Increased maritime activity in the Arctic

Risks and possible environmental consequences

Bachelor thesis in Marine Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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Abstract

Due to a warming climate, the sea ice is melting in the Arctic, which grants easier access to shipping routes through the Arctic in the summer months. Shipping companies are looking to benefit from these shorter routes and the purpose in this project is to investigate the implications an increased maritime activity can have on the Arctic environment. Using literature review, different aspects are evaluated such as what makes the Arctic special. As a result of the shrinking sea ice extent, the Arctic may face environmental consequences due to the potential increase of maritime activity. Pollution from ships is therefore a vital part of this report as well as how current and future ship regulations helps to reduce the environmental impact on the Arctic region. Results show that an increased marine traffic could have a harmful effect locally. Albedo is a major factor when it comes to the melting of the ice sheets. Light absorbing particles, such as black carbon, accelerate the ice melting process which exposes more ocean water. In contrast to the ice and snow, sea water is much darker which makes it absorb more heat from solar radiation. The Polar Code offers guidelines for operating in the Arctic and the IMO is currently working on an HFO ban in the Arctic. This ban could help the region since the added difficulty of navigating in Arctic waters increase the risk of accidents which may result in oil spills.

Keywords: shipping; arctic; sea ice; environment; climate; black carbon; emissions; pollution; hfo

Sammanfattning

På grund av ett varmare klimat smälter isen i Arktis, vilket under sommarmånaderna underlättar för sjöfarten att ta sig till andra destinationer genom de arktiska rutterna. Rederierna ser till att dra nytta av dessa kortare sträckor och syftet med detta projekt är att undersöka de konsekvenser en ökad sjöfartsverksamhet kan ha på den arktiska miljön. Med hjälp av litteraturgranskning utvärderas olika aspekter som gör Arktis speciellt. Som en följd av den krympande havsisens utbredning kan Arktis utsättas för miljöpåverkan på grund av den potentiella ökningen av sjöfart. Föroreningar från fartyg är därför en viktig del i denna rapport, liksom hur nuvarande och framtida fartygsföreskrifter bidrar till att minska miljöpåverkan I den arktiska regionen. Resultat visar att en ökad havstrafik kan få en lokalt skadlig effekt. Albedo är en viktig faktor när det gäller smältning av isen. Ljusabsorberande partiklar, såsom sot, accelererar issmältningsprocessen vilket bidrar till en blottställd havsyta fri från is. I motsats till is och snö är havsvatten mycket mörkare vilket gör att det absorberar mer värme från solstrålning. Polarkoden ger riktlinjer för sjöfarten i Arktis och IMO arbetar för närvarande med ett HFO-förbud i Arktis. Detta förbud kan främja regionen eftersom den ökade svårigheten att navigera i arktiska vatten ökar risken för olyckor som kan leda till oljeutsläpp.

Nyckelord: sjöfart; arktis; havsis; miljö; klimat; sot; utsläpp; förorening; hfo

Preface

After four years of studying in the marine engineering program, the bachelor thesis is the last piece of the puzzle before graduating and receiving the well-earned diploma. Our choice of writing about shipping in the Arctic was influenced by the current environmental challenges that is being debated and discussed about on a global scale. Writing this thesis has been challenging at some points, yet very fun since we both, the authors of this thesis, shared common interests and had the same objective in mind. In the end, we are very satisfied of what we have achieved with this thesis.

Luckily, there has been some people involved in our work that has guided us in the right direction during the writing phase. We want to thank everybody who has helped us in our endeavours of making this report. A special thanks to our supervisor, Ida-Maja Hassellöv, for the guidance and support during our work. Also, a warm thanks to the people at the library for taking time out of their day to help us with all kinds of trouble. We also want to thank friends and family who provided constructive feedback and provided literature we could use.

This thesis was built upon, and made possible, due to the knowledge and experience gathered from the marine engineering program. A big thanks is therefore directed to the Chalmers University of Technology for this valuable time that has granted us with many future opportunities.

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List of abbreviations

AMAP	*The Arctic Monitoring and Assessment Programme*
BC	*Black carbon*
CH_4	*Methane*
CO	*Carbon monoxide*
CO_2	*Carbon dioxide*
DNV	*Det Norske Veritas*
DO	*Diesel oil*
EGCS	*Exhaust gas cleaning systems*
GHG	*Greenhouse gas*
GT	*Gross tonnage*
HFO	*Heavy fuel oil*
IMO	*International maritime organisation*
IPCC	*Intergovernmental Panel on Climate Change*
LAP	*Light absorbing particles*
LNG	*Liquified natural gas*
MDO	*Marine diesel oil*
MGO	*Marine gas oil*
NASA	*National Aeronautics and Space Administration*
nm	*Nautical miles*
NO_x	*Nitrogen oxides*
N_2O	*Nitrous oxides*
NSIDC	*National Snow and Ice Data Centre*
NSR	*Northern sea route*
NSRA	*Northern Sea Route Administration*
NSRIO	*Northern Sea Route Information Office*
NWP	*Northwest passage*
O_3	*Ozone*
PAME	*The Protection of the Arctic Marine Environment*
PM	*Particulate matter*
SCA	*Suez Canal Authority*
SCR	*Selective Catalytic Reduction*
SDG	*Sustainable development goal*
SECA	SO_x *emission control area*
SO_x	*Sulphur oxides*
SRC	*Stockholm Resilience Centre*
TSR	*Transpolar sea route*
UN	*United Nations*
WWF	*World wildlife fund*

1. Introduction

Due to rising global temperature, the sea ice is decreasing in the Arctic region, which makes the Arctic ocean more suitable for passage by ships during a couple of months a year without the assistance of icebreakers. Simultaneously, the global demand for goods is increasing and so is the global shipping activity, specifically in the Arctic ocean because of the shipping routes through this ocean being significantly shorter than those used today (Humpert and Raspotnik, 2012). Arctic shipping routes enables huge cost and time savings for shipping companies when traveling between the continents Europe, North America and Asia (Humpert and Raspotnik, 2012).

An increase of shipping traffic in the Arctic is a great example of human impact that may be harmful to the climate due to the emission from these ships (Corbett et al., 2010). Black carbon particles from the exhaust gases find their way onto the surface of the ice sheets. This affects the albedo since the dark particles have a better ability to absorb heat from sunlight, causing the melting of the Arctic to accelerate and the ocean to heat faster. Furthermore, increased ship activity also contributes to an increased chance for accidents which can cause oil and chemical spills that can be vital for the Arctic climate.

There are many examples of how shipping has affected different ecological systems negatively in the world's oceans. Non-indigenous species can be transferred from one ecosystem to another through ballast tanks, loud propeller noise scare marine animals and disrupt their communication and oil spills can cause the animals to die, just to mention a few examples. In general, oil spills pose the greatest threat towards the marine environment according to the Arctic Marine Shipping Assessment (AMSA, 2009) as it causes major environmental consequences at a very short time if actions are not taken quickly. The Arctic environment can therefore not be ignored and has to be taken in consideration when new shipping routes emerge in the Arctic. The Polar Code, which was implemented by the International Maritime Organisation (IMO) and entered into force in 2017, will further help with the preservation of the Arctic environment as updated guidelines are stated for ships passing through the region.

1.1 Purpose

The main purpose of this thesis is to highlight potential risks with an increased maritime activity in the Arctic region. How will it affect the Arctic environment? Regulations for ships travelling through the Arctic polar region will be addressed, which can minimize the environmental impact from shipping in the Arctic. Moreover, in order to obtain a sustainable development, future and current ships will have to implement systems that reduce their impact on the environment, which will also be discussed further in this report. A cost analysis between the Northern sea route and the Suez canal route will also be discussed and compared.

1.2 Research questions

The following questions form the basis of our report:

1. What are the potential effects on the Arctic environment caused by the increase of marine traffic?
2. What are the present and possible future regulations of maritime presence in the Arctic region?
3. How can pollution be reduced or prevented from ships in order to have a minimized impact on the environment?

1.3 Delimitations

The following delimitations are made in this study:

- Will not target a specific ship type.
- Limited to secondary research.
- Will not investigate the impact of anything other than shipping in the Arctic region.

2. Background and theory

As the Earth is getting warmer due to climate change, the minimum sea ice extent in the Arctic has rapidly decreased (Intergovernmental Panel on Climate Change [IPCC], 2014) creating new shipping routes through the Arctic polar region (Humpert and Raspotnik, 2012). The benefit of Arctic shipping is mainly the shorter travel distances compared to the regular routes through the Panama and Suez Canal (Humpert and Raspotnik, 2012). In turn, fuel cost savings are made tied with fewer days at sea (Humpert and Raspotnik, 2012). However, the Arctic ocean is complex due to the sea ice in the region being unpredictable each year (AMSA, 2009), making it challenging for ships to navigate through the region.

2.1 Arctic geography and climate

The Arctic region consists of both landmass and an ocean covered in ice and is located on the northern part of Earth’s rotational axis surrounding the geographic location of the North Pole (Szalay, 2017). The Arctic ocean is the smallest of the Earth's oceans and is almost entirely covered with ice and snow. The size of the ice sheet varies depending on the season. As the temperatures rise in the summer and autumn, the ice sheet shrinks allowing ships to pass through the ocean on multiple passage routes. Local fishing vessels can also operate more freely and travel longer distances in the region. During the winter and fall, the low temperatures causes the ice sheet to grow again and reach its full extent, typically in March (IPCC, 2014). Icebergs and glaciers are naturally occurring in the Arctic ocean, they consist of freshwater and globally they make up about 75% of Earth's freshwater supply (National Snow and Ice Data Centre [NSIDC], n.d.).

2.2 Anthropogenic climate change

The Earth’s atmosphere naturally contains greenhouse gases (GHGs) which include water vapor, methane, carbon dioxide, nitrous oxide and fluorinated gases (Intergovernmental Panel on Climate Change [IPCC], 2001). Through the so-called greenhouse effect, these gases have the ability to absorb heat radiation and slow its escape-path to space via the Earth’s atmosphere. This process is vital for all life on Earth by balancing the Earth’s average temperature, without the natural greenhouse effect the Earth would be approximately thirty degrees colder (Ma, 1998).

As GHGs increase in the atmosphere by, mainly, the burning of fossil fuels, so does the outcome of the greenhouse effect, which causes the atmosphere to have excess energy that warm the Earth further (IPCC, 2014). The rise in temperature causes global warming which is the reason for climate change in form of rising sea levels due to the melting of glaciers and ice caps in the Arctic and Antarctica (the melting of sea ice does not impact sea level), extreme weather conditions, wildlife habitat changes and numerous other global impacts (IPCC, 2014). Economic and population growth has influenced an increase in anthropogenic greenhouse gas emissions (Fig. 1) according to the IPCC (2014). The increase has become more rapid since the industrial era and the risk for environmental consequences will keep increasing if the anthropogenic greenhouse gas emissions does not decrease (IPCC, 2014).

