribute to more than half of the total fuel consumption, but very little to the use of HFO. The second biggest consumers are the cruise vessels of which around 40% is running on HFO. This is also the vessel category that may be most affected by the future HFO-ban in the region, even though some operators already are following a self-imposed HFO ban within the Arctic (fuel use, they will still have HFO in the fuel tanks). The largest HFO users within the region are the large gas tankers passing through the south-eastern part to and from the Russian gas fields.

Table 5-4 Fuel consumption in the Norwegian Arctic – 2018 – Distillate vs. HFO.

	Distillate	HFO	Grand Total	% Distillate	% HFO
02 - Chemical tankers	450	1 040	1 490	30 %	70 %
03 - Gas tankers	0	10 730	10 730	0 %	100 %
04 - Bulk carriers	200	1 440	1 640	12 %	88 %
05 - General cargo ships	1 180	650	1 830	64 %	36 %
06 - Container ships	0	70	70	0 %	100 %
08 - Refrigerated cargo ships	1 030	2 910	3 940	26 %	74 %
10 - Offshore supply ships	1 390	0	1 390	100 %	0 %
11 - Other service offshore vessels	120	0	120	100 %	0 %
12 - Other activities	7 210	1 810	9 020	80 %	20 %
13 - Fishing vessels	51 200	2 680	53 880	95 %	5 %
14 - Crude oil tankers	0	120	120	0 %	100 %
15 - Oil product tankers	1 040	160	1 200	87 %	13 %
16 - Passenger ships	1 810	170	1 990	91 %	9 %
17 - Cruise ships	7 740	4 720	12 450	62 %	38 %
Grand Total	**73 370**	**26 500**	**99 870**	**73 %**	**27 %**

5.3 The vessel categories operating patterns and ports visited

The ship traffic within the Norwegian Arctic waters is conveniently grouped into four main categories.

5.3.1 The fishing vessels

The fishing vessels are by far the most numerous vessels identified and are found in most parts of the region as shown in Figure 5-5. Out of 278 fishing vessels, 126 were Norwegian. 12 of the fishing vessels in the region used HFO as fuel, but none of these were Norwegian. None of the HFO-using fishing vessels were found to enter any of the regional ports during 2018. As Svalbard does not have any fuelling facilities for HFO or fish processing industry, this is expected.

Some of the fishing vessels do however meet up with reefers for offloading of cargo, or with product tankers for bunkering in Bellsund, south of Isfjorden, before continuing fishing. The costs for the ships offering ship-to-ship (STS) operations may be affected by the HFO-ban, which in turn could increase the prices for the vessels buying STS-operations. It has however not been possible to confirm whether any Norwegian ships regularly buy such STS-services from HFO-run vessels. It is therefore assumed that if these transactions were to exist, the associated costs are marginal.

Since the economic impact of an HFO-ban on the Norwegian fishing industry in the Arctic is considered to be minimal, the subsequent costs are assumed to be close to zero and may be ignored in the economic assessment.

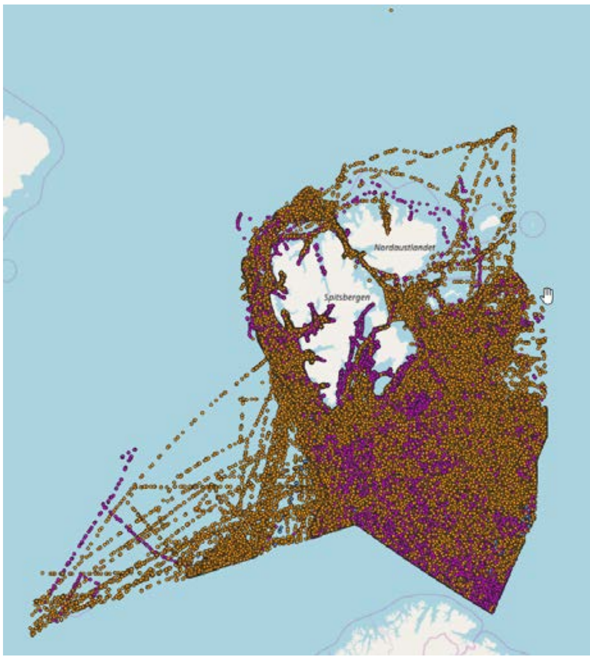


Figure 5-5 Fishing vessels in the Norwegian Arctic.

5.3.2 The inter-continental cargo vessels

The large inter-continental cargo vessels (tankers and bulk carriers) are all HFO users and are only found in the south-eastern corner of the region in their way to/from Russian Arctic ports or along the Northern Sea Route. Nearly all vessels in this category are identified as HFO-vessels, but none are entering the regional ports, see Figure 5-6.

Figure 5-6 Inter-continental cargo vessels.

Even though grounding is less likely due to these vessels distance to land, they may still pose a risk for spills of heavy fuel oil to the sea through collision, foundering and fire. This is more closely discussed in Chapter 7.

5.3.3 Cruise and passenger vessels

The cruise and passenger vessels are numerous and may be sorted in three groups. The first group consists of large cruise vessels (operating on HFO) typically make a 14-16 days round-trip including a short 15 hours stop in Svalbard. The vessels enter the Isfjord and Barentsburg/Longyearbyen where they are not limited by the current HFO-ban in the national parks as shown in Figure 5-7. There are also smaller cruise and passenger vessels that use distillate fuels allowing them to sail all around the Svalbard archipelago during the summer season. Finally, there is a group of small vessels taking tourists around the Isfjord and into the national parks. None of these are using HFO.

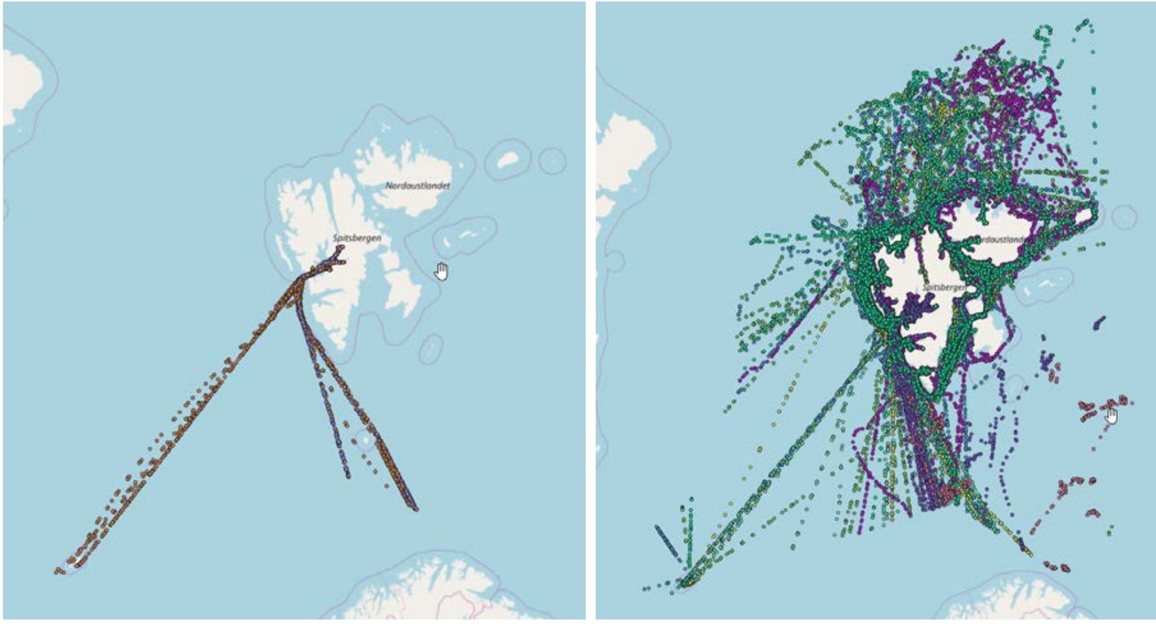


Figure 5-7 Cruise vessels in the Norwegian Arctic – 2018. Large vessels left, medium size and small to the right.

5.3.4 Small wet/dry bulk, general cargo and reefer vessels

The final group consists of relatively small wet/dry bulk carriers, general cargo vessels and reefers. Quite a few of these use HFO, but only a small portion of these provide services to the region.

Only four of the HFO-vessels within this group are identified as entering any Norwegian ports; three general cargo vessels and one bulk carrier. A cost assessment of an HFO-ban for this vessel group is found in Chapter 6.1.

The bulk carrier transports coal from Longyearbyen to the Central Europe with typically four shipments yearly. The three general cargo vessels are all what may be referred to as “stray” vessels that have only visited the port once. In relation to this, port Longyear also claims that 95% of the general cargo arrives on one MGO vessel with a regular 10-days schedule.

Amongst this group of vessels are also a group of vessels providing ship-to-ship (STS) services at several locations around the Svalbard archipelago mostly to fishing vessels. Their economic impact is discussed above under fishing vessels.

The potential costs associated with an HFO-ban for the remaining vessels in this group are consequently overlooked as they are assumed to be non-existent.

6 ADDITIONAL COSTS AS A RESULT OF AN HFO-BAN IN THE NORWEGIAN ARCTIC

This chapter estimates and discusses the additional costs and reduced income for Norwegian interests related to an HFO-ban in the Norwegian Arctic waters. The starting point and baseline scenario for the analysis is 2020, after the introduction of the global 0.5% sulphur cap. This, together with the maritime industry's drive towards de-carbonization, introduces a lot of uncertainties related to fuel pricing and availability, as well as the composition of technology and fuel choices.

The additional costs estimated and analysed in this chapter are related to the increase in operating and one-time costs for the vessels that are identified to interact with the Norwegian economy. What effect these increased costs can have for the Norwegian Arctic economy in general is also analysed and discussed.

The direct increase in operating and one-time costs for the vessels are based on the estimated increase in fuel costs and the number of trips the vessels make to Svalbard. De-bunkering costs, which consists of emptying the fuel tank and cleaning it, are added per trip. The one-time costs are added as the yearly cost of a down payment.

The effect of these direct costs have on the Norwegian Arctic economy is then discussed. Relevant problems can be whether the vessel operators or the Norwegian customers must carry the increased costs, and whether there may be modal shifts or other developments that can mitigate the effect the increase in operating and one-time costs have on the Norwegian Arctic economy. A summary of the additional costs that have been identified are found in Section 6.4.

6.1 Additional operating costs and one-time costs

When an HFO-ban is introduced, the consequences for the maritime fleet will firstly affect operating costs such as fuel costs and de-bunkering costs. Depending on what the baseline fuel is and what fuels the vessels switch to, one-time investment costs may also occur.

The analysis of the additional operating costs and onetime costs associated with an HFO-ban, uses the vessels identified in Chapter 5. In 2018, there were 172 ships in the Norwegian Arctic waters that ran on HFO, but the analysis conducted on these vessels concluded that only 13 of them had a significance for the Norwegian Arctic economy. These 13 ships consist of the following:

- 8 large cruise vessels with scrubbers
- 4 large cruise vessels without scrubbers
- 1 bulk carrier without a scrubber

The following economic analysis assumes that these 13 vessels will continue operating in the Norwegian Arctic waters in 2020 and that they will run on a baseline fuel (LSFO) that is compliant with the 0.5% sulphur cap.

6.1.1 Additional operating costs for the identified vessels affected by an HFO-ban

With the introduction of an arctic HFO-ban, the increase in operating costs will vary substantially depending on vessel type, operations and energy solutions onboard. It will also depend on the technology and fuel choices made by the vessel operators in order to be compliant with the 2020 sulphur cap.

In the analysis it is assumed that the identified HFO-vessels will meet the 0.5% sulphur cap by choosing the most cost-effective technologies or fuels available in the baseline scenario. This implies the following for the 13 identified ships representing the baseline scenario in this assessment:

- The 4 large cruise vessels and 1 bulk vessel will use a VLSFO fuel in the baseline scenario. The 8 large cruise vessels with scrubbers will still continue using HFO. Estimating the costs associated with an HFO-ban involves a series of uncertainties linked to both the prices and properties of the available fuel types in relation to the implementation of the 2020 sulphur cap. This is discussed more in detail in Chapter 4.1.1.
- Because of these uncertainties, the estimated costs of an HFO-ban are calculated with three different alternative fuel switches. The objective of including these alternatives is threefold. Firstly, it gives an indication of how the associated costs of an HFO-ban can vary with the definition of HFO used in the ban. Secondly, it shows how the properties of the different fuels available on the market can affect the costs of an HFO-ban. Thirdly the alternatives also show what happens if the new fuel types are not readily available for the relevant ships.

