Chapter 21 – Black carbon, maritime traffic and the Arctic

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Abstract

Maritime transportation covers approximately 90% of the global traffic volumes. The global fleet consists of approximately 100 000 diesel ships, around 250 LNG ships, and a smaller number of methanol or even electric ferries. When it comes to maritime transportation, the Arctic sea route is becoming more and more interesting for the shipping industry as it has been estimated that the Northeast Passage can shorten the travelling distance significantly compared to Suez Canal.

Black Carbon (BC) is the second largest contributor to climate change emissions after carbon dioxide (CO2). BC particles spread out from different sources and the majority of BC emissions are transmitted to the Polar Regions from other parts of the globe. The share of global BC emission from international shipping is estimated to be up to 3% of the global total.

The Northern Sea Route can shorten the travelling distance, but it is important to find out, will the increase of maritime traffic effect the BC emissions in the Arctic. This paper considers how BC from ships' fuel affects the Arctic. This paper also discusses alternative fuels and emission abatement technologies, which can decrease the emissions from ships and may also affect the BC emissions in the Arctic in the future.

Introduction

Over recent decades, temperatures in the Arctic have increased. The climate of the Arctic Region is known to be warming at almost twice the rate of the rest of the world. Reduction of global CO2 emissions is required to slow this warming, but there is also a need to reduce short-lived climate forcers. It has been estimated that the majority of influence on the radiative forcing in the Arctic is from external emissions of greenhouse gases and particulate matter (PM), with possibly half of Arctic temperature rise linked to black carbon (BC) (IMO 2015). Even though the atmospheric concentrations of BC in remote areas, such as the Arctic Region, are generally low, their effects on the regional climate may be substantial (e.g. Flanner 2013; Winiger et al. 2016; Sand et al. 2016; AMAP 2011; Corbet et al. 2007).

Sources, whose emissions are rich in BC, can be grouped into a small number of categories: diesel engines, industry, residential solid fuel, and open burning. The largest global sources are open burning of forests and savannas, solid fuels burned for cooking and heating, and on-road and off-road diesel engines. Dominant emitters of BC from other types of combustion depend on the location. Industrial activities are also significant sources, but e.g. shipping emissions provide only a minor contribution to BC emissions at the global scale. What makes shipping emissions noteworthy is that shipping emits into regions that otherwise have low concentrations of emissions. Currently, there are few sources of

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pollution within the Arctic itself so almost all BC is transported there from other regions (Bond et al. 2013).

Sea transportation covers approximately 90% of the global traffic volumes and it also contribute global climate change and causes health impacts through emission of greenhouse gases (GHGs) and other pollutants, including CO2, NOx, SOx and various species of particulate matter (PM) including BC. BC emissions from the shipping industry are thought to contribute about 2-3% of global BC (IMO 2015; Corbett et al. 2010).

Decreasing ice volumes in the Arctic sea has increase the interest in efforts to establish new trade passages. The Arctic sea ice retreat is opening up both the Northwest Passage (across Canadian Arctic waters) and the Northeast Passage (also known as the Northern Sea Route passing along the Siberian north coast), during parts of the year (Yumashev et al. 2017: Kiiski 2017). Journeys between Asia and Europe and Eastern US and Asia through the Arctic could cut travel distances by 25% and 50% respectively in the Northwest Passage and Northern Sea Route compared with the current sea routes. In addition, the routes are generally considered to be financially viable as they would bring savings to both time and fuel (Corbett et al., 2010; IMO 2015). Although increased Arctic shipping may provide commercial opportunities, the associated environmental issues should also be considered (IMO 2015; Corbett et al. 2010; Yumashev et al. 2017).

The purpose of this chapter is to consider the Arctic sea traffic and BC relations. This is done through a literature review and by presenting the latest BC emission level data. The regulatory framework is discussed as the backbone that controls commercial activities, and thus, the responsible business potentials in the Arctic maritime transport. The majority of the paper is conceptual and it applies latest measurement data in order to consider the problematics of the Arctic maritime transport. The topic is challenging due to constantly developing technologies for emission reduction and control and other uncertainties related to the shipping industry, such as the asymmetric growth in activity among ship types. These factors make it difficult to estimate the future effects of shipping in the Arctic Region (Corbett et al. 2010; VITO 2013).