The IPCC (2014) concluded the following:

> *“Anthropogenic influences have very likely contributed to Arctic sea-ice loss since 1979 and have very likely made a substantial contribution to increases in global upper*

ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s." (p. 5)

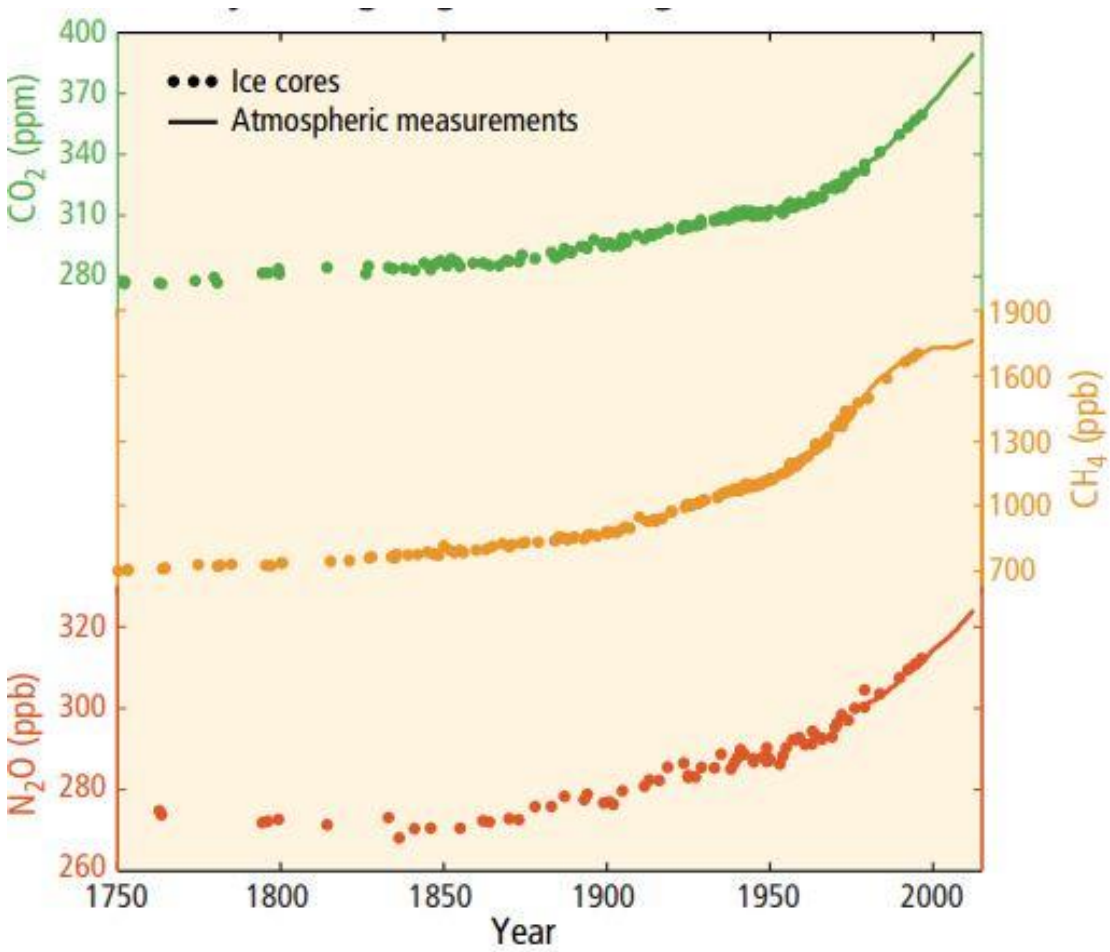

Figure 1. Ice core measurements (dots) and atmospheric measurements (lines) of concentrations of methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) in the atmosphere. Note that N_2O and CH_4 are measured in part per billion and CO_2 in part per million (IPCC, 2014). Reproduced with permission.

In the shipping sector, the annual average emissions of GHGs was estimated to be 3.1% of the global GHG emissions between 2007-2012 (IMO, 2015). Emissions of CO_2 accounted for the biggest portion of GHG emissions from shipping, which was estimated to be 2.8% annually (IMO, 2015).

2.3 Arctic sea ice decline

The annual fluctuation in sea ice in the Arctic is a natural process. In March, the ice sheet reaches its full extent while in September, it diminishes to its minimum (National Aeronautics and Space Administration [NASA], 2017).

Since satellite observations was initiated over the Arctic in 1979 by the National snow and ice data centre, the yearly mean sea ice in the region has decreased between 1979 and 2012 (IPCC, 2014). The IPCC (2014) stated, in their report on climate change, that "The rate of decrease was very likely in the range 3.5 to 4.1% per decade" (p.59). The most rapid Arctic sea ice decrease has occurred during the summer months, which is due to global warming causing warmer summer temperatures (IPCC, 2014). The decrease of the summer sea ice minimum in September is estimated to have been between 9.4 to 13.6% per decade (0.73 to 1.07 million km²) between 1979 and 2012 according to the IPCC (2014).

Further research made by NASA's Earth observatory (2017) indicate that the summer ice extent in September 2002 reached a record low minimum. The summer ice sheet has since not recovered and has, with annual fluctuation taken in consideration, declined even further hitting new record lows (NASA, 2017). Furthermore, a median sea ice extent for March and September was conducted by NASA through satellites between 1979 and 2000 and later compared with annual maximum/minimum sea ice extents. Since September 2002, the summer ice has not reached an extent near the median long-term average (Fig. 2). The maximum ice extent in March has been able to recover better (NASA, 2017), however, it has, as mentioned earlier, still decreased, but at a slower pace.

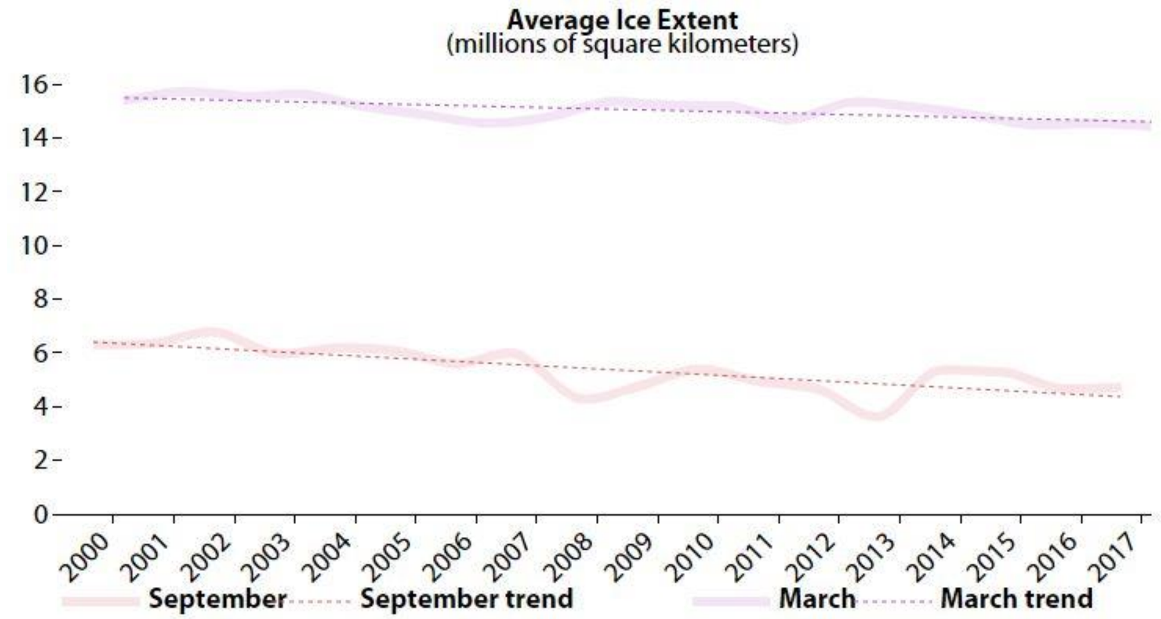

Figure 2. Average ice extent 2000-2017 (NASA, 2017). Reprinted with permission.

2.3.1 Melting ice affects the albedo

Albedo is a measurement of a surfaces reflective capabilities and determines how well a body absorbs heat from solar radiation (NSIDC, n.d.). It is measured on a scale from 0 to 1 where the higher end of the spectrum represents high reflectivity (low heat absorption) and the lower spectrum represents low reflectivity (high heat absorption). (NSIDC, n.d.) also provide some albedo values. Sea water has a albedo value of around 0.06 while bare ice is stated to be somewhere between 0.5 to 0.7 and snow covered ice can have a value of 0.9.

NASA's Earth observatory (2017) states that as a larger area of the ice sheets melts away, the region's properties will change, since seawater takes the ice's place. The sea water is much darker and therefore has a lower albedo. This means that it absorbs more heat from sunlight compared to the bright ice. The exposed sea water will further increase the rate at which the polar ice melts, creating a self-reinforcing effect. Additionally, the albedo can be altered in other ways such as surface area pollution from soot (Clarke & Noone, 2007).

2.3.2 Importance of the Arctic sea ice for marine species

Unlike glaciers and icebergs, which are land masses made from frozen snow, sea ice is frozen ocean water that forms and melts in the ocean. Sea ice has a big impact on animal species and the climate in the Arctic (Arctic Climate Impact Assessment [ACIA], 2004). It is indispensable for the survival of Arctic animals including polar bears, ice-dependent seals, sea birds and the walrus (ACIA, 2004). As mentioned in sect. 2.4, the summer sea ice extent is decreasing (IPCC, 2014), meaning Arctic marine species have much less sea ice to rely on during summertime. Increasing shipping activity during the summer months will further disturb the animals, which will likely become more dependent of land areas where they will be vulnerable due to the encountering of new threats unknown to them (ACIA, 2004). The Arctic climate is also heavily dependent on the sea ice, as it affects cloudiness, ocean currents, humidity, the albedo and the exchange of heat at the ocean surface (ACIA, 2004).

Polar bears
Polar bears are excellent swimmers; however, the sea ice is vital for their survival as they move between areas through ice corridors and hunt ice-living seals (ACIA, 2004). Moreover, female polar bears emerge from their burrows with their cubs during springtime to hunt for food, which mainly consist of ice-living seals. During this time, the female has not eaten anything for 5 to 7 months and the hunting phase, including the survival of the cubs, is highly dependent on good ice conditions. Sea ice decline could therefore have severe consequences for the polar bear as a species, or as Hassol says in the Arctic climate impact assessment (2004), “Polar bears are unlikely to survive as a species if there is an almost complete loss of summer sea-ice cover” (p.58).

The Walrus
The ice edge near coastlines are important areas for the walrus as the depth in these areas are perfect for hunting clams and other shellfish. Walruses rely on sea shelves for feeding and on the sea ice for resting and travelling long distances (ACIA, 2004). As the sea ice extent retreats from the shorelines, walruses cannot hunt clams as the sea gets to greater depths (World Wildlife Fund [WWF], 2018). The declining sea ice, especially in summertime, has led walruses to climb on shore and pack in masses in a phenomenon known as a “haulout”. These haulouts threatens the animals, they are very timid, and the sound of an airplane or human activity can cause a deadly stampede as they rush towards the sea (WWF, 2018). A disturbance of a haulout in Cape Schmidt, Russia in 2017 caused 500 walrus deaths (WWF, 2018).

Seals
There are many types of ice dependent seals in the Arctic including ribbon seals, bearded seals and ringed seals. These species rely on the ice when giving birth to and nursing their pups and when resting (ACIA, 2004). Decreasing sea ice causes the ringed seals to be the most threatened species of seals according to the ACIA (2004). Sea ice is a part of their lifestyle, they construct lairs with snow and raise their pups on the ice, which requires the ice to be stable throughout the spring. Early ice-breakage might separate the pups from their mother, leading to an increased death toll among new-born.

Seabirds
The ivory gulls and little auks are some of the Arctic living seabirds that heavily rely on the

sea ice. Although they nest and breed on rocky cliffs, they scavenge for food on nearby sea ice and fish through cracks in the ice (ACIA, 2004). The ivory gulls depend on the sea ice edge near their nests, however, as the ice edge retreats further due to a warmer climate, they suffer great consequences as they cannot hunt for food under normal circumstances (ACIA 2004). The Arctic climate impact assessment (2004) estimates that the ivory gulls in the Canadian Arctic has decreased by 90% in the last 20 years.