The three different alternatives make the following assumptions:

- The VLSFO alternative assumes that VLSFO fuel is compliant with the HFO-ban and is commercially available for all the vessels operating in the region.
- The ULSFO alternative assumes that all vessels will have to switch to an ULSFO fuel to be compliant with an HFO-ban. It is also assumed that ULSFO is available for all the relevant vessels. The VLSFO fuel types can in this alternative either be understood as non-compliant or not readily available for the relevant vessels.
- The MGO alternative assumes that the ships must switch to a distillate fuel. This could either be because the HFO-ban has a strict definition of HFO, or because neither VLSFO or ULSFO fuels are available for the relevant vessels in the analysis.

6.1.1.1 Fuel price

The fuel costs that the cost calculations are based on, consists of the monthly average of the spot prices for the relevant fuel in Rotterdam. A more detailed discussion on future fuel prices is found in Chapter 4.1.2.

Figure 6-1 below show the increase in fuel cost in USD/ton for the different fuel switch alternatives. In the VLSFO alternative (switch from HFO to VLSFO), the cruise ships with scrubbers that run on HFO in the baseline scenario will get a fuel cost increase of almost 250 USD per ton. The cruise and bulk ships that do not have scrubbers and run on VLSFO in the baseline scenario, will experience no increase in fuel costs. For the MGO alternative, the cruise ships with scrubbers will experience an increase in fuel costs of roughly 250 USD/ton. For the bulk vessel and the cruise ships without scrubber, the increase would be approximately 60 USD/ton.

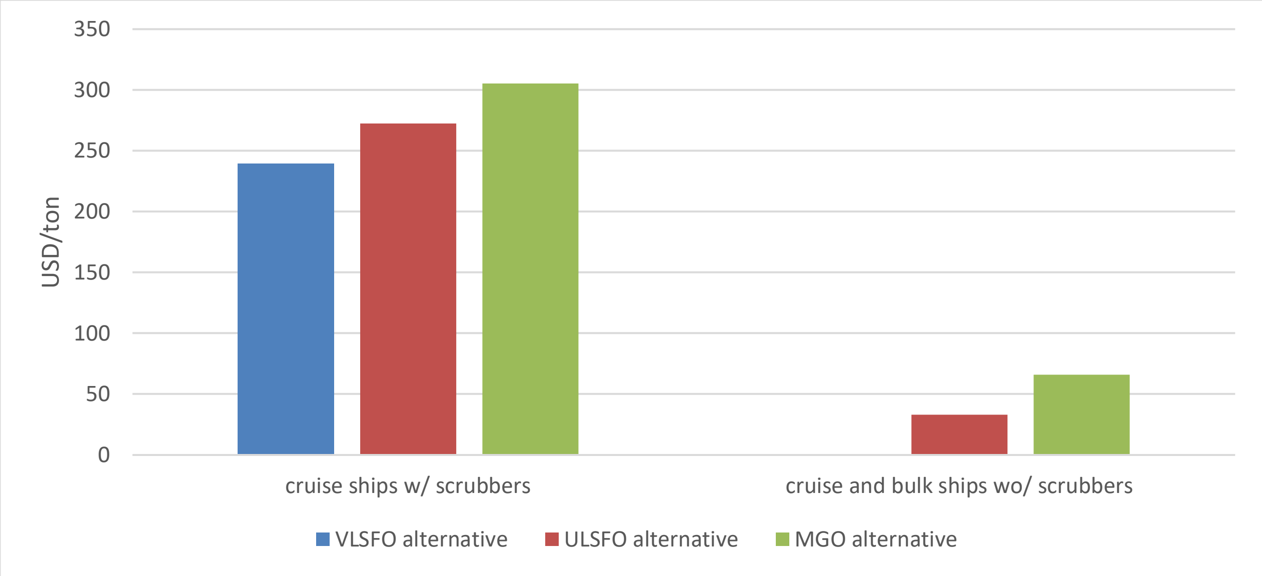


Figure 6-1 Increase in fuel costs (USD/ton) for the current HFO-vessels from the 2020 baseline scenario. The increase in fuel costs are given for the three different fuel switch alternatives.

6.1.1.2 De-bunkering costs

De-bunkering costs are relevant for all vessels in conjunction with switching the content of fuel tanks in order to ensure that the fuel carried is in accordance with regulations. This comprises emptying the respective tank, steam clean and then remove wash-outs/residues. An HFO vessel sporadically entering the Arctic waters following an HFO ban, may have to perform such an operation.

In the analysis it is assumed that de-bunkering has a cost of 20 000 USD. All the relevant vessels in the analysis are assumed to operate in other regions in between the trips made to Svalbard.

The de-bunkering costs are included in the calculations on the increase in operating costs for the different sectors below.

6.1.1.3 One-time costs

Switching from HFO to a hybrid fuel like VLSFO or ULSFO is not considered to require significant investments for retrofitting or any other one-time costs. Some parts in older vessels may however need some maintenance prior to a switch. Associated costs are considered to be minimal and are consequently not included in the calculations for the analysis.

If a vessel has to switch from HFO or a similar VLSFO hybrid fuel to a distillate fuel, there may however be some investment costs needed to adapt the power plants and fuel system in the vessel for a distillate fuel quality. This includes installing heat exchangers (for cooling of the distillate), and gaskets and pumps that can handle lower viscosity fuels.

The cargo vessel identified is on the other hand considered not to be prepared for distillate use and thus a cost for the operator of 15 000 USD is assumed in the analysis. This one-time cost is relevant for the calculation of the increased costs for the coal and mining industry.

6.1.2 Additional operating and one-time costs for Norwegian vessels

The data in Chapter 5 reveals that none of the identified HFO-vessels operating in the Norwegian Arctic waters have Norwegian Arctic ports as their home port or are sailing under a Norwegian flag. Therefore, it is assumed that there are no additional Norwegian fuel, de-bunkering or one-time costs associated with an HFO-ban in the Norwegian Arctic area.

The increased operating costs for HFO vessels may however affect the Norwegian Arctic economy indirectly through the mining and tourism industry. These effects are further described below.

6.2 Economic impact on the tourism and cruise industry

The tourism industry at Svalbard has grown considerably over the last decade with an increase in turnover of almost 80% (Statistics Norway, 2019). In 2018, more than 45 000 cruise tourists arrived by large HFO using cruise vessels to Svalbard. They carry many passengers at a time and normally only stay in Port Longyear for less than a day. As the AIS data in Chapter 5 shows, these cruise vessels make up the majority of the identified HFO vessels in ports in the Norwegian Arctic in 2018.

A typical sailing route for these vessels is a round-trip that starts in Germany or the UK. They then move along the coast of Norway to Svalbard, and return via Iceland, see Figure 6-2. The whole trip lasts typically 14-16 days. In a situation with an Arctic HFO-ban, it is not practically or economically viable for these vessels to empty their HFO-tanks and then clean and re-fill with alternative fuel during a cruise. Therefore, when an Arctic HFO-ban is introduced, the entire round-trip is likely to be operated with Arctic-compliant fuels, with added de-bunkering costs for each trip, assuming the next trip is outside the Arctic.

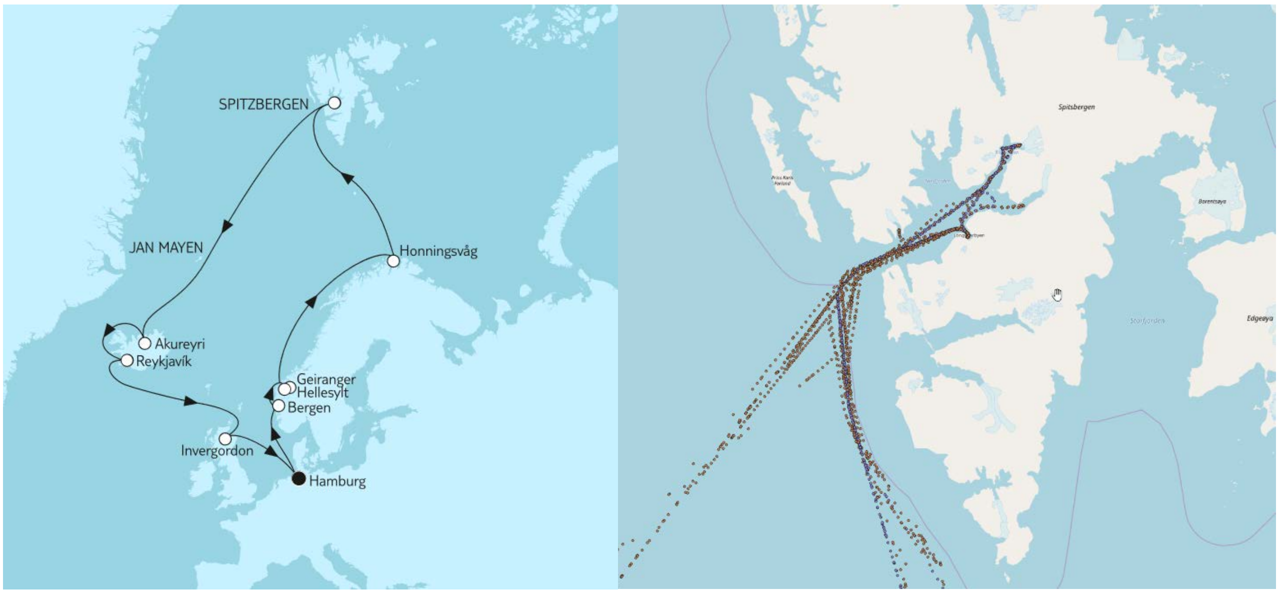


Figure 6-2 To the left: A typical sailing route to Svalbard for the large cruise vessels. To the right: Sailing pattern of the large cruise vessels in Svalbard, 2018.

Source: (Epinion, 2019)

6.2.1 Potential cost increase for cruise operators and effect on cruise tourism

Based on information from Visit Svalbard, there were 27 large cruise vessel visits to Port Longyear in 2018 split between 12 large cruise vessels whereof 8 had scrubbers.

Table 6-1 shows the increase in fuel and de-bunkering costs in NOK, and the effect on total operating costs in percent for the different cruise vessels and fuel switch alternatives. From the table it is clear that the increase in fuel and de-bunkering costs of an HFO-ban will be much higher for the scrubber cruise vessels having to move from low cost HFO to more expensive hybrid fuel or distillates.

Assuming that fuel costs constitute around 20 percent of total operating costs[4], the increase in total operating costs for a cruise roundtrip is estimated to vary between 12-18%. For the cruise vessels without scrubbers, the estimated increase will only be between 0-5%. The weighted average increase in operating costs for the cruise operators is 7-12% depending on fuel switch alternative.

Table 6-1 Increase in annual fuel costs and percentage points increase in operating costs for the selected vessels with and without scrubbers. The numbers are given for the three fuel switch alternatives. USD rounded off to nearest 10 000.

	VLSFO-alternative	ULSFO-alternative	MGO-alternative
Cruise vessels w/ scrubbers	5 670 0000	6 390 000	8 630 000
	12%	14%	18%
Cruise vessels wo/ scrubbers	0	550 000	1 670 000
	0%	1%	5%
Total weighted average	5 670 000	6 940 000	10 300 000
	7%	8%	12%

A report written by Epinion for Visit Svalbard and AECO (Epinion, 2019) has estimated that the average sum that a conventional cruise tourist spends at Svalbard is 810 NOK per day. This number is adjusted for price inflation towards 2020 in the calculations.

Port Longyear has 28 large cruise vessel arrivals confirmed in 2020. This gives an estimated 46 760 cruise tourists based on historic figures. This then gives an expected turnover from conventional cruise tourists of nearly 40 million NOK in 2020. This is the equivalent of approximately 4.4 million USDs.

When an Arctic HFO-ban is introduced, one can assume that this figure can decrease depending on the fuel switch alternative and how price sensitive the cruise tourists are.