Black Carbon

BC emissions come from the combustion process when fossil fuel or biomass is burned. Carbonaceous material is formed near flames during the combustion process (Bond et al. 2013). Fossil fuels are very widely used in transport sector, industry and the household sector, and forest fire produces a lot of BC emissions in world wide. After the open burning of forests and savannas, the largest emission sources include solid fuels burned for cooking and heating, and on-road and off-road diesel engines. Dominant emitters of BC from other types of combustion depend on the location. Industrial activities are also significant sources, but e.g. shipping emissions provide only a minor contribution to BC emissions at the global scale (Bond et al. 2013).

BC is the second major contributor to climate change after CO2 (Petzlod et al. 2013; Aplin 2015; Bond et al. 2013). BC is a short-lived climate forcer or a short-lived climate pollutant. In practice, BC has a greater effect on the Polar Regions' climate than CO2. BC emissions have notable local climatic effects in the Arctic, as the BC particles absorb solar heat very effectively. When such particles are deposited to a reflective surface, such as ice, they may significantly alter the albedo of the surface and increase the amount of absorbed solar heat, which in turn leads to warming of the surface. This leads to increase in the melting of ice and snow coverage and contributes directly to the climate change (Vihanninjoki, 2014; Flanner et. 2007). What makes shipping emissions noteworthy is that shipping emits into regions that otherwise have low concentrations of emissions. Currently, there are few sources of pollution within the Arctic itself so almost all BC is transported there from other regions (Bond et al. 2013).

As yet, there is no universal definition of BC and it has been problematic to reach a consensus on the matter. In order for measurement and emissions control technologies and policies to be able to operate as intended and in a cost-efficient fashion, it is vital reach an understanding on the matter. IMO's Maritime Environmental Committee (MEPS) has in its meeting approved a definition for BC: BC is a solid, carbon-based substance formed as carbon-based fuel's burning process is incomplete. As it enters the atmosphere it can powerfully absorb all lengths of visible light. Over 80% of BC's weight is pure carbon, of which majority have dual-bonds (sp2). In the atmosphere, the particles form into a sphere, which have an aerodynamic diameter of around 20-50nm. Fresh BC can absorb 550 λ per 5m2 gram (Bond et al.2013; IMO 2015; Gogoi et al 2015). The ability of BC particles to absorb light depends on its consistency, shape, size distribution and particle mixing state.

BC's climate effects are either direct or indirect. The effects of different emissions on the climate are divided into three categories: 1) as it floats in the air, BC absorbs sunlight and thus heats up the atmosphere (direct effect); 2) BC affects cloud characteristics (indirect effect); 3) on top of ice and snow, BC absorbs lights and heats it up, thus expediting the melting process (snow effect). In the Polar Regions, the snow effect has the biggest effect on the climate. Globally, the snow effect is estimated to amount to up to 1%. On the other hand, for example, Finland's direct and indirect BC's climate effect only amounts to around one per mil. Estimates are based on climate simulation calculations. The biggest source of BC in Finland is small-scale burning of wood (Twigg 2009, AMAP 2011; AMAP 2015: Bond et al. 2013).

BC is a so-called primary particle, which means that it is in a solid form as it enters the atmosphere. As it forms, BC is also hydrophobic, meaning that it is water resistant. This phase only lasts hours (AMAP 2015). The formation of secondary BC particles takes place only as it reaches the atmosphere. As the carbon nucleus enlarges, they act as a surface for the carbon nitrogen from the gas stream to stick to. The particle grows but also becomes more dense as liquid solidifies and evaporates (AMAP 2015; Twigg 2009).

Black Carbon from different fuel types

Sea transportation covers approximately 90% of the global traffic volumes. Shipping contribute significantly to global climate change and health impacts through emission of GHGs and other pollutants, including CO_2, NO_x, SO_x and various species of particulate matter (PM) including BC. BC emissions from the shipping industry are thought to contribute about 2-3% of global BC (IMO 2015; Corbett et al. 2010), which makes sea transportation a minor BC producer compared to road transportation.