2.4 The Arctic Council

The United States, Canada, Iceland, Denmark (which includes Greenland), Russia, Norway, Sweden and Finland are the eight countries that constitutes the landmass of the Arctic. The mentioned countries form the Arctic council, which is an intergovernmental forum that seek to protect the Arctic environment through cooperation among the Arctic states, Arctic inhabitants and Arctic native communities (Arctic council, 2018). Furthermore, the council consists of six organisations that are permanent participants representing the Arctic native people (Arctic Council, 2018). The work carried out by the council is divided into six different working groups, each having their own area of focus:

- The Protection of the Arctic Marine Environment (PAME)
- The Arctic Monitoring and Assessment Programme (AMAP)
- The Arctic Contaminants Action Program (ACAP)
- The Conservation of Arctic Flora and Fauna Working Group (CAFF)
- The Sustainable Development Working Group (SDWG)
- The Emergency Prevention, Preparedness and Response Working Group (EPPR)

The working groups regularly produce assessments regarding the social, ecological and environmental conditions in the Arctic (Arctic Council, 2018). Aside from the working groups, the council has also established three agreements among the member states of the council (Arctic Council, 2018):

- The Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic (Arctic council, 2011).
- The Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic (Arctic council, 2013).
- The Agreement on Enhancing International Arctic Scientific Cooperation (Arctic council, 2017).

The aim with the agreements is to strengthen the cooperation between the member states so that all states work according to the same rules and standards.

The Arctic council is a forum and all the projects are funded by the member states (Arctic Council, 2018). Assessments, guidelines and recommendations issued by the Arctic council is not enforced upon the member states and the council cannot implement anything themselves in any member state (Arctic Council, 2018). Each state has their own responsibility of implementing material provided by the council (Arctic Council, 2018).

2.5 The sustainable development goals

The United Nations (UN) general assembly adopted 17 new sustainable development goals (SDG) on the UN's 70th-year anniversary in 2015 (UN, 2015). In order to achieve a sustainable future, the SDGs are important to reach well-being among humans, animal species and the environment. The 17 goals address global challenges related to not only Inequality, poverty, peace and justice, but also to the environment, clean energy, and marine life (UN, 2015). Most of the SDGs are relatable to the Arctic. But since shipping in the Arctic has the greatest impact on the climate and the Arctic marine environment (Corbett et al., 2010), SDG number 13: Climate action and 14: Life below water (UN, 2015), is of the most importance for the sustainability of the Arctic region.

Goal 13: Climate action

The main headline for SDG 13 is that urgent actions are required to combat climate change (UN, 2015). As mentioned in section 2.2, the burning of fossil fuels is one of the major causes for climate change due to excessive emissions of GHGs (IPCC, 2014). A reduction of GHGs, not only from shipping, but also from e.g. industries and vehicles, will therefore be of great importance to tackle climate change. Another concern is black carbon emissions, which is a component of particulate matter, released after the combustion of fossil fuels (Andersson et al., 2016). Due to the properties of BC being associated with increased melting rate of snow and ice (AMSA, 2009), reducing BC emissions, especially from shipping in the Arctic, will bring countries closer to achieving the 13th SDG.

Goal 14: Life below water

The seas, oceans and marine resources must be used with sustainability in mind (UN, 2015). The SDG number 14 is about the marine environment in which a number of targets are listed including significant reduction of marine pollution by 2025 and the elimination of overfishing by 2020 (UN, 2015). Pollution from shipping include oil spills and air and water pollution. Oil spill poses the greatest threat towards marine environments (AMSA, 2009) and the Arctic is considered a highly sensitive region (AMSA, 2009). Crew members of vessels traveling through the Arctic will therefore need additional training and education to be aware of the challenges of Arctic shipping. The regulations of the Polar Code also contribute to the preservation of the Arctic marine environment (IMO, 2017a), which will further help with achieving a sustainability for the life below water.

2.6 The blue economy

As the Arctic ice is melting, an ocean of opportunity is emerging and the world is seeking to explore and exploit its resources for economic growth (Johnson, 2019). The blue economy model is much a like the green economy model. The goal with the green economy model is to gain economic growth, improve human health and comfort living and strive towards social equity without over-exploitation of natural resources and diminishing environmental risks (UN, n.d.). The blue economy model strives towards the same goal, but specifically for the preservation of the marine environment, including the Arctic region.

The blue economy model is closely related to and dependent of the UN's 17 SDGs.
The Stockholm Resilience Centre (SRC), an international research unit at Stockholm University in Sweden, has presented the SDGs in a “wedding-cake” model (see Fig. 3) in which they divided the SDGs into four layers (from bottom to top): biosphere, society, economy and partnerships. The aim with the model is to demonstrate that not all the SDGs are of equal importance. Societies and economies are dependent on the wellbeing of the biosphere and partnerships are important in all categories (SRC, 2016). Therefore, the four SDGs in the biosphere weights the most and are the most important to achieve in order to fully succeed with the SDGs concerning societies and economies (SRC, 2016).

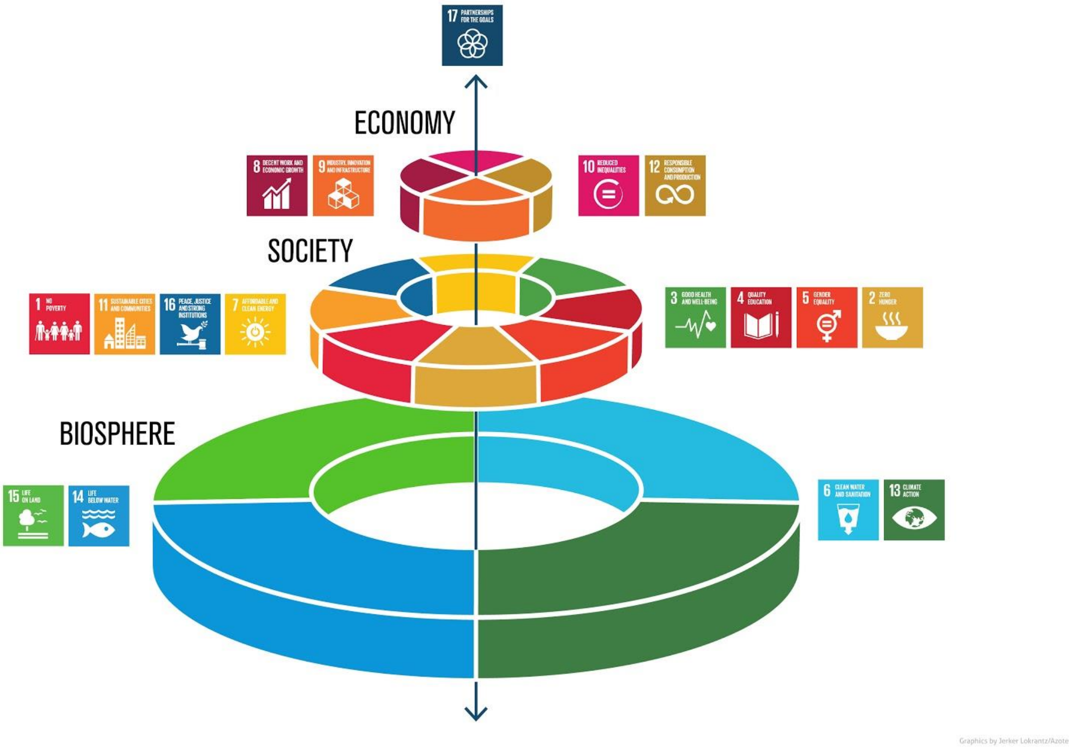

Figure 3. The “wedding-cake” model (Azote Images for Stockholm Resilience Centre, Stockholm University). Reprinted with permission.

Det Norske Veritas-GL (DNV-GL, 2019) made a report about the Norwegian Arctic in which they implemented the “wedding-cake” model focusing the SDGs on the Arctic. Conclusions are made on what needs to be done in order for the Arctic to achieve and maintain sustainability in accordance with the SDGs.

Biosphere

In the “wedding-cake” model, the SDGs divided into this category are life below water, climate action, life on land and clean water and sanitation. In order to maintain sustainable ecosystems in the Arctic, human activities such as ship traffic, discharges from ships and land, the fishing industry and activities related to oil and gas (DNV-GL, 2019) needs to be carefully monitored and regulated.

Society

The biggest number of SDGs lies in the society category, which consists of SDGs related to peace, social justice, good health and extermination of poverty (DNV-GL, 2019). Eliminating the rising economic inequality in the Norwegian Arctic (DNV-GL, 2019), and for the rest of the Arctic’ inhabitants, is key to ensure the wellbeing of the Arctic human population. It is up to each Arctic state to ensure the wellbeing of their inhabitants in the forms of providing good healthcare, keeping the peace and providing proper education (DNV-GL, 2019).

Economy

In the economy category, attention is laid on the SDGs involving industries and infrastructure, responsible production and consumption, reduced inequalities and economic growth without over-exploitation of the Arctic natural resources (DNV-GL, 2019). In the Norwegian Arctic, the employments that are related to the ocean consist of 20%, meaning that Norway is highly dependent on both the Arctic ocean and the North Sea (DNV-GL, 2019). A major goal in the

Norwegian Arctic is the reduction of greenhouse gas emissions in the transportation sector, which is achieved by choosing low-emission cargo transports and developing the railway infrastructure (DNV-GL, 2019). Moreover, sustainability has to be considered by every industry and company in order to grow economically with less/no impact on the environment (DNV-GL, 2019). By introducing more environmental education in forms of programs that explain the importance of increasing material recovery and reducing food waste (DNV-GL, 2019), sustainability can be achieved for all of humanity.

Partnerships
The Arctic council has established good partnerships with the Arctic countries, which is important when the potential of economic growth in the Arctic rises (DNV-GL, 2019). However, during a recent meeting in Rovaniemi, Finland, involving representatives from the 8 Arctic states, an agreement on the challenges in the Arctic failed to be signed (Johnson, 2019). The United States refused to sign the agreement by reason of not acknowledging the wording used in the agreement, which states that the Arctic is threatened by climate change (Johnson, 2019). Moreover, as China and Russia are currently investing in the Arctic in order to benefit economically (Auerswald & Anderson, 2019), the United States sees it as an attempt to gain control over the Arctic area ("US warns Beijing's Arctic activity", 2019). This kind of tense political situation and lack of partnership can lead to drastic measures by countries like the United States in order to be competitive, which could affect the Arctic negatively. Partnerships in the form of strengthened global relations between countries are crucial to reach all SDGs (DNV-GL, 2019).

2.7 Arctic ocean routes

The melting ice allows new sea routes through the Arctic ocean to emerge which could benefit shipping companies by saving fuel cost and travelling time (Humpert & Raspotnik, 2012). Three major potential routes (Fig. 4) are discussed further below.

2.7.1 The Northern Sea Route (NSR)

The NSR runs along Russia's Arctic coast which makes transitions between European and Asian countries easier (Rodrigue, 2017). The regular sea route used today between Europe and Asia is through the Suez Canal, which covers a distance of ca 21,000 km. The NSR through the Arctic ocean decreases the travelling distance between the two continents by a whole 8,200 km, making the journey only 12,800 km and cutting shipment time by 10-15 days (Rodrigue, 2017).

Beluga Foresight and Beluga Fraternity are two German ships who successfully managed to complete the first commercial maritime journey across the NSR in 2009. The crossing, made possible with the help from a Russian icebreaker, was made from the South Korean city of Busan to Netherlands capital, Amsterdam, through the Arctic ocean (Rodrigue, 2017). Since then, the route has increased in popularity making 4 vessels travel across the route in 2010. That number increased significantly in 2011 when 41 vessels completed the journey to various locations followed by 46 vessels in 2012 and 71 in 2013. However, the number of voyages decreased greatly between 2014-2016 due to the ice extent recovering, with a slight increase in 2017 and 2018 (Northern Sea Route Information Office [NSRIO], 2018).

In 2018 alone, 18,174 passages were made by vessels through the Suez Canal (Fisher & Smith, 2019). If the NSR can be open for longer periods during the year, the route could be a serious competitor to the commercially used route today through the Suez Canal. However, that is currently uncertain as it depends on the sea ice extent in a distant future. Nonetheless, it is of high certainty that the NSR will be completely ice-free during two months by 2030 (Torrent, 2019).

