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Navigating the Dichotomy: Maximizing Maritime Trade Profits and Mitigating Black Carbon Impact in the Arctic

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Abstract: Maritime trade, recognized as the most cost-efficient method for long-distance goods transportation, remains the backbone of global commerce despite market volatility and fluctuating supply-demand dynamics. This study examines the intricate relationship between maritime trade and environmental impacts, focusing on the use of Arctic routes and the consequent release of ship-sourced black carbon (BC). An extensive review of the BC literature elucidates its detrimental effects on both environmental integrity and human health. Furthermore, the investigation delves into the specific repercussions of maritime shipping activities in the Arctic region, highlighting how increased ship traffic contributes to global warming through enhanced ice melt. The analysis pivots on the paradox of maritime trade: while seeking cost-effective and rapid routes, such as those through the Arctic, the maritime industry inadvertently exacerbates ecological degradation and climate change. This dichotomy underscores the critical need for a balanced approach in maritime operations, considering both economic viability and environmental stewardship. The study culminates in a nuanced evaluation of the trade-offs involved, proposing strategies for sustainable maritime trade that align with global environmental goals.

Keywords: Maritime trade; Global heating; Black carbon (BC); Arctic; Environmental impact

1 Introduction

According to a well-known general expression, approximately 90 percent of the world's transportation volume is covered by maritime trade. Therefore, the maritime trade route, which is at the center of productivity, is a vital element for a country's trade as a major actor in sustainable competitive advantage. The significance of maritime trade routes gains even more value with the cost incurred while passing through them. Since fuel is one of the important parameters that ensure profitability in the maritime field, fuel costs are closely related to the shortness of the routes. Even the charterers may put pressure on captains to use the shortest route.

On the other hand, melting ice with global warming has changed the maritime routes in the world and brought along the use of new routes. One of these new routes passes over the Arctic, which allows maritime traffic with shorter routes and lower costs. However, the intensity of use of the Arctic route threatens the ecosystem with the BC originating from ships and has an accelerating effect on global warming.

This study emphasizes the effects of ships' use of the Arctic route on global warming. It is considered that the increased traffic of oil tankers and bulk carriers in that region increases the BC emissions from ships, and this situation triggers global warming. BC from incomplete combustion of wood and fossil fuels is very effective at absorbing light and warming the atmosphere where it condenses. Similarly, BC from ships affects the ecosystem. BC that remains in the atmosphere for days and weeks causes glaciers to melt and climate change in the long term [1]. This is why the use of Arctic routes by ships threatens nature due to the BC generated.

2 Literature Review

BC, which is a short-lived climate pollutant after being released into the atmosphere, is produced by the incomplete combustion of fossil fuels, wood, and other fuels. With complete combustion, all the carbon in the fuel is converted to carbon dioxide (CO_2). In this case, combustion is not completed, and carbon monoxide, CO_2, volatile organic compounds, BC, organic carbon, and their particles are formed. BC has crucial indirect and direct effects on the cryosphere (ice and snow), climate, human health, and agriculture in a very short time [1].

BC has negative effects on human health, and the climate is a global environmental matter. Moreover, inhalation of BC causes health problems such as cardiovascular disease, respiratory problems, cancer, and even birth defects. In addition to having an effect on absorbing light as heat, BC also has a significant accelerating effect on climate change. For instance, when BC heats the air, rapid changes occur in the characteristics of the rain, and these changes affect the clouds [2].

The main sources of BC are household energy, transport, agriculture, industrial production, waste, fossil fuel operations, and large-scale combustion, as indicated in Figure 1. To add more, it has impacts on health, climate, weather, snow, ice, agriculture, and ecosystems.