A report written by Epinion for Innovation Norway (Epinion, 2017) maps out how content cruise tourists are with their stay in Svalbard based on interviews with 925 tourists in the summer months of 2017. 82% of the tourists say that it was important for them that Svalbard was a destination when they chose the cruise they were on. A majority of the cruise tourists also booked the cruise the year before. These findings imply that price sensitivity is fairly low for this group of cruise passengers.

Langenfeld and Li (2008) finds that the elasticity of price insensitive customers in the cruise industry is -1.2. This implies that with a one percent increase in prices, a 1.2 decrease in demand would follow. Applying these findings on the cruise traffic in Svalbard, means that an HFO-ban could entail a decrease in cruise traffic to Svalbard of 8-15 per cent, see Table 6-2. For the Norwegian Arctic cruise tourism industry, this could result in reduced income of between approximately 350 000 and 660 000 USD.

[4] Total operating costs also includes expenses such as employee salaries, maintenance, purchased goods etc.

Table 6-2 Estimated percentage point decrease in cruise traffic and reduced annual income for the cruise tourism sector. USD, rounded up to nearest 10 000.

	VLSFO-alternative	ULSFO-alternative	MGO-alternative
Percentage increase in operating costs for the cruise operators	7%	8%	12%
Percentage reduced cruise traffic to Svalbard	8%	10%	15%
Reduced income for the cruise tourism sector	350 000	440 000	660 000

6.2.1 Alternative strategies and modal shifts

There are several ways in which the indirect costs of an HFO-ban for cruise tourism can be mitigated.

The companies that operate the cruise ships could choose to move around their fleet so that ships that did not have scrubbers before the HFO-ban and operated elsewhere, start to operate in the Norwegian Arctic waters instead. This could shift the potential costs over to cruise tourists in other regions.

Modal shifts can also contribute to reducing the impact of the increase in operating costs. It is likely that with a lower price gap between conventional cruise fares on one side, and airfares, and other kinds of tourism such as local expedition cruises and land-based options on the other, some of the traditional cruise passengers can choose other options instead of conventional cruises as they become relatively cheaper.

Land-based and expedition cruise tourists often stay longer than the cruise tourists' part of a round-trip cruise, which means that they also spend more money on local goods and services. For example, according to the Epinion 2019 report, the estimated local daily income from an expedition cruise passenger is around 5 times that of a traditional cruise passenger.

In total, and at least in the medium to long term, these shifts can contribute significantly to mitigate or offset the immediate reduction in income for the cruise tourism industry.

6.3 Economic impact on mining and coal exports

Svalbard has historically relied upon coal mining as its main source of economic activity. It remains a considerable sector in the area today. In 2018 Store Norske Spitsbergen Kullkompani (SNSK) had an economic turnover of 383 million NOK and exported approximately 120 000 tons of coal, most of it of industrial quality, (Det Store Norske Spitsbergen Kulkompani AS, 2018).

To export these quantities, SNSK mostly relies on bulk vessels currently running on HFO to transport the coal to the markets. When the Arctic HFO-ban is introduced, SNSK will most likely have to carry the increased transport costs themselves, as the international market for industrial coal is large and their sales prices to regular customers are based on historic prices.

As the coal from SNSK is sold to the European markets, it is likely that the baseline 2020 fuel for the relevant cargo vessel is VLSFO. The increase in fuel and de-bunkering costs for the different fuel switch alternatives are shown in Table 6-3. Because cargo vessels are quite fuel efficient, the de-bunkering costs has a much larger impact on the increase in operating costs than the increased fuel costs. The one-time cost of a heat exchanger of approximately 15 000 USD is added to the estimation by calculating a yearly down payment[5].

[5] The yearly down payment sum is calculated with an interest of 6 % over 20 years.

The estimated additional costs for the mining industry associated with an HFO-ban is between 0 and 100 000 USD. This reflects the increase in fuel costs, de-bunkering costs and yearly down payment costs of a one-time investment in the MGO-alternative.

Table 6-3 Estimated annual cost increase for the mining sector and percentage point increase in fuel costs for the relevant bunk vessel. USD, rounded off to nearest 10 000.

	VLSFO-alternative	ULSFO-alternative	MGO-alternative
Cost increase for the mining sector	0	80 000	100 000
Percentage point increase in fuel costs	0%	105%	120%

6.4 Summary

Table 6-4 gives an overview over the estimated costs associated with an HFO-ban for the Norwegian Arctic waters, presented with the three different fuel switch alternatives. The alternatives show how the sectors are affected by different kinds of fuel switches.

In total, an HFO-ban could constitute an estimated annual cost for the Norwegian Arctic area of between 350 000 and 760 000 USD.

Table 6-4 Estimated annual additional costs and reduced income of a potential HFO-ban. USD, rounded off to nearest 10 000.

	VLSFO alternative	ULSFO alternative	MGO alternative
Operating and one-time costs, Norwegian fleet*	**0**	**0**	**0**
Cruise and tourism industry	**350 000***	**440 000**	**660 000**
Mining and coal exports	**0**	**80 000**	**100 000**
TOTAL	350 000	520 000	760 000

* No Norwegian vessels are identified as HFO users

7 POTENTIAL BENEFITS TO THE SOCIETY AND THE ENVIRONMENT

In this chapter the monetary and non-monetary benefits of an HFO ban in the form proposed will be discussed and evaluated. The potential effects of an HFO spill in way of impact on marine and coastal ecosystems are also discussed. Instrumental for this discussion is also what will likely replace the current HFO fuel with an introduction of an HFO ban and how this ties up with the up-coming global sulphur cap introduced in 2020.

7.1 The drivers towards a ban

The main driver for introducing a ban on the use of heavy fuel oil in the Arctic is the assumption that the society and the environment will benefit from reduced risk from oil spills to sea in the vulnerable Arctic communities and nature, compared to the situation without such a ban.

Discharges of oil to sea pose environmental risks, both in case of residual fuels (heavy oils and various intermediate and blend products) or distillate fuels (diesel, such as MGO). Although environmental risks depends on environmental conditions and the actual oil spill characteristics, it has traditionally been assumed that discharges of distillate fuel represent, in most cases, lower environmental risk than residual fuel oils. This is primarily because the distillates more efficiently evaporate to the atmosphere or mix and dilute in the water masses. However, the damage potential can still be high, for instance with respect to toxicity to marine organisms.

The heavy oil grades (residual fuels) are viscous and, unlike the distillates, will not efficiently evaporate or be exposed to natural dispersion. Instead large oil slicks may be drifting (in emulsion with water) over long distances, providing damage potential for the water surface, water column, sediments, shore lines, and ice edge. The impacts from the oil spill will depend on the oil spill response effectiveness which is extremely challenging under artic conditions because of cold temperatures, ice and fog, reduced daylight hours and site remoteness.

Heavy fuel oil spills usually also require extensive and costly collection and clean-up efforts. For instance, recently (Delft, 2018) published calculations indicating that clean-up costs that accrue in case of an oil spill are significantly lower if MGO (or a ban-compliant fuel) was spilled instead of a low sulphur HFO (LSHFO). The study estimated the clean-up costs saved to amount to between 3.4 and 45 million USD (LSHFO spill) for one bunker fuel spill. The socio-economic and environmental damage costs in case of an oil spill will also be reduced.

7.2 The fuel alternatives after 2020

The identified direct benefits from an Arctic HFO-ban are related to the effects it can have on the oil spill risk, and the avoided environmental and monetary cost of those spills introduced by an enforced ban.

With the base year for this analysis being 2020, after the introduction of the global 0.5% sulphur cap, the likely fuel composition (without an HFO-ban) in the Norwegian Arctic waters will be VLSFO or ULSFO for most of the current HFO vessels. The vessels with installed exhaust cleaning (scrubber) will continue using HFO, whereas the vast majority of ships using distillate, will continue using distillate. Hence, the situation at which a future HFO ban will be introduced is different from the current situation, and potentially, only the relatively few vessels with a scrubber installed (total of 10 out of the 610 vessels observed in the Norwegian Arctic waters), may be directly affected by the proposed ban.

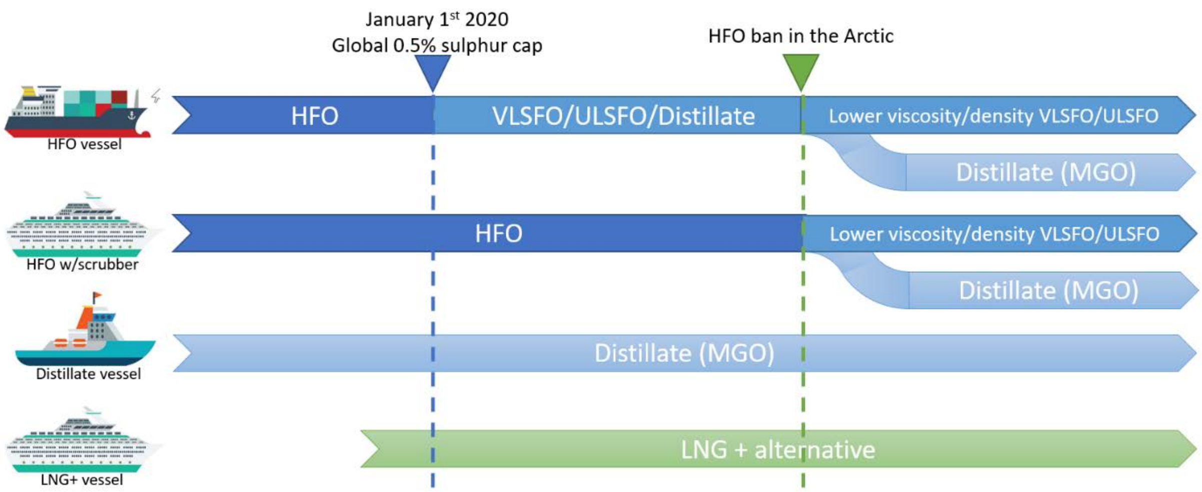


Figure 7-1 - Fuel alternatives following the global sulphur cap and a potential HFO ban.

Figure 7-1 shows how the 2020 0.5% sulphur cap and an HFO ban may change the fuel choices used in the Norwegian Arctic waters for the different fuel users found in the region:

- The traditional HFO vessels will have to comply with the global 0.5% sulphur cap from 2020. This will lead to a likely switch to LSFO fuel (but potentially also distillates). With an HFO-ban in the Arctic, the main change for these ships will be that some of the LSFO types (both max 0.5% and 0.1% sulphur) will likely be allowed under the current Antarctic working definition, even though they will contain residual oil products and potentially have problematic qualities when spilled to cold water.
- Ships meeting the sulphur cap by using exhaust gas treatment systems (SO_x-scrubbers), can continue operation with traditional HFO in the Norwegian Arctic waters, had an HFO-ban not been implemented. This option encompasses the majority (8 out of 10) of the large cruise ships visiting Longyearbyen. Although an HFO ban will force such ships away from traditional heavy fuel oil, the impact on environmental risk is uncertain as long as we do not know whether they will switch to distillate fuel (for instance MGO), or VLSFO/ULSFO, with uncertain effect on environmental risk. A likely outcome is also that the cruise ship operators will re-distribute their scrubber vessels to other areas and use vessels without scrubbers for the Arctic waters.
- The majority of the current vessels in the Arctic waters are already using distillate fuels that are compliant with both ECA-requirements, the new global sulphur cap and any type of HFO ban.

7.3 HFO oil spill risk assessments

The work process for oil spill risk assessments begins with hazard identification and likelihood analysis, including selecting scenarios for assessing environmental risks. This is followed by a mapping of the local ecological and socioeconomic resources potentially affected by an accidental spill, and an assessment of the consequences and risk to these resources. Once the main risk drivers have been identified, analyses can further assist in evaluating both risk-reducing and mitigating measures to ensure a tolerable risk level.

Together with the Norwegian Coastal Administration, DNV GL has over the last three years developed the ship traffic risk model “AISyRisk”. The probabilities and consequences for collisions (head-on, overtaking and crossing), grounding (powered and drifting), fire and foundering are calculated, and risk is expressed in terms of potential for loss of life and acute oil spill. This enables the calculation of the risk of accidents for every single vessel individually. This requires huge computational power but is also a far more accurate and flexible method compared to using aggregated data as has been the tradition up to now. The main goal with the development has been to establish a long-term, sustainable collection of data on ship traffic and navigation risk for Norwegian waters.