2.7.2 The Northwest Passage (NWP)

The NWP is a maritime route through the Arctic ocean along the North American coast that creates a shorter connection between the Atlantic and Pacific ocean. Vessels travelling this route must go through the Canadian Arctic Archipelago, which is an area in the Arctic ocean consisting of more than 36,500 islands (Adams & Dunbar, 2015). Due to the density of these islands, the route can be accomplished via several routes through the Arctic Archipelago (AMSA, 2009). Travelling on the NWP shortens the distance between Western Europe and East Asia by over 9,000 km compared to the regular route through the Panama Canal (Rodrigue, 2017).

Although the route is only possible to navigate a few months a year, July to September (Swoop Arctic, n.d.), the route is projected to be used on a regular basis for commercial purposes by 2020 (AMSA, 2009). However, due to the annual ice extent and thickness being unpredictable on the NWP by each year, it is not certain that the route can be used annually (Atkisson et al., 2018). The government of Northwest territories (2015) mentioned that a total of 30 vessels travelled the route in 2012 compared to 17 vessels in 2014 due to a colder and shorter summer period than in 2012. This concludes that the future of the route is uncertain for annual use and has to be evaluated each year.

2.7.3 The Transpolar Sea Route (TSR)

The easiest and most effective way of transport through the Arctic is straight through it, which is normally done in ice free oceans. Although it is not yet possible to cross the Arctic ocean straight from the Bering strait to the Atlantic Ocean, a possibility might arise in the future and the route already has a name - The transpolar sea route. The route is considered hypothetical (Rodrigue, 2017), however, Atkisson et al. (2018) argues that the route will be possible to navigate by 2030 in the summer period as it is expected that the Arctic will be completely ice-free in the summer months by 2050.

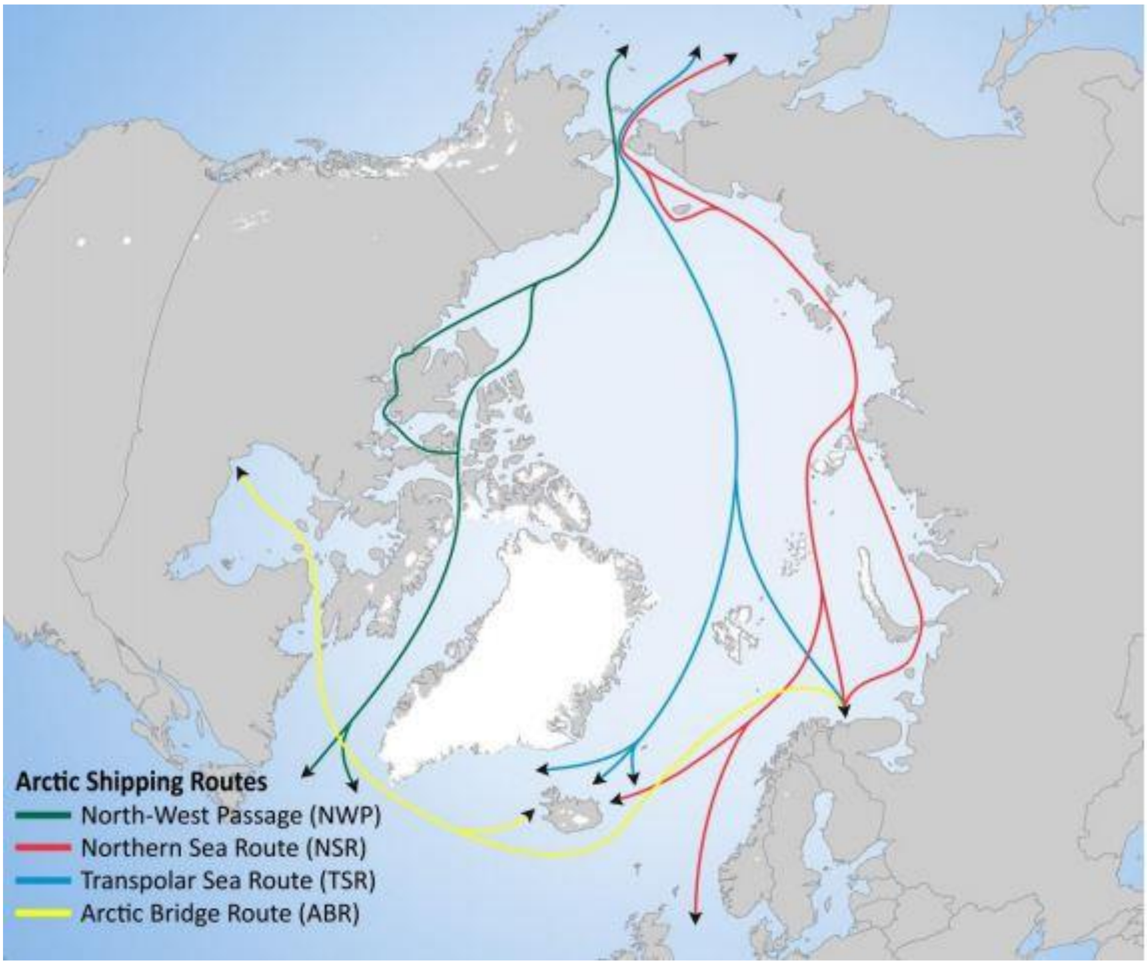

Figure 4. Arctic shipping routes (Humpert and Raspotnik, 2012), The Arctic bridge route is excluded from this study. Reprinted with permission.

3. Method

The method in this thesis will be secondary analysis which means that it will be based on research that has already been published. The thesis will therefore be based on already established research; no primary research will be performed. The means of gathering information will be reading and analysing research papers and other academic texts, so called literature review.

3.1 Literature review

Literature review is a useful tool for identifying if a subject lacks knowledge or if someone's findings need further research. With access to a wide range of literature we are allowed to gather information with ease and to establish an overview of a subject. When we had a better understanding of the topic and could discuss more specifically what our report should be about.

Backman (1998) writes that the reviewed material should come from literature, original articles or other primary sources. Some of this data or sources are for example theses, public inquiries, academic articles, monographs, and books. The texts vary in the amount of processing and peer review before its publication, which determines the reliability of the text in a scientific point of view.

According to Holme and Solvang (1997) the collected data should be categorized into primary and secondary data. The determining factor is the writer’s relation to the referred content. For example, if the authors have participated in the gathering of data or if they use information from reports collected by other people.

We took an interest in the Arctic region as we noticed the lack of reports on shipping in the Arctic. When the research question at hand was finally defined, it was possible to proceed with the research. When the various factors affecting the Arctic was illustrated, empirical data was needed to back up the claims.

After the sources had been collected and reviewed, they could be processed and added to our report as evidence of our points.

3.2 Procedure

The first step in finding relevant data for the thesis was to do a wider search on the different search engines listed below, with the goal to find primary sources. The searches could then be narrowed down and be increasingly specific. Furthermore, we searched for highly cited scientific papers which means that they are referenced in many works by other people and is an indication of quality.

Search engines
Wiley
Web of Science
Britannica
Google Scholar
Reg4Ships

Search terms
Arctic albedo, Albedo feedback, Light absorbing particles, Arctic AND pollution, “Arctic pollution”, Arctic AND “emissions to air”, Arctic AND “oil spills”, “Black carbon” AND Arctic, “Arctic shipping routes”, Arctic AND routes, “Sulphur oxides” AND scrubber, “Marine scrubber”, “Selective catalytic reduction”

3.3 Credibility and research ethics

It is important to know what you are analysing. Under the whole process we constantly reflected on the relevancy of the source material to our question at hand. Being unbiased towards the subject is critical in developing a valid analysis of the chosen source material. Furthermore, it is important to be objective when handling the data. The gathered information may be affected by the authors personal values and scientific approach which may affect our result.

4. Results

The results will present possible effects the Arctic can face due to pollution from shipping. Pollution prevention methods will therefore also be presented in order to protect and preserve the Arctic environment and the animal species living there. The connection between albedo and sea ice will be explained followed by a cost analysis of a made-up scenario of a vessel travelling through the NSR and the Suez Canal route.

4.1 Emission to air

Ships are powered by engines and fuels that emit carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), water vapor, black carbon (BC) and other particulate matter (PM) (AMSA, 2009). Each of these emissions have different effects on the climate and/or environment, some emissions are more harmful than others and their environmental consequences can be noticed both locally and globally.

CO_2 is a greenhouse gas emitted from ships after combustion (AMSA, 2009). All of the emitted CO_2 and other GHGs has a global impact on the environment (IPCC, 2014). The ACIA working group (2004) found out that there is a relationship between the global temperature and CO_2 concentrations in the atmosphere. Measured data and historical data derived from ice cores showed that the global temperature rise or fall simultaneously when CO_2 concentrations increase or decrease (ACIA, 2004).

Another potential problem is Arctic haze that can be formed as a consequence of the exhaust gases being released into the atmosphere. The haze can affect visibility through excessive amounts of Ozone (O_3). Ozone is formed by chemical reactions of NO_x that in turn creates particles when reacting with CO. The AMSA (2009) claim that increasing summertime levels of O_3 can be directly linked to an increasing shipping activity during the minimum ice sheet extent occurring annually in September.

Both SO_x and NO_x emissions from shipping contribute to acidification of land and sea (Andersson et al., 2016). During rainfall, the water drops absorbs the SO_x emissions in the atmosphere, creating acids and causing a phenomenon known as acid rain which acidifies land and sea (Andersson et al., 2016). NO_x emissions also contribute to over fertilization, inducing excessive amounts of algae, which can be toxic to marine animals in some forms (Andersson et al., 2016).

4.1.1 Black carbon

BC is proven to accelerate the melting of snow and ice due to its climate forcing effects in the form of darkening the snow and ices white surface which prohibits their sunlight reflecting properties (AMSA, 2009). BC from shipping affects the snow and ice locally in the Arctic due to the emissions being emitted in close proximity to the snow and ice (AMSA, 2009).

Due to the light absorbing properties of BC, the particles affects the albedo of the snow and ice in the Arctic. The albedo effect is an important mechanism when it comes to the melting of the Arctic sea ice. Ocean water has a low albedo compared to the bright polar ice meaning it will absorb a lot more heat from solar radiation. As the global temperature rises and the ice sheets starts to melt, a larger surface area of the Arctic sea will expose water. This creates a positive feedback loop called ice-albedo feedback (Mann & Selin, 2019). If the shipping industry contributes to more exposed water, by breaking the ice and keeping the routes ice free, it will accelerate the process even more. The impact from shipping will most likely be limited to the coast lines since they strive to take the shortest routes due to economic reasons.

Measurements of ice and snow albedo in Antarctica (Brandt et.al, 2005) was taken and thick first-year ice was found to have an albedo of 0.49. When snow covered the ice, the albedo value was increased considerably. A layer of just 5-10 mm increased the albedo from 0.49 to 0.81 which was close to values measured for deep snow. Other types of ice were also measured such as “young grey ice” which had an albedo of 0.25 and nilas (an early stage of ice) which had an albedo of 0.14. Comparatively, the albedo value of open water is 0.07. Additionally, it was found that the weather and season affected the reflective properties of the ice and snow. Cloudy weather increased the albedo value of first-year ice from 0.49 to 0.54, an increase of about 10%. During the spring months (September to November), snow covered first-year ice had an albedo value of 0.81 in clear weather conditions which then decreased to 0.75 during the summer months (December to February).

Albedo and light absorbing particles

Another aspect of the albedo effect is the pollution of the sea ice from light absorbing particles (LAP). When the ships pass through an area, carbon and other dark particles are released as a rest product from the combustion process and carried into the snow by the exhaust gas. These particles have a low albedo and absorb most of the light they come in contact with. Comparatively the snow is bright and have a high albedo, so the LAP alters the overall albedo of the ice sheets. If a route is heavily trafficked, there could be a significant impact in that region. More and more LAP would build up over time as the ships pass by. The ice sheets would melt faster as a result of more exposed ocean water.