The emissions from maritime transport do not only depend on the total traffic but also on the characteristics of the fleet, which are at least equally important. Significant factors include the average engine power, engine type and fuel type (VITO 2013). The global fleet consists of approximately 100 000 diesel ships, around 250 LNG ships, and a smaller number of methanol or even electric ferries. According to Winther et al. (2014) & Timonen et al. (2017) in 2012, the largest share of Arctic ships' BC emissions originated from fishing ships (45%) followed by passenger ships (20%), tankers (9%), general cargo (8%) and container ships (5%).

Approximately 10-20 % of global BC emission are from road transportation (Bond et al. 2013; Lund et al. 2014). From this, BC emissions from diesel engines are responsible of about 90%. In some countries, diesel engines produces 70% of total BC emissions (Lund et al. 2014). The International Council of Combustion Engines (CIMAC) came to the same results, as they measured BC amounts from different fuels by using Filter Smoke Number (FSN) method, which is standardized, in ISO 10054 and in ISO 8178. (CIMAC 2012; IMO 2015) FSN is an optical measurement based on filter darkening or photoacoustic method. In photoacoustic method, particles are heated by laser and the sound and lights absorbing are measured from particles. Typically a different measurement technology gives different results. In the small car diesel engines with automotive diesel fuel, the elementary carbon (EC) or BC can be over 70% in diesel particulate matter. Figure 1 presents typical diesel particulate matter composition by using ISO 8178 Measurement method, which is NSF (CIMAC 2012).

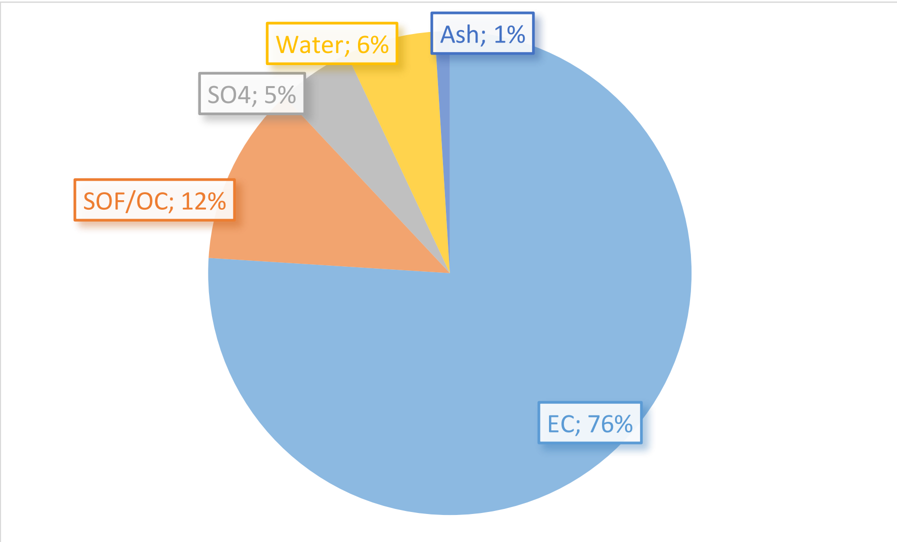

Fig. 1 Typical diesel PM from vehicle diesel engine and automotive diesel (CIMAC 2012).

Figure 2 presents the share of EC/BC from four-stroke diesel engine with maritime type distillate fuel or light fuel oil (LFO). These kind of diesel engines are medium speed and running relatively heavy load. In these measurements, the amount of EC in fuel PM was 11%. According to Helle (2015), variation is typically around 10 to 15%.