According to the statistical AISyRisk model, an accident within the Norwegian Arctic waters involving an HFO vessel is likely to happen every 20 years. It is however important to note that far from all ship accidents will lead to bunker spill to sea. The system calculates that the most likely return period of such an accident is up to 350 years. It should be noted however that several of the distinctive risk parameters to Arctic ship operation such as ice, darkness, quality of mapping and availability of rescue services is not part of the assessment. Hence, the actual risk situation is likely to be underestimated.

Figure 7-2 under shows the identified hotspots within the Arctic waters with the outer parts of Bellsundet with the highest calculated risk of an HFO oil spill to sea. This is related to the relatively many ship-to-ship operations carried out between HFO fuelled reefers and the fishing fleet as well as the bunkering operations carried out by the HFO fuelled product tankers.

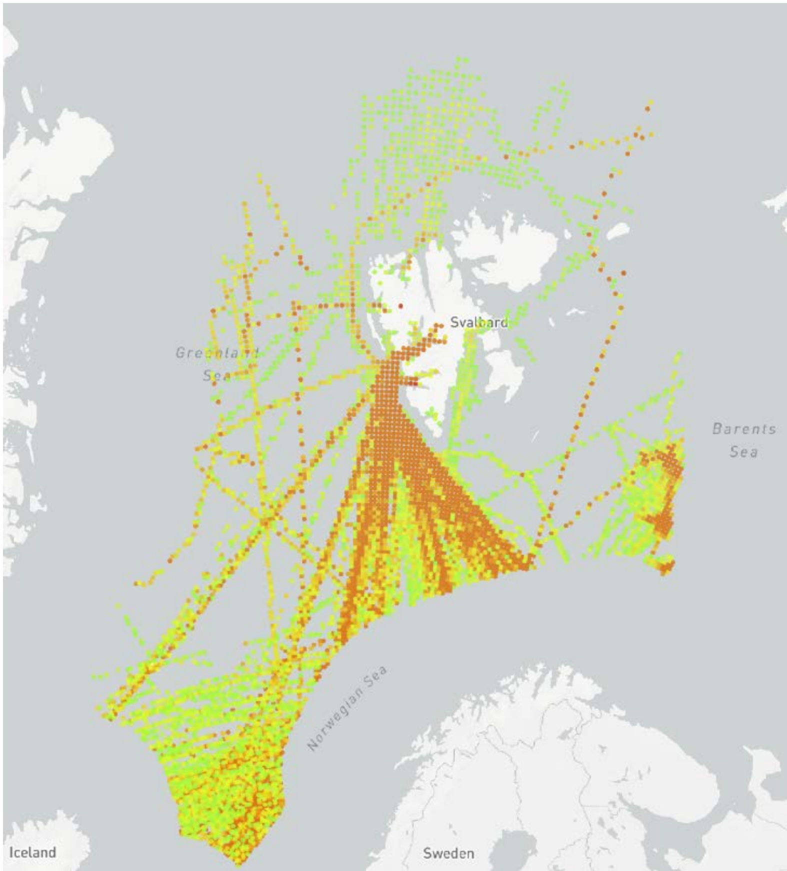


Figure 7-2 Distribution of the likely HFO bunker spills in the Norwegian Arctic waters as estimated by the AISyRisk system.

7.4 Environmental effects of an oil spill

The potential environmental and socioeconomic impacts of a spill vary by location, time of year, and amount and type of cargo spilled. Both the nature and degree of environmental impact heavily depend on whether a ship is carrying light fuels (e.g. MGO), or more heavy fuels (e.g. Residuals bunker fuel). As reported in (Trang. Cao Thi Thu, 2013):

"*In general, light oil and light crude oils do not persist on the surface of the sea for long, as a result of the fast evaporation of the volatile components and the easy dispersion, especially when the sea is rough. But, other types of oil such as heavy crude, emulsified crude and heavy fuel oils are persistent in the environment, because they contain a high ratio of non-volatile components and they have a high viscosity*".

State-of-the-art numerical oil spill model can simulate the potential transport and fate of acute spills in the marine environment. The oil spill models incorporate key physical and chemical processes that transport and weather the oil at sea surface and in the water column. The model predicts transport and fate of a release of oil e.g. from a vessel,, see Figure 7-3.

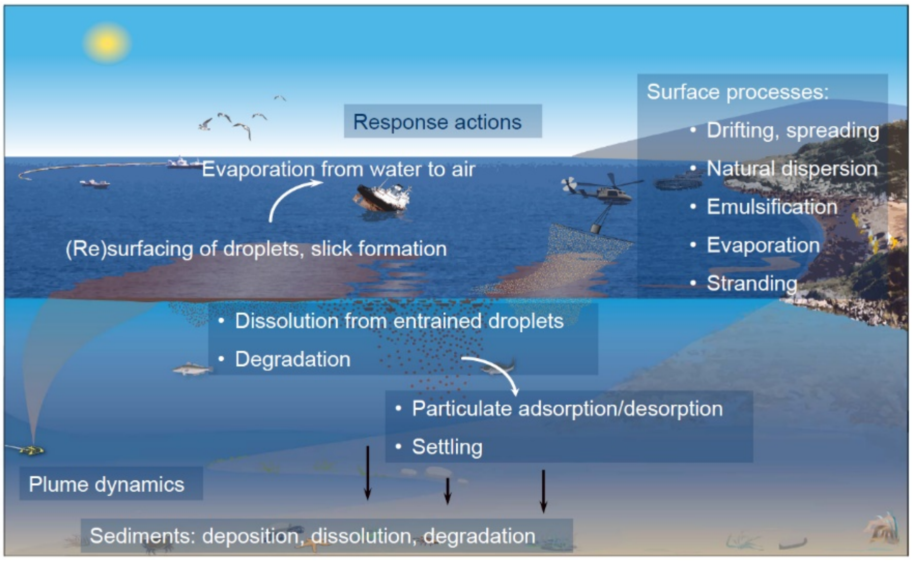


Figure 7-3 Processes included in the OSCAR oil spill model (source: Sintef).

It is Important to recognize that in cold climate and in presence of ice, weathering behaviour, transport and fate, and response effectiveness of oil will change significantly. Cold temperatures for example decrease evaporation rates significantly and certain oil types could solidify on the sea surface at low temperatures. Presence of ice limit the oil spreading, and absence of breaking waves reduces both emulsification and natural entrainment of oil droplets into the water column.

The Arctic Council's Emergency Prevention, Preparedness, and Response (EPPR, 2017) recently commissioned a Circumpolar oil spill response viability analysis. It estimates the percentage of time that metocean conditions (data related to meteorological conditions found at the respective location) may be favourable, marginal, or not favourable for a particular oil spill response system. The study considers the combined effects of wind, waves, air temperature, wind chill, sea ice, superstructure icing, horizontal visibility, and daylight/darkness on 10 marine oil spill response systems. The (EPPR, 2017) reported that the overall viability of marine oil spill response in the Arctic is low, particularly during winter conditions and in high Arctic. All systems are likely to face "non favourable" conditions more than 50% of the time over the whole area, some of them more than 75% of the time. It is noted that lower latitudes will have a higher percentage of time when response is favourable or marginal than in the High Arctic.

7.4.1 Challenges reported from tests on the new hybrid fuels (VLSFO/ULSFO)

The new fuel blends expected to replace most of the traditional HFO from 2020 leave a high degree of uncertainty with respect to their environmental impact. Few studies have been carried out in order to investigate their environmental properties, and this is particularly so regarding their behaviour in cold water. SINTEF and the Norwegian Coastal Administration (NCA) have cooperated on a study of three "new generation" low sulphur fuel oil:

- Shell's Ultra Low Sulphur Fuel Oil (here called ULSFO), ExxonMobil's ULSFO is a residual fuel oil with a broad spectre of both lighter and heavier components (C9-C40).
- Heavy Distillate Marine ECA 50 (HDME 50). HDME 50 is a heavy distillate cut (C15-C55).
- Mongstad's Wide Range Gas oil (WRG). WRG is a heavy distillate cut (C12-C35).

Challenges reported for the hybrid fuels relates to low evaporation, risk for solidification at low temperatures, and low oil spill response effectiveness (Fritt-Rasmussen, Wegeberg, Gustavsson, & Sørheim, 2018). Weathering testing of three "new generation" low sulphur fuel oils, shows distinctly different weathering behaviour and weathering properties. For all three oils, sea temperature highly affected these properties. According to the SINTEF results, the tested hybrid fuels creates emulsions that may solidify and have a relatively high viscosity, rendering recovery by use of skimmers and pumps difficult.

Some key findings from the testing hybrid fuels (Hellstrøm et al, 2018):

- ULSFO, HDME 50 and WRG had low content of water-soluble components and caused little toxic effect.
- Due to their high pour points, HDME 50 and ULSFO may solidify on the sea-surface and form solid lumps.
- The emulsion viscosities of HDME 50 and ULSFO were measured up to 50 000 mPa·s at 2 °C, indicating that high viscosity skimmers may be required for effective recovery of the oil/emulsion.
- Chemical dispersion of the "new generation" fuel oils may have limited effect due to high pour point values, particularly in colder temperatures.
- *In-situ burning* may have potential under special circumstances where spreading and emulsification is prevented, though long ignition time is expected for WRG and HDME 50.

The key question will then be how different the weathering properties and behaviour could be for the hybrid oils, as they seem to have “similar” weathering properties as HFOs’, and in addition could solidify on the sea surface at low temperatures?

It is therefore important to continue the testing of hybrid fuel oils to gain better understanding of their composition (e.g. share of lighter and heavier components, wax content, toxicity), behaviour, and fate in a release situation. This knowledge is vital to make the best choices for response operations, particularly for Northern regions, considering the observed temperature dependent behaviours and reported response gaps.

7.5 Environmental effects of an HFO-ban

Figure 7-4 -Perceived environmental risk with the regulatory shifts.

An important premise for actual and significant reduction of environmental risk from a future ban of the use of heavy fuel oil in the Arctic, is that the ban actually targets the relevant oil qualities representing the particularly high environmental risks, and that the risk is reduced compared to a reference scenario. In the current, and historic, fuel market (pre 2020), this premise may have been present in the Norwegian Arctic waters. In 2020 however, in DNV GL's view, it is highly uncertain whether the definition of heavy fuel oil (as per the working definition used in the MARPOL Convention) is well suited to achieve an actual and significant reduction in environmental risk, compared to the new baseline scenario following the 2020 sulphur cap on fuel.

From a spill risk and response perspective, two main uncertainties complicate the evaluation of the environmental benefits of an HFO-ban:

- How much reduction in the HFO related spill risks can be expected *in the baseline situation* (i.e. without the traditional HFO fuel) because of changes in the fuel marked due to the 2020 global sulphur cap and other regulations and drivers?
- Even if an HFO-ban will rule out many 0.5% fuels with high environmental risk potential, the alternatives actually permitted (many of the ULSFOs and some of the VLSFOs) may be new products and blends with particular environmental risk properties in line with traditional heavy fuel oils, maybe particularly in case of spills under Arctic environmental conditions.

Figure 7-4 shows the likely effects of the 2020 sulphur cap and the HFO ban for the most relevant fuel combinations in the Arctic fleet. Our conclusion is that we do not know which oil qualities will dominate within the region from 2020. However it is likely to include a range of new and modified products for which we have little or no experience with regards to properties when spilled to the Arctic environment, and where the traditional definition of HFO in the ban is not necessarily well suited to rule out the particular Arctic environmental oil spill risks.

In the longer term, comes the emerging GHG focus in shipping. This includes the IMO's climate strategy which is likely to fundamentally change the shipping industry's fuel mix over the next decades (DNV GL, 2019).

7.6 Potential cost savings from an HFO ban in the Norwegian Arctic

The costs and damages that accrue in case of an oil spill are highly dependent on the actual circumstances. Relevant factors include the oil type spilled, the amount of oil spilled, the geographic location of the spill (proximity to the shoreline and sensitive resources), the local response capacity and the clean-up technologies used, as well as weather and sea conditions (Etkin, 2000). Hence, estimating the cost related to such spills introduces many uncertainties, not at least the fact that little information about the clean-up costs of bunker fuel in Arctic waters is published. We know that remoteness, temperature, ice and weather conditions all add to the expected added complication of an Artic clean-up operation.