Marks & King (2013) carried out an experiment where snow from different regions was collected and then analysed to determine the impact of BC. Both first-year and multi-year ice was tested with addition of BC in a range between 1 and 1024 ng/g within 5 cm from the surface. It was found that an increase in BC content from 1 to 8 ng/g equated to a reduction of the albedo compared to the initial value. The albedo decreased to 98.7% in first-year ice and 99.7% in multi-year ice respectively. This means that first-year ice is more vulnerable to BC pollution compared to multi-year ice. It was also found that the relation between the decrease in albedo and the mass ratio of BC is non-linear. For example, in first-year ice, if the mass of BC was doubled from 2 ng/g to 4 ng/g; 99.7% of the original albedo value was retained, but doubling the mass from 512 ng/g to 1024 ng/g yielded a value of 54% of the value at 512 ng/g. Similar results was reported in multi-year ice but with a less severe drop in albedo.

Black carbon and engine load

BC emissions are linked to engine load and fuel quality (Lack & Corbett, 2012). Engine load can be 0% to 100% with 0% meaning full stop and 100% being maximum ship speed. Low engine loads equal more BC emissions, as the load increases, the BC emissions decrease. (Lack & Corbett, 2012). A study done by Lack and Corbett (2012) states that BC emissions increase by 3 to 6 times when ships are sailing at very low speeds (less than 25% engine load). Considering that the Arctic ocean is full of sea ice and being hard to navigate through, it can be considered that ships in the region run at lower speeds at some points, thus emitting a higher portion of BC emissions.

Heavy fuel oil

The most used fuels for propulsion and energy generation on board are low-quality residual fuels like heavy fuel oil, which is the cheapest alternative for shipping companies, but also the dirtiest fuel (AMSA, 2009). HFO contain high amounts of BC, heavy metals, sulphur aerosols and ash (AMSA, 2009) which will accelerate the melting of snow and ice even further. The IMO has not issued an emission control area in the Arctic, which means ships are free to use HFO as fuel according to the global limit for sulphur content in fuel which is currently 3.5% (IMO, 2008). However, the new global sulphur limit of 0.5% will come into force by 1 January 2020 as confirmed by the IMO (2019). Moreover, A potential ban on HFO in the Arctic is currently being negotiated (Nunatsiaq news, 2018) which could be very beneficial for the Arctic environment.

4.1.2 Emissions from shipping in the Arctic

Winther et al. (2017) has calculated emissions by shipping in the Arctic by using, “satellite AIS data, ship engine power functions and technology stratified emission factors” (p. 2). BC particles, SO_2 and NO_x emissions are based on the fuel consumption and are sorted by each year (Fig. 5). After 2015, a fuel switch is made from fuel oil containing 1.0% sulphur to marine diesel oil (MDO) or marine gas oil (MGO) due to the new regulations in sulphur emission control areas (SECA) regulated in MARPOL 73/78 Annex VI (IMO, 2008). The majority of the vessels are fishing vessels (Winther et al., 2017).

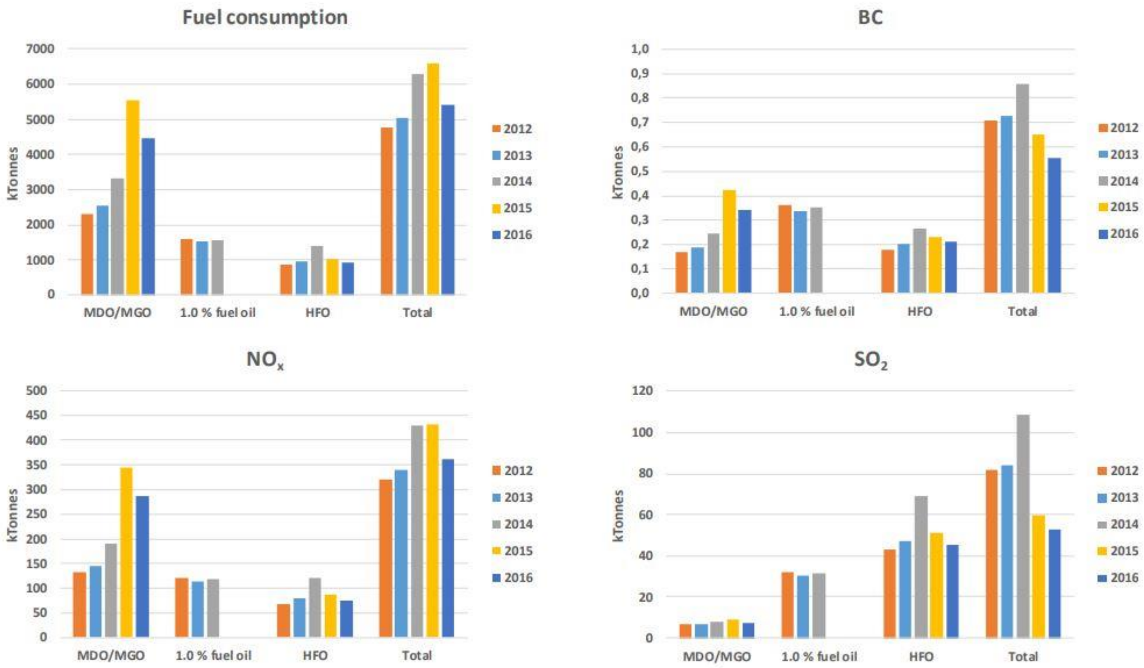

Figure 5. Total fuel consumption, NO_x, SO_2 and BC emissions from shipping in the Arctic 2012-2016 (Winther et al., 2017). Reprinted with permission.

The calculated emissions show the current situation in the Arctic in terms of emission to air. This data will be used to monitor the future emission development caused by ships in the Arctic (Winther et al., 2017). However, by using the collected data, the authors have made emission projections that are possible by 2020, 2030, and 2050 based upon three scenarios:

- Baseline scenario (Fig. 6) - The authors assume more vessels use liquified natural gas (LNG) as ship fuel and that exhaust gas cleaning systems (EGCS) for the reduction of SO_x are used together with vessels running on HFO.
- SECA scenario (Fig. 7) - Current SECA areas in the North sea/Baltic sea and America are expanded to cover the Arctic inventory area. The studied vessels running on HFO

without an EGCS is also assumed to be switching fuel to MGO/MDO (Winther et al., 2017)

- HFO ban scenario (Fig. 8) - HFO is assumed prohibited in the Arctic inventory area. Vessels running on HFO is assumed to use LNG or MGO/MDO as fuel instead (Winther et al., 2017).

The results of each scenario conducted by Winther et al. (2017) is presented below. The measured data of fuel consumption and emission data of BC, NO_x and SO_2 from 2016 is used in each of the figures as comparison to the projected emissions of 2020, 2030 and 2050. In all scenarios, HFO is considered having a sulphur content of 2.45% (Winther et al., 2017). In the baseline scenario, the 0.5% fuel oil represents fuel oil with a sulphur content of 0.5%. The grand total value in each figure represents the total value from all fuel types.

Baseline scenario

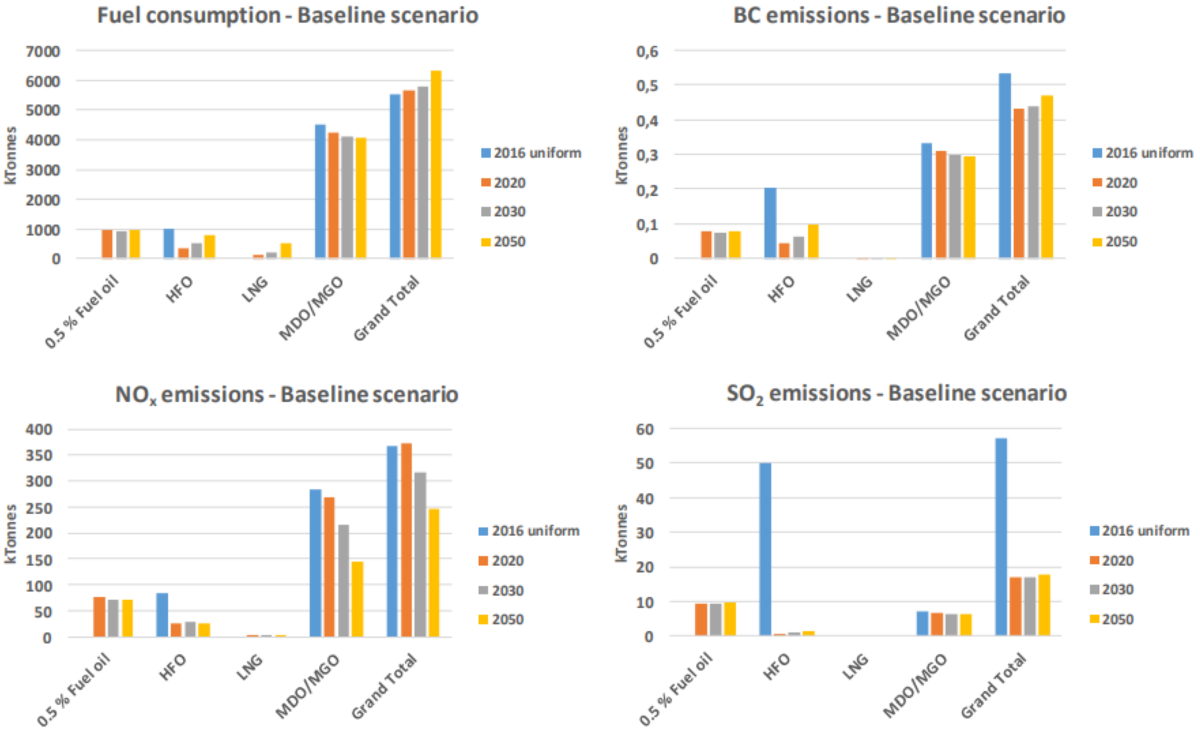

Figure 6. Emission projections according to the baseline scenario, compared with measured emission values from 2016 (Winther et al., 2017). Reprinted with permission.

SECA scenario

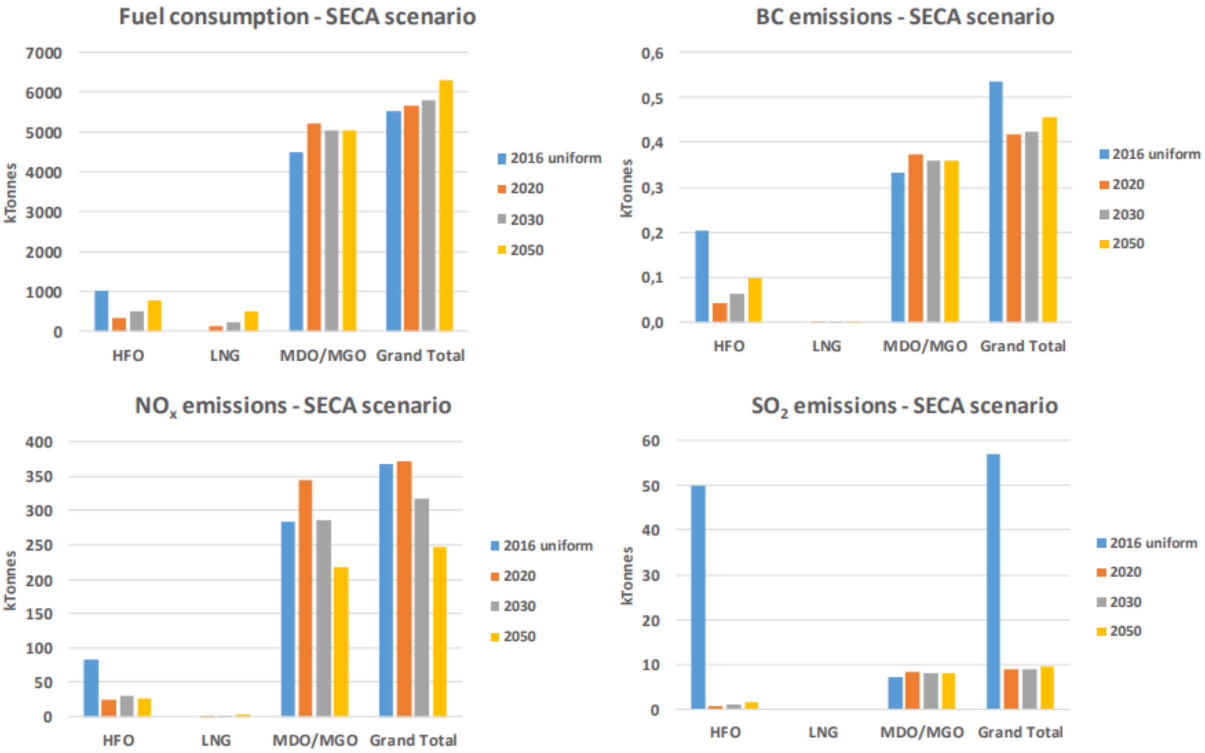

Figure 7. Emission projections according to the SECA scenario, compared with measured emission values from 2016 (Winther et al., 2017). Reprinted with permission.