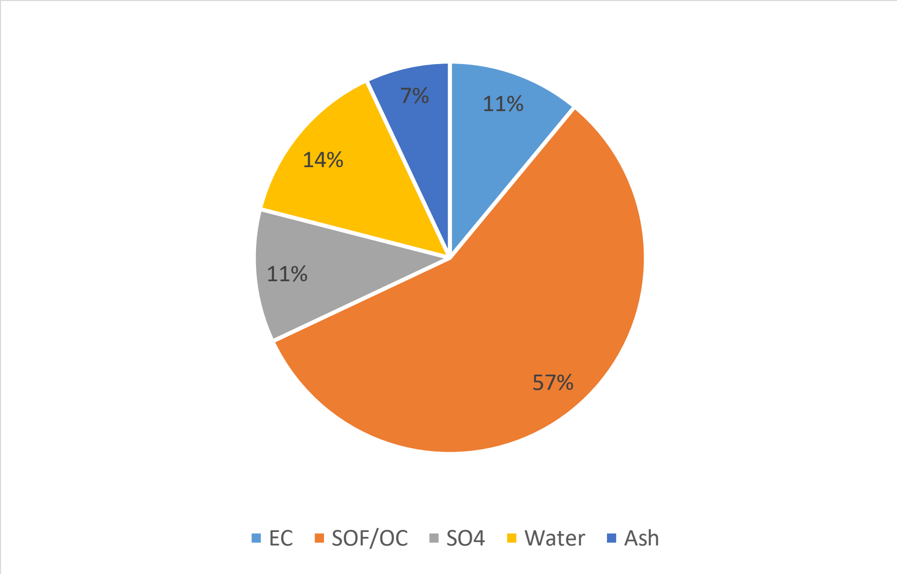

Fig. 2 Distillate fuel PM from 4 stroke marine diesel engine (CIMAC 2012).

Figure 3 presents heavy fuel oil PM shares. When heavy fuel oil (HFO) is measured, the PM typically consist of 2-5% EC/BC. In the perspective of BC's warming effect, in automotive fuel in small diesel engines, PM consistency is approximately 75% BC. In HFO, in the PM, the share is only 2 to 5%. Compared to BC, Sulphates, Organic Carbon (OC) and mineral dust have a cooling effect on the environment. (CIMAC 2012; Fuglestved et al. 2009).

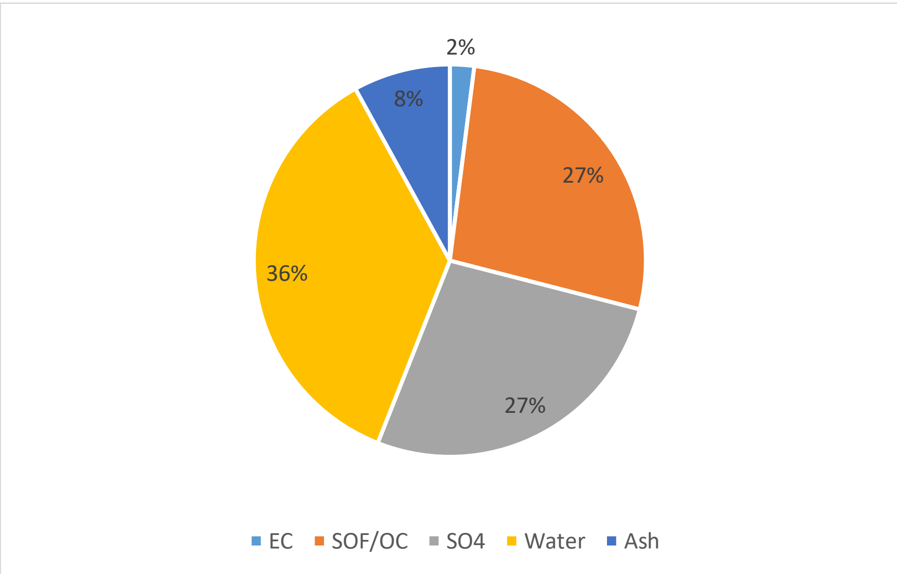

Fig. 3 Heavy fuel oil PM from 4-stroke marine diesel engine (CIMAC 2012).

New fuel types can significantly reduce the amount of emissions from shipping. Nevertheless, given the long turnover rate of maritime vessels, the effects of introducing alternative fuels will not be significant in the near-term (VITO 2013).

BC emission abatement technologies

BC emissions have been measured and calculated in several studies. The amount of BC varies based on the fuel type and method of determination. According to CIMAC (2012), the BC emission vary from 0.1 to 1 g/kg per fuel burned. CIMAC (2015) also concluded that, for shipping, the emissions of BC seems to be highly over-estimated. According to different studies, there are several ways to mitigate BC emissions (Azzara et al.2015; CIMAC 2012 and IMO 2015). In addition, IMO regulations for decreasing BC emissions are in the making. Table 1 below presents, how IMO categorizes BC abatement technologies.

Table 1 IMO abatement technologies for BC.