7.6.1 Potential clean-up costs related to a bunker oil spill in the Norwegian Arctic waters

In their study regarding the cost of Oil spill in the Arctic, CE Delft (Delft, 2018) present a compiled table as shown in Table 7-1. This clearly illustrates the spread in cost between the different studies and this illustrates the uncertainties involved in such assessments. It also shows that the clean-up cost related to a residual oil spill may be expected to be several times higher than that of distillate fuel.

Table 7-1 – Compilation of clean-up costs from relevant studies (Delft, 2018).

Reference	Location of oil spill	Fuel	Spilled oil (t)	Total cleanup costs (million USD)	Cleanup costs per tonne spilled (USD/t)	Cleanup costs per tonne spilled (USD_{2017}/t)	Distillate/ residual
ICCT (2017b); based on Etkin (2000)	Worldwide	No2 fuel (similar to marine distillate fuel)	-	-	3,100 USD_{2015}/ton	3,300	Distillate
		No6 fuel (similar to HFO)	-	-	22,400 USD_{2015}/ton	23,600	Residual
		< 0.5% S residual fuel[14]	-	-	16,800 USD_{2015}/ton	17,700	Residual
Etkin (2000)	Worldwide; 1999 USD	No2 diesel fuel	-	-	2,300 USD_{1999}/ton	4,700	Distillate
		Light crude	-	-	4,300 USD_{1999}/ton	8,900	Crude
		No4 fuel	-	-	23,900 USD_{1999}/ton	49,200	Blend
		No5 fuel	-	-	23,200 USD_{1999}/ton	47,800	Residual
		Crude oil	-	-	7,300 USD_{1999}/ton	15,000	Crude
		Heavy crude oil	-	-	8,500 USD_{1999}/ton	17,500	Crude
		No6 fuel	-	-	17,000 USD_{1999}/ton	35,000	Residual
Deere-Jones (2016)	Spain/Portugal (Prestige, 2002)	HFO	63,000 of which 43,000 cleaned up	1,163 (shore cleaning costs)[15]	27,000 USD_{2009}	34,600	Residual
	Bay of Biscay (Erika, 1999)	HFO	20,000	244 (material damage)[16]	12,200 USD_{2008}	16,000	Residual

[14] Clean-up costs for LSHFO (which ICCT called "<0.5% S residual fuel") is assumed to be 25% less than for HFO because some proportion of the fuel is assumed to be lighter distillates that evaporate off.

[15] 1.3948 USD/Euro.

[16] 1.4708 USD/Euro.

Reference	Location of oil spill	Fuel	Spilled oil (t)	Total cleanup costs (million USD)	Cleanup costs per tonne spilled (USD/t)	Cleanup costs per tonne spilled (USD_{2017}/t)	Distillate/ residual
	Sea of Japan (Nakhodka 1997)	MFO	17,400	186-203	11,000-12,000 USD_{2013}	13,200-21,100	Residual
	Ulanaska Island (Selendang Ayu, 2004)	Mainly MFO	1,200	103 (incl. compensation for lost taxes)	86,000 USD_{2007}	122,100	Mainly residual
Department of Environmental Conservation (2018); Desroches (2018)	Port William, Southern end of Shuyak Island	Fuel Oil No. 6 (Bunker C)	11.5	9	783,000 USD_{2018}		Residual

A study undertaken by XX (Etkin, 2000) determines an average clean-up cost for HFO to be around 15 000 US$/ton (1999) higher per ton HFO than a distillate spill. Assuming a price index of 1.50 between 1999 and 2020, this makes the difference 22 500 US$/ton.

In a study undertaken by XX (ICCT, 2017) it is assumed that the clean-up costs for ULSFO and VLSFO are 25% less than for HFO, because some proportion of such fuels are assumed to be lighter distillates that evaporate off and do not have to be cleaned up. However, this notion is not supported by recent studies (Hellstrøm et al, 2018), and for this study, it is assumed that no reduction in clean-up cost may be expected. Again, it should be noted that the uncertainties in such an assumption are huge, mainly because there is little experience to draw on, but also the fact that the properties of the new hybrid fuels vary considerably.

In order to exemplify the potential reduction in the expected clean-up cost of possible accident scenarios, 3 possible accident cases with different HFO vessels currently populating the area were calculated and tabulated. In these cases a clean-up cost of 22,500 US$/ton has been used.

- Sample1; Bulk carrier – Isfjorden – Fuel capacity of500 tons
- Sample2; Reefer – Bellsundet – Fuel capacity of 500 tons
- Sample 3; Cruise – Isfjorden – Fuel capacity of 5 200 tons

It is assumed a filling rate at the time of accident of 65% and that 50% of the fuel is spilled in the accident. Based on these assumptions, the figures are calculated and presented in Table 7-2.

Table 7-2 - Cases showing the reduced clean-up cost potential with LSFO's and distillates.

Vessel type	Fuel spill (ton HFO)	Clean-up cost reduction with VLSFO/ULSFO (US$)	Clean-up cost reduction with distillate (US$)
Bulk carrier	160	0	3.6 mill
Reefer	160	0	3.6 mill
Cruise	1 700	0	38 mill

7.6.2 Potential changes in oil recovery contingency

The Norwegian Coastal Administration (NCA) is responsible for any oil recovery contingency for Norwegian sea and land areas. Oil booms dedicated for Arctic climate are currently stationed onboard the coastguard vessel MV Svalbard as well as in storage in Vadsø and Horten. With the emerging new

LSFO oils, it is acknowledged that this will require additional investments in testing and research in order to better understand the behaviour of these oil qualities in cold climate and ice. This will apply to the use of skimmers, pumps, dispersants as well as booms. With this in mind, an increased need for investment in oil recovery contingency may be expected in the near future. Following interviews with representatives from the NCA, they consider it unlikely that this will change with a future HFO ban in the Arctic provided the hybrid LSFO oils are potentially accepted under the ban. Hence, it is considered to be unlikely that an HFO ban in the Arctic in the form proposed will reduce the oil recovery contingency in the near future.

7.7 Non-monetized effects from oil spill to sea in the Norwegian Arctic

Marine shipping accidents can create a range of social, cultural, health, and economic impacts. These impacts can arise directly, such as injury from a collision or economic loss from supply chain disruptions, or indirectly as a result of environmental impacts. For example, an oil spill can have impacts that may include economic impacts (e.g., loss of tourism revenue), social impacts (e.g., disruption in community relationships), and physical and mental health impacts.

A study conducted following the Exxon Waldez oil spill in Alaska (Palinkas et al, 1993) suggest that the oil spill's impact on the psychosocial environment was as significant as its impact on the physical environment. The Exxon Valdez experience identified a number of implications for the mental health needs of disaster victims, particularly in primary care settings. The survey comprising 13 Alaskan communities found substantially higher rates of generalized anxiety disorder (3.6 times as likely), posttraumatic stress disorder (2.9 times as likely), and depressive symptoms (1.8 times as likely) in communities directly affected by the Exxon Valdez spill than in communities with similar demographic and economic characteristics that were not located near the spill.

8 CONCLUSIONS

8.1 Ships operating in the Norwegian Arctic water and their fuel options

610 unique vessels were found to populate the Norwegian Arctic region in 2018. Out of these, only 172 were identified as using HFO as fuel, of which 10 were identified to have scrubber installed. Most of the vessels using HFO as fuel were just passing through the region, and only 13 HFO vessels were entering a Norwegian port (Longyearbyen) and potentially interacting economically with the local Norwegian economy. 12 of these HFO vessels were large cruise vessels visiting Svalbard as part of a round-trip, and one was a bulk carrier transporting coal out of Longyearbyen.

From January 1st, 2020, all vessels will be subjected to a sulphur cap of 0.5% for all fuels. This means that new fuels are developed and the baseline for a future HFO ban will be a fuel situation considerably different from what has been the fuel norm over the last decades. The operators of the 172 identified HFO vessels must develop their strategies for how to comply with the upcoming sulphur regulations. Their available options are either to use the new low sulphur (VLSFO/ULSFO) hybrid fuels, shift to distillate fuels or install exhaust gas cleaning systems (scrubber) and continue using HFO until the ban applies.

For the vast majority of the HFO vessels, there are developed low sulphur alternatives that still contain residues making them potentially problematic as they seem to have “similar” weathering properties as HFOs’ when spilled to water, and in addition could solidify on the sea surface at low temperatures.

8.2 Likely environmental effects of an HFO ban

Depending on price differentials amongst the new fuel blends and distillate fuels, and consequently their marked penetration, the risk of oil spills having similar dispersibility and weathering effects as today’s HFO fuels might persist. If distillate fuel is preferred by more operators due to implications of an HFO ban, positive effects to the environmental risk picture may be achieved. The uptake of new fuel blends should therefore be monitored closely in order to identify the residual fuel definition that most effectively fulfil the goals of an Arctic HFO-ban, not only to limit emissions to air but also to limit the risks posed by oil spills on the local environment.

Therefore, in DNV GL's view, it is uncertain whether the proposed ban’s definition of heavy fuel oil (as defined under the IMO/MARPOL for Antarctica) is well suited to ensure an actual and significant reduction in the environmental risk, compared with the baseline scenario from 2020 without a ban.

8.3 Added costs and potential savings related to an HFO ban

The very few HFO vessels found to interact economically with the Norwegian communities in the Arctic, means that imposing an HFO ban will likely have minor economic effects on the region. Taking into account cost of adapting some of the vessels, expected added fuel cost and the subsequent effect of increased cruise prices (reduction in passengers), results in an estimated annual added cost for the Norwegian Arctic area of between 350 000 and 760 000 USD.

The likelihood of an HFO spill in the Norwegian Arctic is considered to be small. This is related to the fact that the HFO vessels are relatively few and far between, and also that the current residual fuel ban in the national parks at Svalbard limits the movements for the HFO vessels close to the shores. Still, the consequences of a spill to sea, and subsequently the shores, is potentially devastating to the community, nature and the local economic activity.

Following the new fuel situation in 2020, an increased need for investment in oil recovery contingency may be expected in the coming years. Following interviews with representatives from the NCA, they consider it unlikely that this situation will change with a future HFO ban in the Arctic provided the hybrid LSFO oils are potentially accepted and used under the ban. Hence, it may be concluded that it is unlikely that an HFO ban in the Arctic in the form currently proposed will reduce the oil recovery contingency in the near future.

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APPENDIX A

Incident study - HFO vessels versus distillate vessels drifting in Norwegian waters

The Norwegian Maritime Authority has requested this additional assessment to evaluate the available statistics on drifting vessels in Norwegian waters. Specifically, to determine if any relationships can be established between recorded engine failures and fuel types carried.

DNV GL was given access to a three-year data set of all drifting vessels recorded in Norwegian waters between 2017-2019. The data set includes short descriptions of root cause together with vessel identification number, vessel type, vessel size and engine RPM values. For the same period (2017-2019) DNV GL cross referenced the drifting vessels with all vessels recorded operating within Norwegian waters, a data set including additional key parameters such as fuel type and operating hours and distances sailed.

To sort out relevant failure modes a high-level assessment was done on the root cause descriptions from drifting vessels between 2017-2019. The most obvious failures not related to fuel carried or from the engine failures were discarded and taken out of the statistics presented in this section. A more accurate process of failure identification would benefit conclusions made but based on the short and often inconsistent format of reported failure data only a rough assessment could be done at this time. Out of 279 drifting incidents reported in the dataset, 83 incidents were discounted as caused by vessel engine or fuel failures and an additional 7 incidents were discarded due to missing vessel identifiers.

Drifting vessels caused by engine failure

Out of the identified 189 total drifting incidents incurred by failures related to engine, or fuel type carried, the incidents were divided in accordance to the Norwegian Main vessel categories for Gross tonnage and vessel types. The reported incidents are shown in Table 9-1 for each vessel category accordingly.

Table 9-1 Number of Engine related incidents 2017-19 – All fuel types.