HFO ban scenario

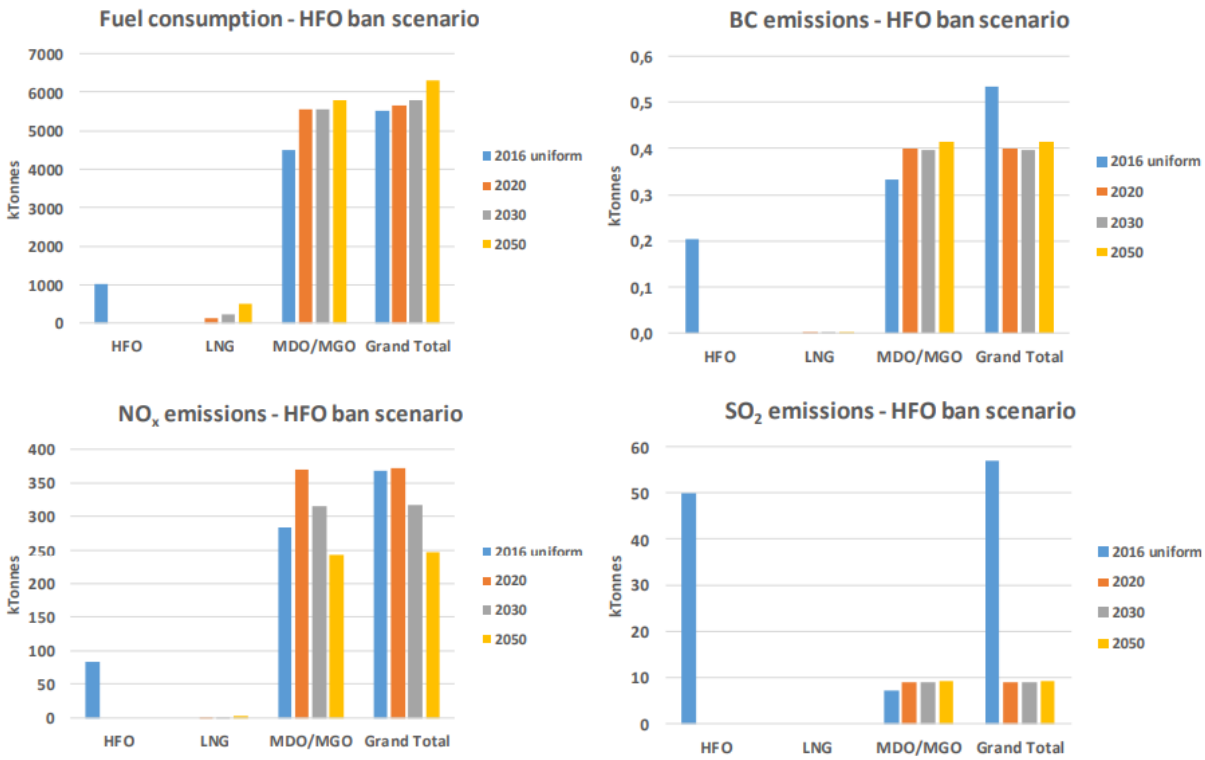

Figure 8. Emission projections according to the HFO ban scenario, compared with measured emission values from 2016 (Winther et al., 2017). Reprinted with permission.

The most significant decrease in all three scenarios is the SO_2 emissions due to the assumptions that EGCS are used on all HFO vessels and due to HFO being out-phased (Winther et al., 2017). BC emissions decrease in all scenarios when HFO sulphur content is decreased in 2020 or when HFO is banned (Winther et al., 2017). The fuel switch from HFO to MGO/MDO keeps the BC emissions at almost the same level between 2020 and 2050 (Winther et al., 2017). The fuel switch is also the reason for higher NO_x emissions in 2020 in 2 of the 3 scenarios. The NO_x emission decrease between 2030 and 2050 is assumed by reason of the new NO_x emission control areas that will apply to the North and Baltic Sea by 2021 (Winther et al., 2017).

4.2 Oil spills

An increased maritime activity in the Arctic poses an increased risk for oil spills in Arctic waters primarily caused by accidents or by people onboard making mistakes. Since the Polar Code came to force in 2017 by the IMO, ships passing through the Arctic and Antarctica are encouraged to follow stricter rules. The use of HFO was banned in Antarctica but not in the Arctic, one of the major concerns is therefore vessels running on HFO or tankers transporting crude oil via the Arctic. At present, no oil spills have occurred in the polar region (AMAP, 2007), but the consequences can be much more severe compared to other oceans due to the sea ice. There are many scenarios of how oil spilled in the Arctic behave in ice covered waters (as illustrated in Fig. 9) which makes it more difficult to clean up. The pollution will last longer when oil is trapped in the ice and oil can be transported to other areas far away from the original spill source (Det Norske Veritas [DNV], 2011). In winter, limited daylight, harsh weather and navigational difficulties could further harden the clean-up process when a potential spill occurs (AMAP, 2007).

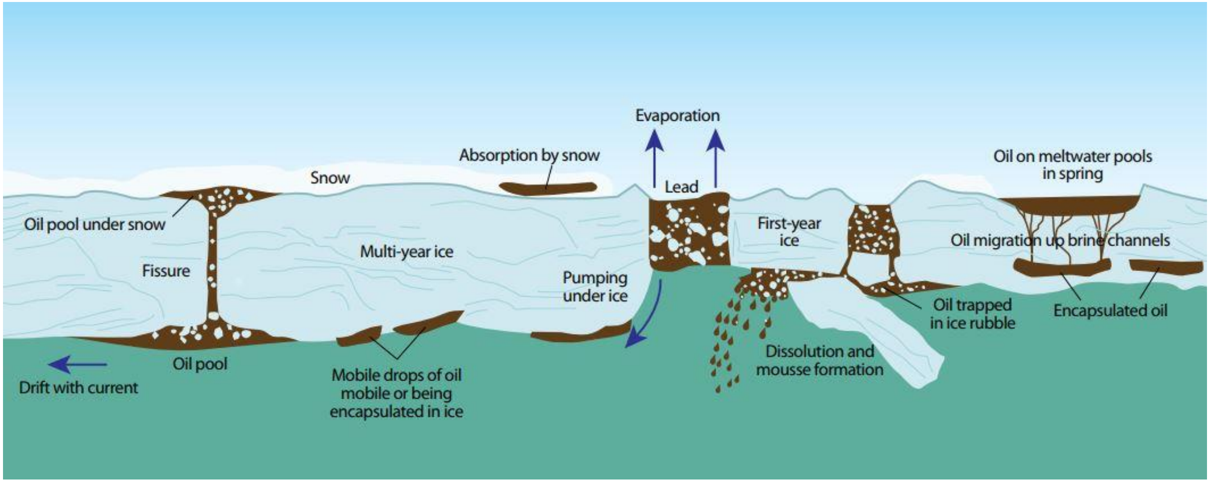

Figure 9. How oil behave in ice covered waters (AMAP 2007). Reprinted with permission.

When any oil is spilled in water, several weathering processes begin including dispersion, evaporation and emulsification (DNV, 2011). The evaporation process of lighter fuel components from the surface begins almost immediately when the oil is spilled in water, other water-soluble components disperse and dissolve in the water (Andersson et al., 2016). The duration of the weathering processes varies depending on the fuel properties, water temperature, wind and waves (DNV, 2011). A test reported by DNV (2011) has proven that it takes much longer time for the weathering processes to tackle an oil spill of HFO compared to a diesel oil (DO) spill. In the test, all of the DO had naturally dispersed (80%) and evaporated (20%) from the water surface in just 3 days, while most of the HFO was still present on the surface after 20 days (DNV, 2011). Moreover, the HFO had started to emulsify and reached its maximum water content of between 40-80% after just 3-5 days (DNV, 2011), expanding the volume of the oil/water-mix 2-5 times (Andersson et al., 2016).

Exxon Valdez

The Exxon Valdez was a tanker vessel transporting Crude oil that ran aground 24th of March 1989, in Prince William Sound, Alaska during a voyage from Valdez, Canada (History, 2018). The vessel started leaking oil and it is estimated that 11 million gallons (41 640 m^3) of oil leaked into the ocean making it the worst oil spill in U.S history until the Deepwater horizon disaster in 2010 (History, 2018). The spill had a major impact on wildlife killing an estimating 250 000 seabirds, 300 seals, 3000 otters and 22 killer whales (History, 2018). The population of otters did not recover until 2014 and the herring, which was an important source of income for fishermen, had not recovered yet in 2018 (History, 2018). Local fisheries went bankrupt when the salmon and herring population collapsed the following years after the oil spill, affecting small towns such as Valdez and Cordova. Economic losses were estimated to be $2.8 billion (History, 2018).

This disaster shows the magnitude of an oil spill in open waters. An accident like this in the Arctic could have been even more difficult to clean up due to the sea ice and other climate conditions as mentioned earlier. Since the Exxon Valdez was a single hulled vessel (History, 2018), meaning that only one layer of metal was separating the oil from the water, the importance of regulations is key to prevent oil spill disasters. Directly after the disaster, the Oil Pollution Act of 1990 went into force in the United States stating, among other requirements, that tanker vessels had to be double hulled in order to operate in U.S waters (Environmental Protection Agency [EPA], 1990). The same requirement is mandatory for oil tankers operating in Arctic waters according to the Polar Code (IMO, 2017a).

Operational discharges

Normal ship operation require regular elimination of substances which is transferred to port facilities, burned in an incinerator or discharged into the ocean. The substances include bilge water, ballast water, black and grey water, sludge, garbage, and oil (AMSA, 2009). The IMO (2017) has prohibited the release of any oily mixtures for all ships operating in the Arctic. New ships constructed on or after 1 January 2017 that will operate in polar waters need additional protection to fuel tanks, sludge tanks and bilge tanks that will hold more than 30 m^3 of bilge water (IMO, 2017a).

4.3 Pollution prevention from shipping

In order to prevent large scale pollution from shipping in the Arctic, ships has to be modified by applying abatement technology or by switching to a better-quality fuel. If an increase of shipping in the Arctic is inevitable, the goal is having ships travel through the Arctic with less or no impact on the Arctic environment. This section will therefore focus on solutions to reduce pollution from ships.

4.3.1 SOX Scrubbers

Instead of switching fuel, HFO can be used together with a scrubber that cleans the exhaust gas from sulphur oxides. The process can be done in either a wet or dry scrubber. The wet scrubber, being the most prominent choice on ships (Andersson et al., 2016), uses a liquid medium, usually freshwater or seawater, that is sprayed inside the scrubber. The spray of water produces fine water droplets that absorb not only sulphur oxides, but also BC particles (Andersson et al., 2016). Cleaner air is then sent out in the environment and the wash water, containing the pollution, is either discharged into the sea or reused as wash water depending on if the system is an open-loop system (illustrated in Fig.10) or closed-loop system (Andersson et al., 2016).