1) Fuel efficiency – vessel design (excludes engine, fuel options)
2) Fuel efficiency – monitoring options
3) Fuel efficiency – engine options
4) Slow steaming
5) Fuel treatments:
•Colloidal catalysts
•Water in Fuel Emulsion (WiFE)
6) Fuel quality (traditional fuels)
7) Heavy Fuel Oil – distillate
8) Alternative fuels:
•Biodiesel
•LNG
•Methanol – Dimethyl Ether (DME)
•Nuclear
9) Exhaust treatment:
•Electrostatic precipitators (ESP)
•Diesel particulate filter (PDF)
•Diesel oxidation catalysts (DOCs)
•Selective catalytic reduction (SCR)
•Exhaust gas recirculation (EGR)
•Exhaust gas scrubber (EGS)

Previous studies suggest that the use of diesel particulate filters, LNG, scrubbers and low-sulphur fuels (LSF) can reduce shipping BC emissions by up to 70% (Azzara et al. 2015). Based on the studies of Aakko-Saksa et al. (2016) and Timonen et al. (2017) done in two different measurement campaign laboratories and on board, the laboratory measurements showed that BC amount was higher in 0.5% sulphur fuel than in 2.5% sulphur fuel at 25% engine load, but not at 75% engine load. Low BC amount was observed in the 0.1% Sulphur fuel and Bio30 fuels, with a particularly low BC and polycyclic aromatic hydrocarbons amounts for the Bio30 fuel. The measurements on board a modern ship showed that the new engine emission control technologies (SCR + scrubber) and lower sulphur (~0.7% sulphur) fuels dramatically reduced the BC and PM concentrations of ship exhaust when compared to those of an old marine engine at 25% engine load. The engine load also had less influence on BC for a newly built ship when compared to an old marine engine.

As stated above in table 1, IMO has defined several abatement technologies, including scrubbers and slow steaming. In addition, emissions can be controlled with other environmental policy instruments. These include different kinds of negative and positive incentives and legislative actions, such as the introduction of emission control areas. Despite the fact that IMO has not yet regulated BC, it is already indirectly regulated by IMÓs MARPOL Annex VI, which sets limits for nitrogen oxides and the sulphur content of fuel. BC is also indirectly regulated in the Emission Controlled Areas (ECAs), where a 0.1% limit on sulphur emissions is already in force. The Baltic Sea is one of these special emission controlled areas. In these areas, vessels need to use either low sulphur fuel or exhaust cleaning technologies such as scrubbers. In the future, IMO will drive further research on the impacts of BC, potentially bringing about future BC emission regulations (Aplin, 2015; IMO, 2015).

According to Brunila et al. (2017) there is no single solution that would decrease BC emissions. Different abatement technologies; scrubbers, fuel type selection, slow steaming, better maintenance for engines and better burning of fuel are all together factors that can decrease emissions and BC. Currently the focus is more on how to measure BC emission than in how to decrease BC emission because there are no regulations or limitations for BC at the moment.

Ship traffic in the Arctic

The Northern Sea Route has been in the interest of seafarers for centuries. The decline in Arctic sea ice has reignited interest in efforts to establish new Arctic trade passages (Mjelde et al. 2014; Winther et al. 2014; Mukunda et al. 2018; Kiiski, T. 2017; Yumashev et al. 2017). Polar Regions are warming twice as fast as other regions on Earth. Reason for this include the escalated shrinking of the snow and ice cover. As snow and ice disappear, more radiation from the sun is absorbed in the dark surfaces unearthed (Rubbel 2015; Vihanninjoki 2014). Shipping in the Arctic Region is expected to grow by around 1.8–5% by 2050 (AMAP 2015). The growth rate depends on the capacity of the already established shipping routes and the costs of the new route in comparison to the current routes (AMAP 2015, Vihanninjoki 2014).

The Arctic sea ice retreat is opening up both the Northwest Passage (across Canadian Arctic waters) and the Northeast Passage (also known as the Northern Sea Route, NSR, passing along the Siberian north coast), during parts of the year (Yumashev et al. 2017; Kiiski, 2017). Journeys between Asia and Europe, and Eastern US and Asia through the Arctic could cut travel distances by 25% and 50% respectively in the Northwest Passage and Northern Sea Route, compared with the current sea routes. Both routes are considered to be financially viable as they would bring savings to both time and fuel (Corbett et al., 2010; IMO 2015). It has been estimated that around 5% of the world's trade could be shipped through the Northern Sea Route in the Arctic alone under year-round and unhampered navigability (Yumashev et al. 2017).