Row Labels	1. < 1000 GT	2. 1000 - 4999 GT	3. 5000 - 9999 GT	4. 10000 - 24999 GT	5. 25000 - 49999 GT	6. 50000 - 99999 GT	7. ≥ 100000 GT	Grand Total
02 - Chemical tankers		14	4	1	2			21
03 - Gas tankers					1			1
04 - Bulk carriers	2		2	7	4	3	1	19
05 - General cargo ships	4	64	15	3	1			87
06 - Container ships			4	1				5
07 - Ro-Ro cargo ships			2					2
08 - Refrigerated cargo ships		6						6
10 - Offshore supply ships		1						1
11 - Other service offshore vessels	1							1
12 - Other activities	7	3						10
13 - Fishing vessels	8	9						17
14 - Crude oil tankers						1		1
15 - Oil product tankers	3							3
16 - Passenger ships	5	4			3			12
17 - Cruise ships	2				1			3
Grand Total	32	101	27	12	12	4	1	**189**

Drifting vessels with engine failure and fuel type

Not all vessels in the two main data sets (drifting vessels and vessel operations in Norwegian waters 2017-2019) included reliable or conclusive vessel fuel data. In fact, 109 of the 189 identified vessels did not contain fuel type reporting. In order to provide a fair estimate for all drifting vessels a combination of metrics presented below was employed.

Vessel size and segment

Smaller vessel size is a good indication that the vessel runs on marine grade diesel oil, or distillate fuels, and most of the statistics for gross tonnage category 1 can be prescribed as distillate. The largest vessel categories 5 through 7 were identified as carrying residual fuels. In addition to the vessel size category certain segments such as offshore service vessels are more likely to utilize distillate fuels regardless of size. Vessel size and vessel type considerations combined gave a fuel estimate for many of the missing data points presented in Table 9-1.

Engine RPM

Where vessel size and type could not conclusively be used as metric, RPM data was instead used as a fuel divider. This ruling was applied mostly for vessels identified within size category 2 (1000 - 4.999 GT) of Table 9-1 if they weren't identified otherwise, which amounted to 10 incidents in total. Engine RPM values above 300 were then used to indicate distillate fuels carried, while lower RPM values were used for the HFO vessel identification.

Scrubber installations

Finally, available data for the world fleet with scrubber installations planned or installed were used to verify that no residual fuel vessels had been wrongly identified as pure distillate. However, none of the vessels found in the drifting vessel data set included vessels with installed, or planned, scrubber systems. In the end the following two tables could be produced showing the identified HFO and distillate fuel vessels and their respective share of drifting failure incidents within the period 2017-2019 show the proportions of distillate fuel vessels. Table 9-3 presents the HFO vessels identified.

Table 9-2 Number of incidents 2017-19 – Distillate Fuels.

Row Labels	1. < 1000 GT	2. 1000 - 4999 GT	3. 5000 - 9999 GT	4. 10000 - 24999 GT	5. 25000 - 49999 GT	6. 50000 - 99999 GT	7. ≥ 100000 GT	Grand Total
02 - Chemical tankers		13	1					14
03 - Gas tankers								0
04 - Bulk carriers	2			2				4
05 - General cargo ships	4	52	1	1	1			59
06 - Container ships								0
07 - Ro-Ro cargo ships			1					1
08 - Refrigerated cargo ships		5						5
10 - Offshore supply ships		1						1
11 - Other service offshore vessels	1							1
12 - Other activities	7	3						10
13 - Fishing vessels	8	9						17
14 - Crude oil tankers								0
15 - Oil product tankers	3							3
16 - Passenger ships	5	3						8
17 - Cruise ships	2							2
Grand Total	32	86	3	3	1	0	0	**125**

Table 9-3 Number of incidents 2017-19 – Residual fuels.

Row Labels	1. < 1000 GT	2. 1000 - 4999 GT	3. 5000 - 9999 GT	4. 10000 - 24999 GT	5. 25000 - 49999 GT	6. 50000 - 99999 GT	7. ≥ 100000 GT	Grand Total
02 - Chemical tankers		1	3	1	2			7
03 - Gas tankers					1			1
04 - Bulk carriers			2	5	4	3	1	15
05 - General cargo ships		10	14	2				26
06 - Container ships			4	1				5
07 - Ro-Ro cargo ships			1					1
08 - Refrigerated cargo ships		1						1
10 - Offshore supply ships								0
11 - Other service offshore vessels								0
12 - Other activities								0
13 - Fishing vessels								0
14 - Crude oil tankers						1		1
15 - Oil product tankers								0
16 - Passenger ships					3			3
17 - Cruise ships					1			1
Grand Total	0	12	24	9	11	4	1	**61**

Hours sailed between failures

To establish any connection between increased probabilities for engine failures between the two fuel categories used the incidents were matched with operating hours per vessel per incident. For each vessel the sum of operating hours and failures were added during the time period 2017-2019, generating a value for hours sailed per incident encountered by that vessel. In Figure 9-1 the average hours sailed between incidents are summarized for each fuel type group.

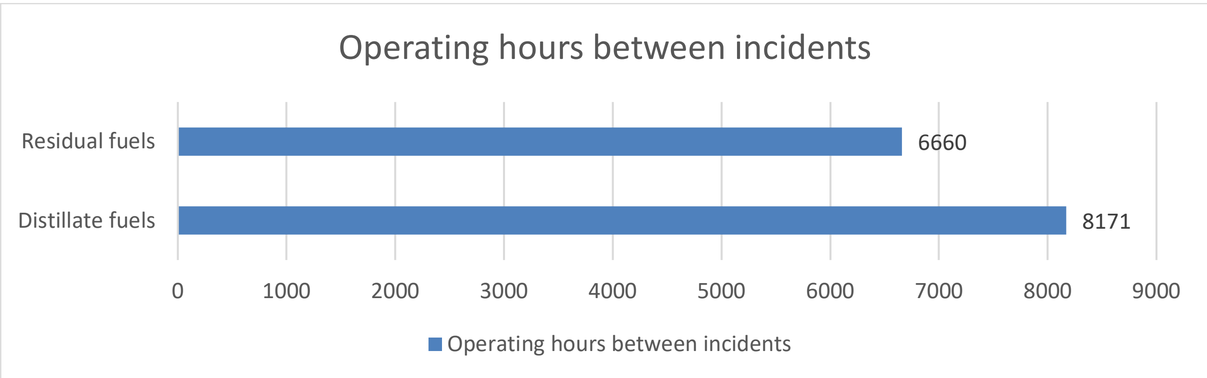


Figure 9-1 Operating hours between drifting incidents in Norwegian waters, sorted by fuel type.

The results presented in Figure 9-1 indicate that an HFO fuelled vessel would be expected to sail ~80 % of the time compared to a distillate fuelled vessel between engine failures.

Discussions

Several steps in the analysis included assumptions that carry uncertainties and correct identification of failures caused by the fuel employed is uncertain due to limited information available from the drifting vessel reporting. The data collected by the Norwegian Coastal Administration is normally triggered by a VTS-central identifying a ship drifting. The ship is then contacted and the data about the situation is collected. The information about the incident may be limited, and it is not always possible to distinguish what may be referred to as “planned maintenance” and a real engine problem. Most HFO vessels are normally dual-fuel vessels and it is not easily captured in this binary assessment. Additionally, the database of drifting vessels within Norwegian waters include all instances of vessels found drifting for any reason, with no regard to severity. Some vessels might have scheduled downtime for repair or maintenance while lying in sheltered waters or far from land. Most of the reported incidents in the database represent vessels that regained operation after only a short amount of time and might not equate to an additional safety risk in an Arctic environment as such.

With this in mind, the stipulated hours between incidents are not realistic intervals between machinery incidents as such, but rather statistical figures providing some sort of comparative magnitude.

Similar studies carried out by Rambøll and Marintek (Henaug, Norddal, & Stenersen, 2016) support the conclusion that no great difference between fuel type employed as related to engine failures or drifting scenarios can be identified. Many of the findings identified by Rambøll and Marintek correlate well with DNV GL’s own experience on engine related failures. The numbers presented in from the data set should be read with this overall understanding in mind.

APPENDIX B
Fuel qualities

In this report we will use either the term HFO or residual oil as overall term for oils within the different ranges. Thus, we will include available information on all oil types within this range of refined oil products regardless of the specific name/classification system.

When deciding on a future ban on the use of HFO in the Arctic, it is important to note that this is done in a period when a dramatic change in the fuel use is expected due to the global sulphur cap introduced in 2020. The expected result is illustrated in Figure 9-2 below and clearly illustrates the expected drop in the use of the traditional HFO from January 2020, leaving only the relatively small portion of the fleet with scrubber installed to continue using traditional HFO. There are few reasons to believe that this will differ significantly in the Arctic. From January 2020 it is expected that most of the traditional HFO use will be replaced by some form of Low Sulphur Fuel Oil (LSFO), also referred to as hybrid fuel oils or MGO. Even though some of these oil qualities will not be sorted under the MARPOL definition of HFO (used for the protection of Antarctica from pollution by heavy grade oil), initial tests have shown that their weathering properties in a cold climate may be as problematic as HFO (Fritt-Rasmussen, Wegeberg, Gustavsson, & Sørheim, 2018).

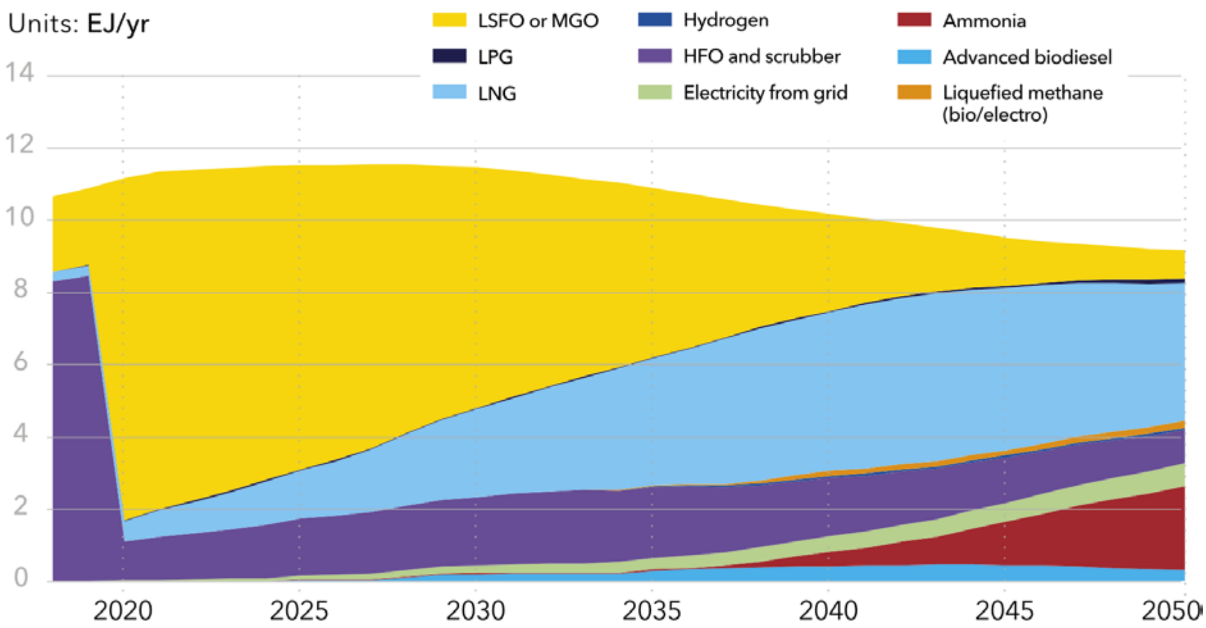


Figure 9-2 Projected fuel mix needed to reach IMO 2050 GHG emission levels.

Residual and Distillate fuels

There are generally two types of marine fuel; residual and distillate fuels. Distillate fuel is composed of petroleum fractions of crude oil that are separated in a refinery by a boiling or "distillation" process. Residual fuel or "residuum" is the fraction that did not boil, sometimes referred to as "tar" or "petroleum pitch".

The fleet found in the Norwegian Arctic waters is dominated by ships using some forms of distillate fuel, with 73% of the totals as opposed to 27% residual fuel (see Table 5-4).

Heavy Fuel Oil (HFO) is one of several terms used to cover a rather broad range of different marine residual fuels, or blends of residual and distillate fuels. In industry terminology, such fuel may be called by different names, such as heavy fuel oil, heavy diesel oil, residual fuel, bunker, or fuel oil. Different types of HFO are labelled corresponding to the RM (A, B, D, etc) qualities under the ISO 8217 Specification of Marine Fuel.