In an open-loop system, the SO_x gases in the wash water form acids. When wash water is discharged in the ocean, the natural alkalinity of seawater reacts with the acids, forming sodium sulphate, which is naturally occurring in the oceans (Tran, 2017). The PM trapped in the wash water is separated in a treatment plant, forming sludge residue (Tran, 2017). Dry scrubbers do not use wash water as an absorbent, instead, small granules of calcium hydroxide are used to react with the sulphur oxides as the exhaust pass through the granules (Lloyd's Register, 2012). Calcium hydroxide is a harmful substance (Andersson et al., 2016). However, after reacting with the sulphur oxides, it forms gypsum which is a harmless substance (Tran, 2017) that can be reused for other purposes on land (Lloyd's Register, 2012).

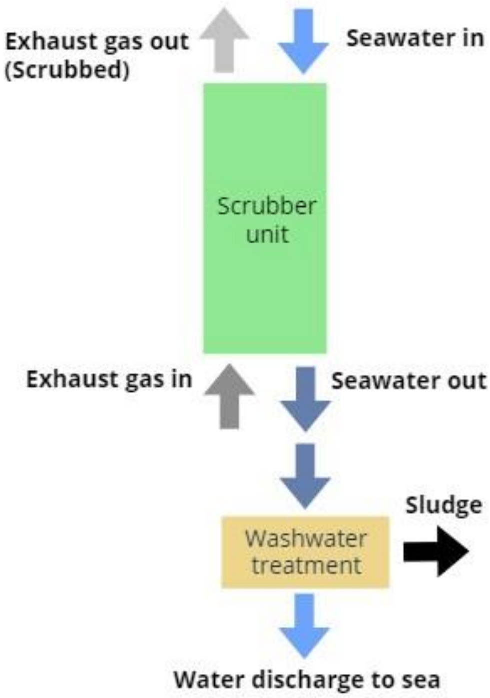

Figure 10. Simplified view of an open-loop wet scrubber. Authors' own work.

Scrubber systems has been proven very efficient in removing SO_x and BC particles from exhaust gases in shipping. Lloyds register (2012) claim that an open-loop scrubber removes 98% of the SO_x from the exhaust gases. Tran (2017) further concluded in his report that scrubber systems had a SO_x gas emission removal efficiency of at least 95% and a PM removal efficiency of 60%. Lack and Corbett (2012) argues that the BC removal efficiency of scrubbers is somewhere in the range of 40-70%.

The installation of scrubber systems is much cheaper than switching to a low sulphur fuel (Laville, 2018). However, there are some concerns with scrubber systems on vessels (Laville, 2018). In the case of an open-loop system, some argue that the SO_x emissions cleaned from the exhaust emissions is discharged into the sea instead along with the wash water (Laville, 2018). Metals such as zinc and copper has also been found in discharged wash water (Andersson et al., 2016). But since SO_x emissions become sulphate after being scrubbed (sulphate being a natural component of seawater) an increased attention to this manner is required, especially from the IMO.

4.3.2 Selective catalytic reduction

The selective catalytic reduction (SCR) system is used onboard ships to reduce emissions of nitrogen oxides. Like the scrubber system, the exhaust gases formed from the engine is after-treated in the SCR system. NO_x emissions are reduced using a reducing agent, for example ammonia, that is injected into the exhaust gases (Andersson et al., 2016). The ammonia reacts with the NO_x emissions and converts them to diatomic nitrogen and water (Andersson et al., 2016). Instead of using the gaseous ammonia, urea mixed with water can also be used as reducing agent (Andersson et al., 2016).

The process of reducing NO_x emissions through an SCR system is simply described in Fig.11. The exhaust gases enter a mixing tube after being produced by the engine. A spray of urea dissolved in water is injected in the mixing tube, which mixes with the exhaust gases (Stt Emtec, n.d.). When urea and the exhaust gases mix, the urea disintegrate to ammonia (Stt Emtec, n.d.). In turn, the ammonia will react with the NO_x emissions in the catalyst and significantly reduce the released NO_x to the environment.

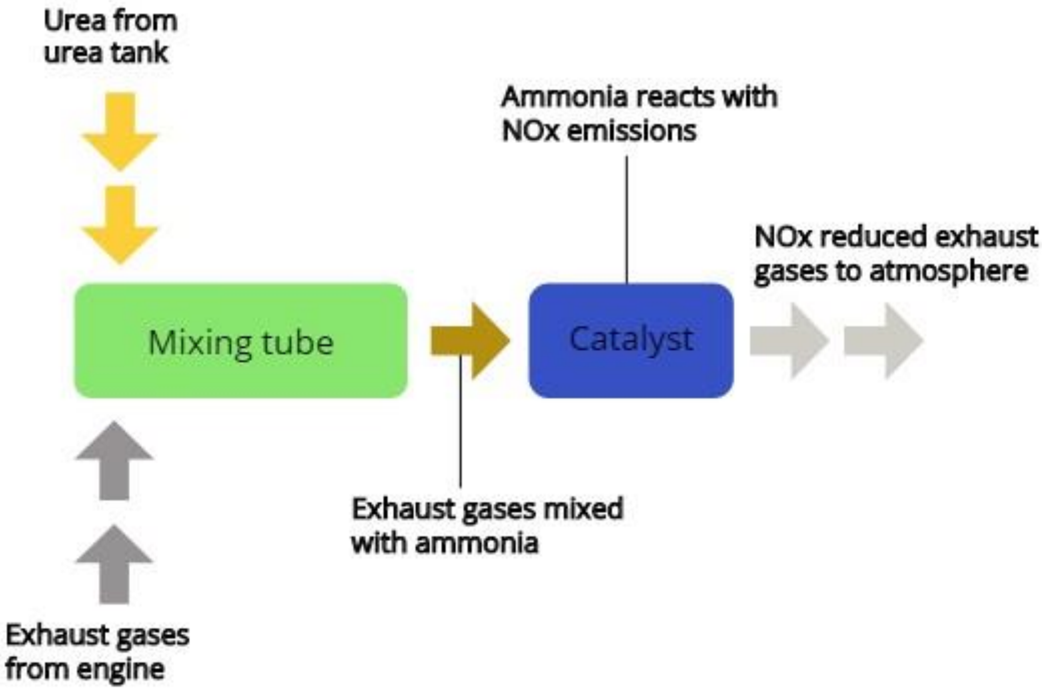

Figure 11. Simplified view of how an SCR system can look like. Author's own work.

The SCR has been proven very efficient in reducing the NO_x emissions. The Swedish company Stt Emtec AB (n.d.) claim that their SCR systems reduces NO_x emission up to 90%. Azzara et al. (2014) concluded that SCR systems can achieve a NO_x removal of more than 90%. Moreover, an investigation made by Xiao et al. (2018) also concluded a NO_x removal efficiency of approximately 90%. On land, industrial SCR systems are capable of reducing up to 95% NO_x emissions (The Babcock & Wilcox Company, 2005).

4.4 Regulations in the Arctic

By establishing rules and regulations, pollution from shipping can be minimized. Additionally, the risk of major accidents involving oil can also be minimized by providing sufficient guidelines and improving ship construction. Since the implementation of MARPOL 73/78 by the IMO, all types of pollution from shipping could be regulated for the protection of the environment. In regard to the Arctic and Antarctica, additional regulations and guidelines apply to ships passing these polar regions, mainly for the protection and preservation of these sensitive areas.

4.4.1 The Polar Code

The Polar Code has been developed especially for the polar regions of Antarctica and the Arctic with the goal to provide information and guidance for safe navigation through these environments and for the protection of them (IMO, 2017a). The code may demand additional measures on ships traveling through these regions beyond of the exiting requirements of SOLAS (1974) and MARPOL 73/78 (IMO, 2017a). Amongst other things, the Polar Code regulates pollution from ships. It is strictly forbidden to discharge anything oil related from ships in the Arctic sea. This rule does not apply to clean or segregated ballast water, however. Since navigation in the Arctic is at an elevated level of difficulty, certain structural requirements to prevent oil pollution have been added such as the placement of fuel oil tanks, sludge tanks, and other tanks designed to carry oil. Additional regulations to the discharge of sewage and garbage has also been made to prevent any harm that could be done to the ecology.

On the request from IMO, DNV (2011) performed an event leading up to the development of the Polar Code. The event was a hazard identification workshop and its aim were to control the predicted increase in shipping through the Arctic and Antarctic waters. The main point of the workshop was to discuss the impact on the polar environment as well as the special factors that elevate the risk of accidents in polar waters. Although the Polar Code is written to be applicable on both polar regions, there are some differences that were mentioned during the workshop. Firstly, Antarctica is a continent covered in ice and snow and is surrounded by a deep ocean while the arctic is a shallower ocean which is covered by multi-year and single-year ice that lies in between land masses. Secondly, the Arctic has indigenous people living there while the Antarctic does not. Finally, there are fewer international laws protecting the Antarctic than ones protecting the Arctic.

DNV (2011) also mention the mechanisms that are unique to polar waters in terms of marine discharges. The cold climate alters the degradation of the released material by slowing down the biological and chemical processes. As a consequence of the floating ice, foreign species and discharged matter may be transported over longer distances. Both the South and the North Poles have extensive seasonal variation and their ecosystems may be more vulnerable from outside influence. If an accident were to occur, the response time would be longer and with the added complications of polar waters.

4.4.2 HFO ban in the Arctic

To protect the Arctic waters from the risks posed by HFO, a ban for both use and carriage has been discussed. Antarctica is already protected in this way by a special chapter in MARPOL Annex I regulation 43 (IMO, 2011) that came into effect in 2011. The Polar Code (IMO, 2017a) encourages that these rules should be applied for the Arctic as well, but it is only a recommendation and not an actual law. On their 71st session, the IMO's Marine Environment

Protection Committee (MEPC) agreed to start a new project where the goal was to reduce the risks associated with carrying HFO in the Arctic waters (IMO, 2017b). Participation governments and international corporations were invited to bring proposals to the 72nd MEPC session (IMO, 2018a) which would take place the following year. The work to evaluate and develop the ban was delegated to the IMO's Sub-Committee on Pollution Prevention and Response (PPR) and during MEPC 72 they were instructed to work on a definition of HFO as well as guidelines for the ban. On PPR's 6th meeting (IMO, 2019b) the work of developing the ban started and a methodology was agreed upon. Additionally, a definition for HFO was presented: "*heavy fuel oil means fuel oils having a density at 15ºC higher than 900 kg/m³ or a kinematic viscosity at 50ºC higher than 180 mm²/s*" (IMO, 2019b). PPR set a correspondence group in charge of developing the guidelines for minimizing the risks of carrying HFO in Arctic waters, a task which was discussed at MEPC 71 back in 2017. It was suggested that the guidelines could include sections on navigational measures and the following points were noted in the meeting summary (IMO, 2019b):

- Ship operations.
- Infrastructure (onshore and offshore) and communications.
- Enhanced preparedness for emergencies of oil spills, early spill detection and response.
- Drills and training.
- Economic assessment of potential measures.

4.5 Cost analysis of the NSR and Suez Canal route

As mentioned in section 2.6, the Arctic shipping routes saves a large amount of travelling time compared to commercial routes used regularly through the Panama and Suez Canals. But there are other obstacles than sea ice when considering the Arctic NSR over the Egyptian Suez Canal route; namely the cost savings.

The Suez Canal fee

The Suez Canal is operated by the Suez Canal Authority (SCA), which is state-owned by the Egyptian government (Fisher & Smith, 2019). To be able to pass through the Suez Canal, a fee must be paid which is based on the following criteria's according to Wilhelmsen's Suez toll calculator (Wilhelmsen, n.d.):

- Vessel type (e.g. Crude oil tanker, container ship)
- Vessels maximum draft
- Suez Canal net tonnage (based on vessel deadweight)
- Gross tonnage (GT) of vessel
- Ship status - Laden (The cargo is loaded onto the vessel and the vessel is still in port) or Ballast (The vessel has no cargo onboard, but ballast tanks are loaded to add weight to the vessel).