Although increased Arctic shipping may provide commercial opportunities, the associated environmental issues should also be considered. Increases in Arctic shipping will introduce direct near-surface emissions of pollution, including BC (IMO 2015; Corbett et al. 2010; Yumashev et al. 2017). Due to the increasing interest in Arctic ship routes, the IMO preparing limits in BC emissions of ships (Timonen et al. 2017; Brunila et al. 2017).

Currently, Arctic shipping does not contribute a significant amount to the region's emissions, but the emissions occur further north and thus, they have a stronger regional impact (Quinn et al., 2008). Direct emissions are significant contributors as Arctic warming is most sensitive to emissions within the region compared to the current emissions where most must survive long-range transport from its source before directly impacting the region (IMO 2015). Due to the remoteness and poor accessibility, the current emission levels in the Arctic are relatively low compared to the global averages. In such an environment, even small absolute increases are likely to lead to significant relative increases (Vihanninjoki, 2014).

Most significant for the Arctic is the additional source of short-lived climate forcing agents, such as BC, from ships in proximal transport distance (Corbett et al. 2010). BC emissions might have significant local climatically effects in the Arctic, because BC particles absorb solar heat very effectively. When such particles are deposited to a reflective surface they may significantly alter the albedo of the surface and increase the amount of absorbed solar heat, which in turn leads to warming of the surface and contributes directly to the climate change (Flanner 2013; Vihanninjoki, 2014).

In order for the shipping industry's interest on Arctic trade passages to grow, several requirements need to be met. First of all, the duration of potential ice-free periods has to increase or at least remain the same. Other factors that need to be taken into consideration are, for example, appropriate fuels, bunker prices, possible icebreaker assistance and cost of icebreaking and transit fees, investments in equipment and personnel training and insurance costs. The administration, coastal infrastructure improving the safety along with suitable rescue equipment also needs to be improved along the route. (AMAP 2015, Vihanninjoki 2014).

In general, the regulation of operation in the Arctic is still insufficient. Due to the lack of regulation, inappropriate equipment and preparations may lead to adverse consequences in the Arctic region. Vihanninjoki (2014) has listed several contributing factors related to shipping in the Arctic:

- Insufficiently equipped and insufficiently ice-strengthened vessels
- Crews that are not trained to handle the difficult navigational and operational challenges in the Arctic waters
- Lack of shoreside infrastructure
- Arctic waters are not very well charted
- Search and rescue infrastructure is limited and regionally varying

According to Mjelde et al. (2014), in the year 2012 almost 1350 vessels operated in the Arctic Region. These ships sailed a total of 5.8 million nautical miles and consumed about 0.166 million tons of distillate fuels and 0.135 million tons of HFO. Calculations show that these ships produced 105 tons BC annually. It can be said that, on average, the majority of large cargo vessels (wet and dry bulk) use HFO. HFO is most notably used in container vessels. The fishing fleet in the Arctic uses mainly distillate fuels. In the Arctic shipping, biggest BC emission peaks occur in the summer time, during which the weather and ice conditions are most suitable for the ships to operate. Geographically, the BC emission distributions are close to the Behring Sea, the Barents Sea, and the Labrador Sea, in which most of the popular sea routes are located.

Several studies have been conducted on how vessel traffic and emission load will developed in the future in the Arctic (e.g. Corbett et al. 2010; Dalsoren et al. 2009; Dalsoren 2013). Depending on the development scenario (high, business as usual, or low), it has been estimated that the global shipping will increase 1-3% in the Arctic areas. At the same time, shipping outside the Arctic areas will increase 2-3% depending on the scenario.

Increased shipping and increased emissions can have a huge effect in the polar latitudes. Emission peaks especially during the summer time will grow. Yet, it is unlikely that the Arctic will become a viable alternative for transit shipping in the near future. For example, the Northern Sea Route has only a fraction of the vessel traffic compared to the traffic quantity in the Suez Canal or other busier sea routes. Most of the traffic in the Arctic area consists of intra-Northern Sea Route journeys that are related to the Russian Yamal and Gydan Peninsula LNG projects. Currently, Russian energy companies have several energy projects in the Arctic areas that can increase the amount of ship traffic during a certain period of time, usually only for a month or two.