Distillate fuel - referred to as marine gas oil (MGO) and marine diesel oil (MDO), or just distillates, normally corresponding to qualities within the DM (X, A, Z, B) of ISO 8217. Table 9-4 describes the range of marine fuels and indicates whether it's an HFO or distillate as applied in this report.

Table 9-4 - Typical marine fuel types

Marine Fuel Oil Name	Composition	Type
Bunker C/Fuel oil No. 6	Residual oil	HFO
Intermediate Fuel Oil (IFO) 380	Residual oil (~ 98%) blended with distillate	HFO
Intermediate Fuel Oil (IFO) 180	Residual oil (~88%) blended with distillate	HFO
Low sulphur marine fuel oils	Residual oil blended with distillate (higher ratio of distillate to residual)	HFO derivative
Marine diesel oil (MDO)/ Fuel oil No. 2	Distillate fuel that may have traces of residual oil	Distillate
Marine gas oil (MGO)	100% distillate	Distillate

There are two main qualities or parameters that make the distinction between HFO and distillates appropriate. The first is the behaviour and impact of the fuel when released to water (oil spill risk). The second is the levels of exhaust emissions when the fuel is combusted, in particular SOx, PM and BC.
Oil spills could have particularly severe impacts on Arctic wildlife, the marine environment and could threaten Arctic communities' food security and livelihoods. This is due to the slow rate of degradation because of a very limited evaporation (typically less than <10%) and limited dispersion into the water column. HFO also emulsifies in water, is extremely viscous and could potentially remain at sea for weeks, having a large damage potential. In ice-covered waters an oil spill may result in oil becoming trapped in ice, causing the oil to persist even longer, and enabling oil to transport over even longer distances. HFO is also difficult to handle using conventional recovery measures. Effective response operations are also challenged by lack of infrastructure, remoteness, harsh weather conditions, darkness, and possible ice conditions. WWF has summarized some of the key considerations for different marine fuels, including spill cleanup limitations.

Table 9-5 - Oil spill characteristics and properties of different marine fuel types (WWF, 2018, their figure 4.1).

FUEL TYPE		CHARACTERISTICS AND PROPERTIES		
Marine Fuel	**Composition**	**Behavior when spilled**	**Spill Cleanup**	**Ecological Impacts**
Bunker C/ Fuel oil No. 6	Residual oil	May sink or become neutrally buoyant. Forms tar balls and patties. Emulsifies (incorporates water).	Limited technologies for on-water recovery. Most of the cleanup will likely involve remediating shorelines and oiled substrate.	Coats feathers and fur. Persistent and sticky, can have long-term impacts to shoreline, intertidal, and benthic communities.
Intermediate Fuel Oil (IFO) 380	Residual oil (~ 98%) blended with distillate	May sink or become neutrally buoyant. Emulsifies (incorporates water) and may increase 2-3 times original spill volume.	Fresh product may be recoverable within hours of initial spill, but as oil emulsifies it becomes more difficult to recover with skimmers. Weathered oil will coat surfaces and may be difficult to remove from coarse sediments and substrate.	
Intermediate Fuel Oil (IFO) 180	Residual oil (~88%) blended with distillate			
Low sulphur marine fuel oils	Residual oil blended with distill$ate (higher ratio of distillate to residual)	Initial laboratory and mesoscale testing suggests that it will behave similar to other residual oils, emulsifying and generally acting as a persistent fuel.	Poorly studied. Information from recent pipeline spill in Hawaii suggests that residual blends will pose similar response challenges to other residual fuels.	Poorly studied, likely to be similar to IFO. May have higher initial toxicity than residual fuels because of higher percentage of distillate, which will initially disperse or evaporate.
Marine diesel oil (MDO)/Fuel oil No. 2	Distillate fuel that may have traces of residual oil	High percentage will evaporate or disperse into water column within first few hours of release. Will remain floating but slick will spread in open water.	Can be skimmed from surface if contained to sufficient thickness. As oil spreads and weathers, more difficult to recover.	High initial toxicity to wildlife, particularly in water column, but oil is less persistent in environment. Will still harm fur and feathers when it comes into contact.
Marine gas oil (MGO)	100% distillate			

HFO and distillates also have different properties when it comes to levels of exhaust emissions when the fuel is combusted, with higher levels of SOx, PM and BC emitted for HFO. BC emissions are of particular interest in the Arctic. Atmospheric BC absorbs radiation both from incident sunlight and sunlight reflected from snow and ice. In addition, BC deposited on snow or ice reduce surface reflectivity (i.e. albedo), thus accelerating the ice melting process (Flanner. M.G et al, 2007) (Hansen J. and L. Nazarenko, 2004). BC are short-lived, and only stays in the atmosphere for a few days or weeks. Reducing BC emissions from ships would have an immediate impact on shipping's overall global warming effects. According to (ICCT, 2017) are BC largely ignored as a climate pollutant from ships ("missing inventory"). (ICCT, 2017) indicates that after CO2, BC contributes the most to the climate impact of shipping.

New fuel types meeting the global sulphur cap

From 1 January 2020, a 0.5% global sulphur cap for vessel fuels will enter into force. Without exhaust cleaning technologies (scrubbers) this effectively makes residual fuels unviable as vessel fuel. The market has reacted to the coming changes in allowable sulphur content with one of two strategies. One solution is to transition to compliant distillate fuels or blended fuels. This strategy will result in a marked increase in fuel cost for the operator, and in some cases modifications to the existing engine configuration. Another strategy is instead to install a scrubber system onboard, an exhaust gas cleaning system that wash out sulphur oxides from the engine exhaust, allowing the vessel operators to continue using residual fuels also after 1 January 2020.

Global adoption rates of scrubber technology have so far proven low, with only 3 763 known vessel installations as of 1 October 2019, based on data taken from the DNV GL operated Alternative Fuels Insight platform (DNV GL, 2019). [6]/AFI/. The expectations moving into 2020 and beyond is therefore

[6] https://afi.dnvgl.com/Statistics?repId=2

that a mix of distillate fuels, very-low sulphur content heavy fuel oils or new fuel blends will be the dominating choice for vessels operators sailing with residual fuels today.

When the Sulphur limit in the emission control areas (ECA) was reduced to 0.10% in 2015, a number of alternatives to MGO appeared in the market. These alternatives were designed to be compliant with the ECA requirement, while still containing a residual part making it less costly than MGO. The term “hybrid fuel” refers to such a blended product with specifications similar to HFO, and/or to certain refinery products that have previously not been used as marine fuels. Therefore, they also do not necessarily fit into the traditional specifications for MGO, MDO or HFO fuel. These oils may not be fully compatible with ordinary heavy fuel oils and can pose potential technical challenges in operation in connection with the change-over.

Several hybrid fuels combine properties of both distillate and residual marine fuels. According to CIMAC (2015), these new fuels can be divided into the following categories;

- Ultra-low Sulphur HFO oils; Typically, these fuels have lower viscosity and density, and better ignition and combustion properties compared with conventional residual marine fuels
- Blends of a distillate fuel with small amount of oil (DMB type)
- Heavy distillates; fuels with low metal content but with higher viscosity than conventional DMA

As fuel suppliers seem to have designed their own unique formulation, properties of the new hybrid fuels may vary significantly, which means that each fuel has its own specifics in terms of storing, handling and using the fuel (CIMAC, 2015). The oil properties are also important, if oil is released to sea during an Arctic accidental bunker spill. Challenges reported for hybrid fuels relate to risk for solidification at low temperatures, and low oil spill response effectiveness (Sintef, 2017). To reduce their environmental damage potential, proportions may be changed in the future.

Fritt-Rasmussen et al. (2018) state that it is highly important to characterise the new fuel oils on the market, and to gain better documentation of the differences in fate and behaviour in case of a spill at sea and to document the potential / feasibility of the different response options.

Apart from the traditional distillate fuels, very low sulphur fuel oils, blended residual fuels and larger LNG uptake is foreseen to enter the energy mix in shipping after 1st January 2020.

Even amongst the current HFO fuels employed in the Arctic regions today, variability on oil spill effects has been registered (Fritt-Rasmussen, Wegeberg, Gustavsson, & Sørheim, 2018).The new blends poised to enter the market are expected to exhibit behaviours varying from close to MGO up to, and potentially worse, than current HFO fuels when exposed to a cold-water environment.
Since weathering properties of the new hybrid fuel oils are mainly unknown, these types of fuel oils pose an uncertainty regarding its behaviour in different spill situations. Individual weathering studies would provide good information for each oils' properties and expected behaviour in an acute situation.
For the HDME 50 and Shell ULSFO fuel oils, application of dispersant may have limited effect, particularly in cold climate. Repeated application will likely increase the effectiveness, but the oils are not expected to be completely dispersed. HDME 50 and Shell ULSFO may solidify at low temperatures and the solid oil lumps will not be dispersible. The applications of dispersant should ideally be performed before emulsion viscosities become too high, in effect as rapidly as possible after the release.
http://kystverket.no/globalassets/beredskap/beredskap/forskning-og-utvikling/oc2017-a124---weathering-properties-and-toxicity-of-marine-fuel-oils.pdf

Oil spill risk assessments

The work process for oil spill risk assessments begins with hazard identification and likelihood analysis, including selecting scenarios for assessing environmental risk. This is followed by a mapping of the local ecological and socioeconomic resources potentially affected by an accidental spill, and an assessment of the consequences and risk to these resources. Once the main risk drivers have been identified, analyses can further assist in evaluating both risk-reducing and mitigating measures to ensure a tolerable risk level.

State-of-the-art numerical oil spill models can be used to simulate the potential transport and fate of acute spills in the marine environment. The oil spill models incorporate key physical and chemical processes that transport and weather the oil at sea surface and in the water column. The model predicts transport and fate of a release of oil (e.g. from a vessel) (Figure 9-3).

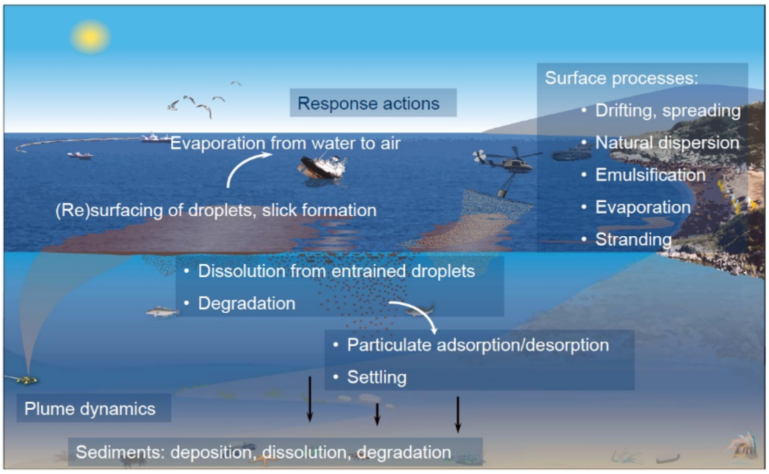
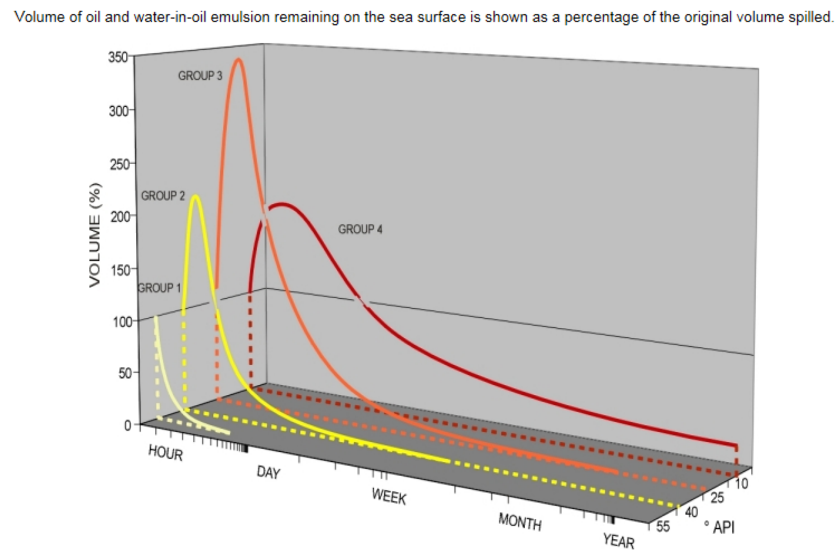


Figure 9-3 - Processes included in the OSCAR oil spill model (source: Sintef).