All the above factors affect the total fee. To demonstrate how much it costs to cross the Suez Canal, an assumption is made of a crude oil tanker in Table 1 using Wilhelmsen's Suez toll calculator (Wilhelmsen, n.d.). The vessel is assumed to have a deadweight of 72,000 tons, which gives it a Suez Canal net tonnage of 36,000 m³ according to calculation guidelines from Leth Agencies (n.d.). An assumption of 27,000 m³ is made for the GT and ship status is chosen to be laden. The maximum draft is considered to be 22 meters.

Table 1.
The total Suez Canal crossing fee of a crude oil tanker with assumed specifications.

Vessel type	Crude oil tanker
Vessels maximum draft (Meters)	22
Suez Canal net tonnage (m^3)	36,000
GT of vessel (m^3)	27,000
Ship status	Laden
Total fee in USD	$221,375

Note: Total fee calculated using Wilhelmsen's online Suez toll calculator (Wilhelmsen, n.d.). Authors' own work.

The NSR fee

The NSR is administered by the Northern Sea Route Administration (NSRA), which is a federal government institution in Russia established in 2013 (NSRA, 2013). In order to travel along the NSR when it is open in the Summer/Autumn months, an icebreaker assistance fee has to be paid. The fee is based on the following criteria according to the NSRAs own calculator (NSRA, n.d.):

- GT of vessel
- Ice class (how well a vessel can operate in ice covered waters)
- Number of zones (Icebreaker operating area consist of 7 zones along the NSR. Assistance can be chosen from 1 to 7 zones, which can be translated to how long of a distance a vessel needs/wants icebreaker assistance).

There is a total of 9 ice classes in which ice class 1 being the worst and ice class 9 being the best. The better ice class a vessel traveling through the NSR has, the cheaper is the icebreaker fee. A calculation of the cost by travelling through the NSR is made in Table 2 using the NSRA calculator (NSRA, n.d.). The same assumed vessel GT as the Suez Canal route is used and an assumption of ice class 3 is made. Icebreaker assistance is set to 4 zones.

Table 2.
The total NSR crossing fee of a crude oil tanker with assumed specifications.

GT of vessel (m^3)	27,000
Ice class	3
Number of zones	4
Total fee in USD	$214,562

Note: Total fee calculated using the NSRA online calculator (NSRA, n.d.). Authors' own work.

Insurance
A correct insurance cost is hard to determine because insurance companies do not display the transactions publicly (Furuichi & Otsuka, 2015). An estimation of the NSR insurance of $125,000 per trip is therefore made according to Schøyen and Bråthen (2011). The NSR insurance is additional to normal ship insurance along the NSR (Schøyen and Bråthen, 2011), normal operation insurance will therefore be excluded from this example.

Vessel voyage
In order to estimate the fuel costs of both routes, the data of the prerequisites shown in Table 3 will be based on the voyage from London, Great Britain to Yokohama, Japan as used in the study by Schøyen and Bråthen (2011). The speed is assumed constant throughout the voyage (Schøyen and Bråthen, 2011).

Table 3.
Vessel voyage prerequisites.

	Length (nm)	Speed (knots)	Days at sea
Via Suez Canal	11,400	15	32
Via NSR	7,200	15	18

Note: Data gathered from Schøyen and Bråthen (2011). Authors' own work.

Fuel cost
The fuel costs in Table 4 are based on data from Liu and Kronbak (2010), with the exception of the voyage routes distances which is used from Schøyen and Bråthen (2011). For simplicity reasons, the fuel consumption is assumed the same for both routes and also kept constant throughout the voyage. The fuel price is assumed to be $700/tonne according to Liu and Kronbak (2010).

Table 4.
Total fuel cost of the vessel travelling on the two routes.

	Via Suez Canal	Via NSR
Distance (nm)	11,400	7,200
Fuel consumption (tonne/nm)	0.3	0.3
Fuel consumption (tonne/trip)	3,420	2,160
Total fuel cost in USD ($700/tonne)	$2,394,000	$1,512,000

Note: Data partly collected from Liu and Kronbak (2010) and Schøyen and Bråthen (2011). Authors' own work.

Total cost
Using the numbers gathered from Table 1-4, the total voyage costs are presented and compared in Table 5.

Table 5.
The total cost of the made up scenario of a vessel travelling through the NSR compared to the Suez Canal route.

	Via Suez Canal	Via NSR
Total fee	$221,375	$214,562
Total fuel cost	$2,394,000	$1,512,000
Additional insurance		$125,000
Sum of expenses	$2,615,375	$1,851,562

Table 5 show that traveling through the NSR could be economically beneficial. However, this is a very simplified example based mostly on fairly realistic assumptions. The real costs can be very different from this result based on factors such as actual fuel consumption, insurance costs and passage fees. Moreover, the vessels ice class and number of zones wanting icebreaker assistance affects the vessel fee greatly on the NSR.

5. Discussion

5.1 Result discussion

Emissions projection study

The results of the study conducted by Winther et al. (2017) show that both a SECA and an HFO ban could have an impact when it comes to the reduction of emissions from marine vessels. Decreasing the amount of sulphur in the fuel or banning HFO resulted in less BC emissions in all scenarios from 2020 and onward. Between 2030 and 2050, NO_x emissions was reduced as a consequence of the NO_x emission control areas that will come into force in 2021. This emission control area is in the North and Baltic Sea but many vessels operating in the Arctic pass through there, which makes these future laws affect the Arctic sea indirectly. The alternative scenarios showed the biggest reduction in SO_2 where they assume that EGCS are in use on vessels using HFO as well as HFO being out phased. The reduced SO_2 can also be explained by scrubbers discharging SO_2 into the water instead of into the air.

SO_x Scrubbers

Abatement technology is a cheaper choice for shipping companies than a fuel switch to low sulphur fuels. When the global sulphur limit of 0.5% comes into force in 2020, the installation of scrubbers will likely increase significantly until then. The current regulations of IMO regarding wash water, which is discharged from the scrubber into the sea, needs to be updated in order to be relevant and clear. Otherwise, wash water may be treated insufficiently, causing an increased risk of potentially harmful substances to be discharged into the sea along with the wash water. The management of the residue produced by the scrubbing process also needs to be correctly handled worldwide.

The route cost analysis

Due to limited information about actual fuel price, vessel fuel consumption, passage fees and insurance costs, calculating the actual travel cost of the two routes was proven challenging. Other factors were also excluded in the analysis such as operating costs including mandatory vessel insurance, crew salary and reparation costs which affects the probability of the result. By reason of the analysis being very simplified due to insufficient information, port costs for when the vessel stopped for bunkering, or for other reasons, were also excluded.

Use of HFO in the Arctic

A future ban on HFO in the Arctic region could have big impacts on its marine environment. The prevention of the harmful by-products created from HFO stated by the AMSA (2009), will in itself reduce the build-up of LAP which would most likely increase the longevity of the ice. In addition, the SO_x content would be lower as a result of the HFO ban which helps to balance the acidity of the region. This is something that the global sulphur limit of 0.5% coming in 2020 (IMO, 2019a) would also achieve but a bit of redundancy is seemingly a positive thing in this case. Restricting HFO in the Arctic region discourage some shipping companies from operation there due to the increased operational costs of using a more expansive higher-grade fuel, thus reducing pollution even more. If it is prohibited to carry HFO as fuel or cargo in Arctic waters, then the consequences of an accidental spills would be less severe assuming the replacement fuel is a “cleaner” one. As previously mentioned in 4.1.2, no oil spills have happened in the polar region (AMAP, 2007). Note that Exxon Valdez went aground in Prince William Sound which is not part of the Arctic region. Since there have not been any significant recorded oil spills, a future HFO ban would be proactive. It is usual for the shipping industry to be reactive rather than proactive because many marine laws have been created as a result of a major accident.

It is common knowledge in the maritime industry that HFO needs to be heated to high temperatures when used in marine engines, usually up to around 120°C. The cold Arctic climate might prove to be an obstacle if a loss of power were to happen and the fuel oil starts cooling down. The temperature of the fuel determines its kinematic viscosity as well as its flash point which means that if the HFO cools down enough, it might not be usable.

There is a bit of a contradiction between what was said in the AMSA 2009 report and numbers presented by (Winther et al., 2017). The AMSA (2009) portrays HFO as the most common fuel in the Arctic while on the scenarios from (Winther et al., 2017), HFO is the least used fuel in terms of fuel consumption. The difference can probably be explained by the fact that most vessels in (Winther et al., 2017) were fishing boats.

Albedo and melting ice

Through the experiment by (Brandt et.al, 2005), an idea about the differences in albedo values of various ice types and water can be perceived. The result showed a wide spectrum from 0.07 to 0.81 which differs considerably from the lowest value to the highest. Sea water has an albedo of 0.07, meaning that it absorbs 93% of the sun rays heat; and snow covered first-year ice has an albedo of 0.81 which means that it absorbs only 19% of the heat from the sun rays. When comparing the two, it is found that sea water absorbs almost 5 times more heat from the sun than snow covered first-year ice does (0.93÷0.19=4.89. . .). Although the experiment took place in Antarctica, the result can still be applied to the Arctic due to the similarities of the two regions. The result from (Brandt et.al, 2005) matches what was said by NASA’s Earth observatory (2017) in regards of ice and water albedo as well as the albedo values from NSIDC, n.d.

The fact that LAP accelerate the melting process of polar ice is going to be a problem worth evaluating in regard to arctic shipping. The exponential decrease of the albedo value with a linear increase in BC mass demonstrated by (Marks & King, 2013) was an interesting find. This means that heavily trafficked routes will melt faster due to pollution and in turn expose more water. Increased marine activity will with certainty contribute to a faster melting Arctic through the self-reinforcing effects related to albedo.

5.2 Method discussion

The gathering of data was mainly done in Web of Science which Chalmers granted access to. Web of Science is connected with many different databases with a wide variety of disciplines. The scope of literature which this engine provided was advantageous since marine activity in the Arctic is a fairly unexplored subject with limited or old and possibly outdated research. Other search engines, such as Google Scholar, have also been used for collecting data. In some cases, a promising article was found but access to it was restricted. This could be solved by performing a search on the articles title in Web of Science. In most cases the desired article could be found there.

In hindsight, the chosen research question may have been too wide and unspecific and a more focused one would have been more beneficial.

The focus on primary sources proved to be a good choice regarding reliability of the data. Secondary data has a higher risk of being bias since the information has been processed but multiple authors. However, the assortment of literature will be lesser if secondary sources are excluded from the selection process. The fact that almost none of the sources used in this report contradicts each other without explanation points towards valid and reliable data.

Literature review as the chosen method felt like a reasonable approach for answering the research questions. In some cases, the inclusion of other methods, such as interviews, could have led to better result. For example, an official statement from the IMO would be more definitive than a summary of a meeting session held by one of their subcommittees.

Search engines
Wiley
Web of Science
Britannica
Google Scholar
Reg4Ships

Search strings
Arctic albedo, Albedo feedback, Light absorbing particles, Arctic AND pollution, “Arctic pollution”, Arctic AND “emissions to air”, Arctic AND “oil spills”, “Black carbon” AND Arctic, “Arctic shipping routes”, Arctic AND routes, “Sulphur oxides” AND scrubber, “Marine scrubber”, “Selective catalytic reduction”

6. Conclusion

The result of this report generally points towards a negative impact in the Arctic from an increased maritime activity. The temperature in the Arctic region will increase as a consequence of the self-reinforcing effects of ship emissions and melting sea ice. Perhaps the shorter trading routes may result in less global emissions which would benefit the rest of the planet. Being more complex to navigate through, the Arctic has an increased risk of accidents, making the Arctic waters more susceptible to oil spills which could damage the environment. Hopefully future regulation could address this such as a ban of HFO. Everyone involved in Arctic shipping should consider the implied stress to the Arctic environment when planning voyages there.

6.1 Continued research

In the process of the literature review, there was a lack of research regarding the contribution of BC build up by local shipping in comparison to global industrial emissions.

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