Only 19 vessels and 214,513 tons of cargo transited through the Northern Sea Route in 2016. In comparison, 16,800 vessels and 974 million tons of cargo transited the Suez Canal that year. The peak year in the Northern Sea Route was in 2013, when 71 vessels and 1.36 million tons of cargo transited through the route. In comparison, 16,600 vessels and 915 million tons of cargo transited through the Suez Canal in 2013 (Northern Sea Route Administration, 2017). Operating in the Arctic will pose challenges especially to maritime safety and environmental issues. Polar Code entered into force in 1 January 2017 and it will improve the safety issues and standards. (Yliskylä-Peuralahti et al. 2016)

Conclusions

In order to conclude, the following interpretations may be drawn concerning BC emissions and Arctic areas. A clear starting fact is that during the recent decades, temperatures in the Arctic have increased. Reduction of global CO2 emissions is required to slow the warming, but there is also a need to reduce short-lived climate forcers, especially BC, which is considered to be specifically harmful in the arctic environment (e.g. IMO 2015; Winiger et al. 2016; Sand et al. 2016; AMAP 2011). The temperature increase in the Arctic has also lead to the decline in Arctic sea ice. This, in turn, has reignited interest in efforts to establish new trade passages. Although increased Arctic shipping may provide commercial opportunities, the associated environmental issues should also be considered, since increases in Arctic shipping will introduce direct near-surface emissions of pollution, such as BC (IMO 2015; Corbett et al. 2010; Yumashev et al. 2017). Due to the remoteness and poor accessibility, the current emission levels in the Arctic are relatively low compared to the global averages. In such an environment, even small absolute increases are likely to lead to significant relative increases. BC emissions are likely to have notable local climatic effects in the Arctic, as the BC particles absorb solar heat very effectively. When such particles are deposited to a reflective surface they may significantly alter the albedo of the surface and increase the amount of absorbed solar heat, which in turn leads to warming of the surface and contributes directly to the climate change (Flanner 2013; Vihanninjoki, 2014).

Second, the emissions from international maritime transport do not only depend on the total traffic but also on the characteristics of the fleet, which are at least equally important. Significant factors include the average engine power, engine type and fuel type. Yet, since the turnover rate of vessels is usually quite slow, the effects of alternative fuels are not that rapid (VITO 2013). There are several means for reducing emissions from shipping in the Arctic. IMO has defined several abatement technologies, including scrubbers and slow steaming. In addition, emissions can be controlled with other environmental policy instruments. These include different kinds of negative and positive incentives and legislative action, such as the introduction of emission control areas (Makkonen & Inkinen 2018). On the other hand, before there are clearly defined limits and regulations for BC and other emission in the Arctic areas, there will be a lack of investments for new cleaner technologies and cleaner fuels (Brunila et al. 2017). Currently, IMO has not defined the area that would become the 'Artic Emission Control Area'. In addition, the IMO has not defined whether BC regulations and limits should concern shipping merely in the Artic areas or should BC limits be introduced in international shipping more widely and concern also other areas, such as the Baltic Sea and North Sea?

Finally, it is difficult to estimate the future effects of shipping in the Arctic region. This is due to constantly developing technologies (for emission reduction), control regulations (IMO), and other uncertainties (such as asymmetric growth in activity between different types of ships) that are associated with the shipping industry (Corbett et al. 2010; VITO 2013). In addition, the introduction of new legislation related to e.g. emission control areas may lead to a reduction of interest of the shipping industry in the Arctic passages. In order for the shipping industry's interest on Arctic trade passages to grow, several requirements need to be met. First of all, the duration of potential ice-free periods has to increase. Other factors that need to be taken into consideration are, for example, bunker prices, possible icebreaker assistance and transit fees, investments in equipment and personnel training and insurance costs (Vihanninjoki, 2014). In general, the regulation of operation in the Arctic is still insufficient. Due to the lack of regulation, inappropriate equipment and preparations may lead to adverse consequences in the Arctic region.

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