As pointed out by (Trang. Cao Thi Thu, 2013), "*In general, light oil and light crude oils do not persist on the surface of the sea for long, as a result of the fast evaporation of the volatile components and the easy dispersion, especially when the sea is rough. But, other types of oil such as heavy crude, emulsified crude and heavy fuel oils are persistent in the environment, because they contain a high ratio of non-volatile components and they have a high viscosity*". Figure 9-3 indicate the differences in behaviour for different density categories of oils (generally, oils with a lower density will be less persistent) based on simplified modelling (ITOPF, 2019). The figure shows the estimated volume of oil and water-in-oil emulsion remaining on the sea surface as a percentage of the original volume spilled. The simplified results indicate that lighter oils will stay at sea for hours/day at sea, opposite to the heavier fuels that creates water-in-oil emulsion and will remain for a long time at sea (if not beached/interacting with ice).

This is supported by Moldestad and Daling (2006), reporting that Marine gas oils were the only products tested that did not leave a residue on the water surface to be handled. They recommended that only Marine gas oils are used as a fuel in specific sensitive areas on Svalbard since they disperse naturally and relatively fast into the water column.



Group	Density	Examples
Group I	less than 0.8	Gasoline, Kerosene
Group II	0.8 - 0.85	Gas Oil, Abu Dhabi Crude
Group III	0.85-0.95	Arabian Light Crude, North Sea Crude Oils (e.g. Forties)
Group IV	greater than 0.95	Heavy Fuel Oil, Venezuelan Crude Oils

Figure 9-4 - Estimated volume of oil and water-in-oil emulsion remaining on the sea surface as a percentage of the original volume spilled (ITOPF, 2019). Simplified modelling is made for different categories of oils.

Oil spill response viability

The Arctic Council's Emergency Prevention, Preparedness, and Response (EPPR) recently commissioned a Circumpolar oil spill response viability analysis. A response viability analysis estimates the percentage of time that metocean conditions may be favourable, marginal, or not favourable for a particular oil spill response system. The study considers the combined effects of wind, waves, air temperature, wind chill, sea ice, superstructure icing, horizontal visibility, and daylight/darkness on 10 marine oil spill response systems.

EPPR (2017) reported that the overall viability of marine oil spill response in the Arctic is low, particularly during winter conditions and in high Arctic, as illustrated in Figure 4 below. All systems are likely to face "not favorable" (red) conditions more than 50% of the time over the whole area, some of them more than 75% of the time. The percentages represent an average across the entire study area for the 10 years of metocean data compiled. It is noted that lower latitudes will have a higher percentage of time when response is favourable or marginal than in the High Arctic.

A more detailed response gap analyses is also made per month for Svalbard (Figure 9-5). As indicated the not-favorable" (red) conditions are dominating during the winter season.

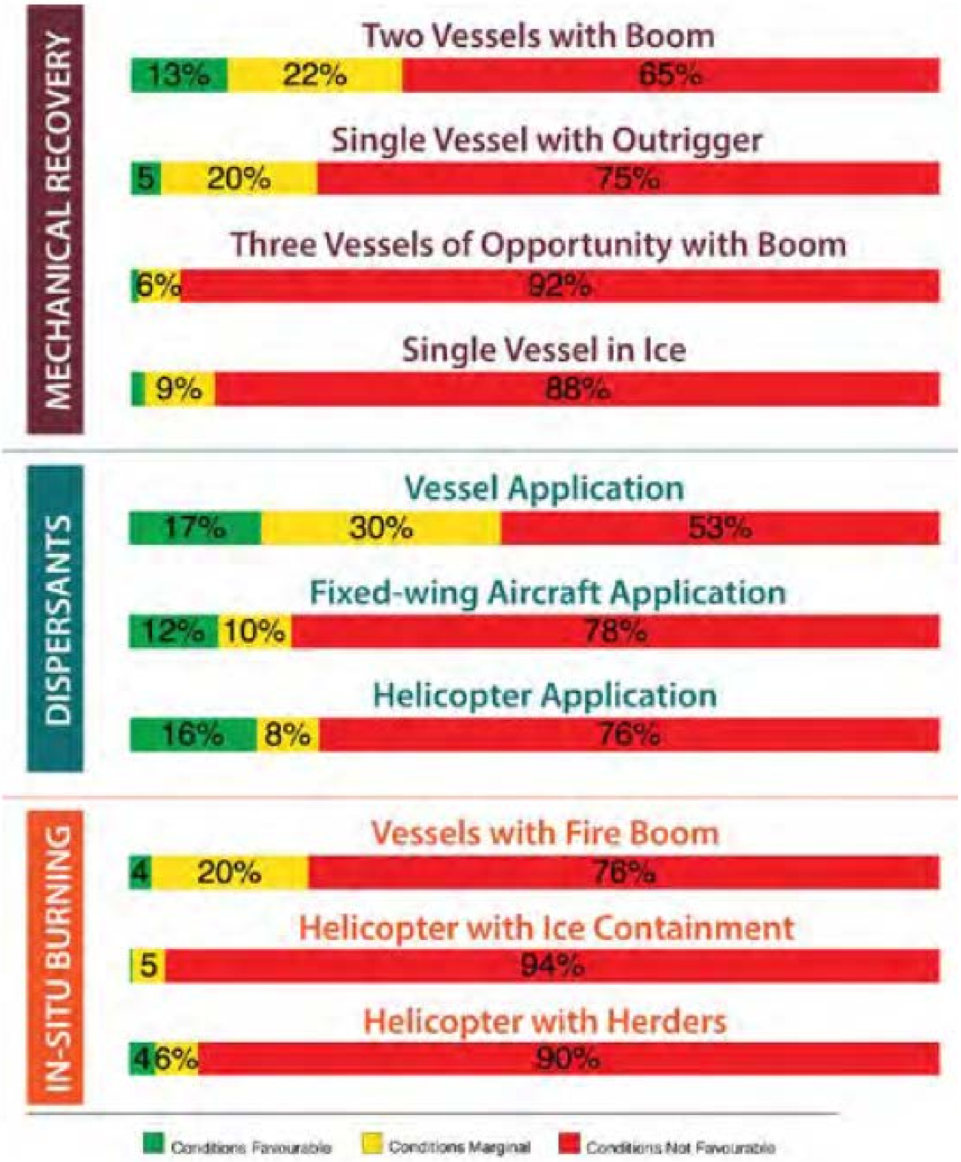


Figure 9-5 - Annual percentage of time that conditions are favourable (green), marginal (yellow), or not favourable (red) for response systems studied (averaged for entire study area) (EPPR, 2017).

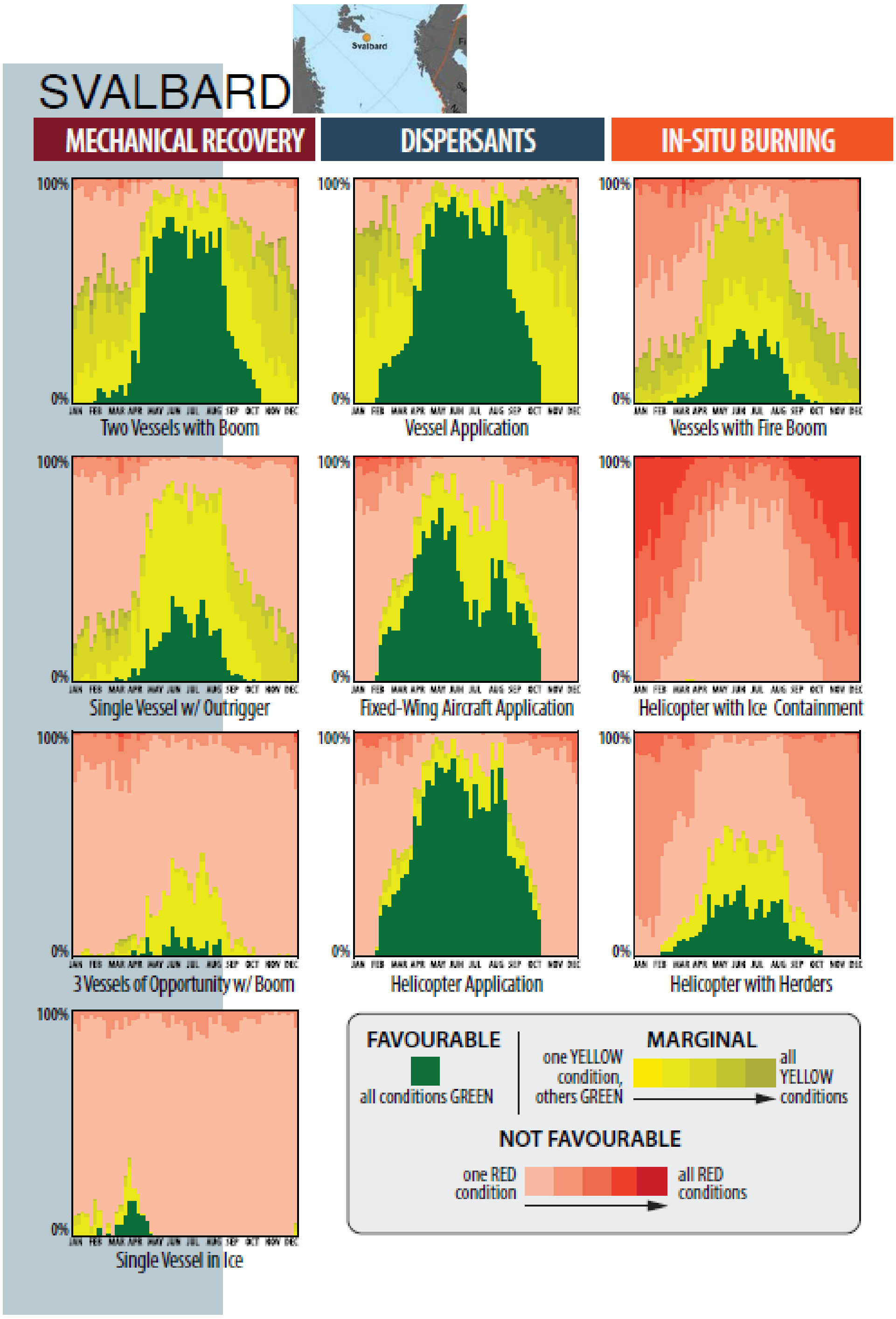


Figure 9-6 - The percentage of time that response conditions are favourable, marginal, or not favourable during the study period for any one of the systems studied (EPPR, 2017).

Switching between fuels

Most ships will switch between fuels during their operation, for example when complying with the EU requirement for ultra-low sulphur fuel to be used in EU-ports.

Burning MGO in 4-stroke engines

The diesel generator installed on ships these days operate on both residual and distillate fuel. The valve seat deposits (on the inlet valve) is significantly less when using distillate fuel as compared to using residual fuel oil. This is because the distillate fuels such as Marine Gas Oil produces fewer combustion deposits.

Burning MGO in 2-stroke engines

The 2 stroke engines operate typically under heavy fuel oil outside the ECAs and before entering the Emission Control Areas they switch over fuel from HFO to LSFO.During the switchover process, there is a mixing of heavy fuel oil with a low aromatic hydrocarbon distillate fuel. This increases the risk of two incompatible fuels burning inside the engine cylinder, causing the asphalt of the heavy fuel to precipitate as heavy sludge and leading to filter clogging
As the names suggest, LSFO produces a negligible amount of sulphuric acid, and hence if the correct TBN lubricating oil is not used, the alkaline components produced in the cylinder will not be neutralised. This will potentially harm the liner and other parts of the combustion chamber. These alkaline deposits will lead to the removal of cylinder oil film causing contact of metal to metal parts between liner and piston rings and resulting in scuffing and seizure of the engine. Leakages when using MGO or LSFO is another problem experienced in 2 stroke marine engines.

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