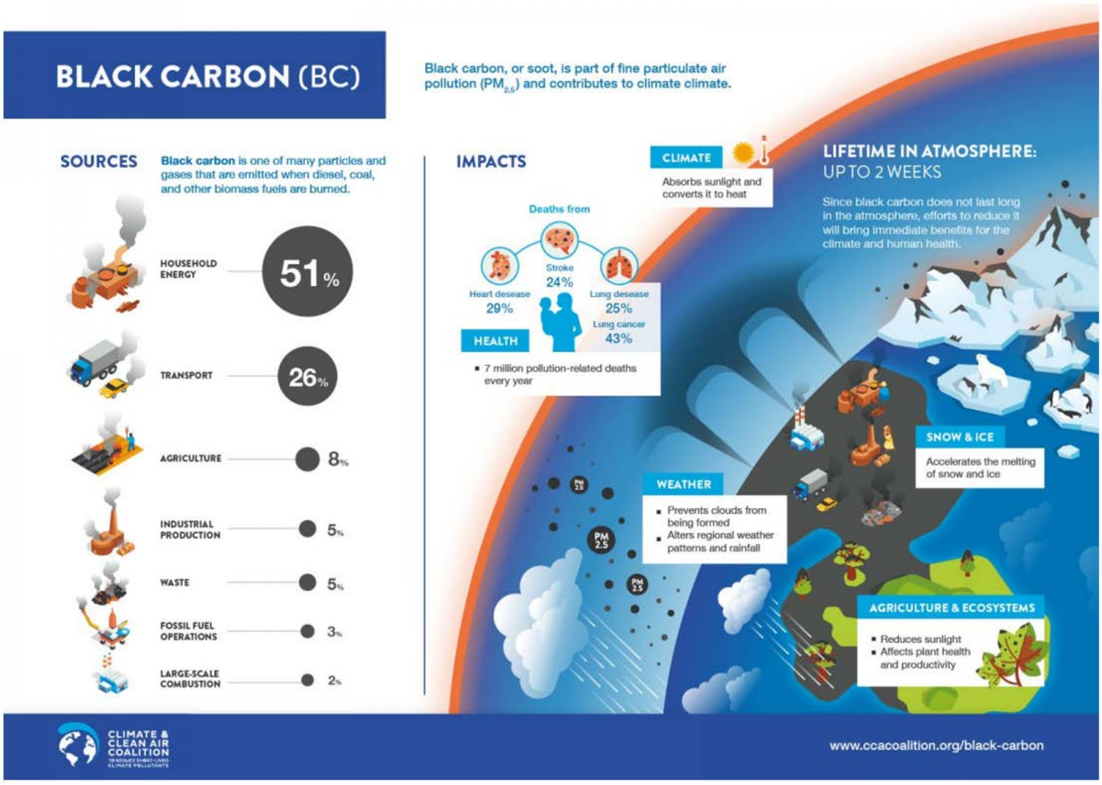


Figure 1. BC [1]

BC ranks second among the factors contributing to global climate change. Since BC particles absorb sunlight strongly, they give their black color to drying. BC can occur both naturally and as a result of incomplete combustion due to human causes. Primary sources of BC include emissions from diesel engines, forest fires, and wood burning. BC remains in the atmosphere for only a few weeks, and therefore reducing these emissions will positively affect the warming rate, especially in the Arctic, which is changing rapidly [3].

BC affects Earth's temperature by absorbing solar energy in the atmosphere and releasing it as heat. Warm air flows from low latitudes to the North Pole. As indicated in Figure 2, when BC falls from the atmosphere onto ice, it heats the surface and significantly increases the rate of melting [4].

BC contributes to climate change in two ways: When BC is suspended in the air, it traps sunlight, which causes heat to be produced in the atmosphere. This process primarily causes the air to warm up and permeate the local cloud formation. If BC builds up on ice and snow, it absorbs sunlight and contributes to heat generation. Then this situation also accelerates melting as the heat warms both the snow and the air. Climate effects are strongly localized, as BC stays one to four weeks in the atmosphere. Since these emissions are short-lived, if they are reduced, their impact on the climate will also decrease. Therefore, countries that deal with policies that decrease BC emissions profit from this. Studies suggest that more than 30 percent of warming in the Arctic is maybe caused by BC. Because it is thought that an increase in the BC ratio may contribute to accelerating the sea ice melting in the Arctic, and this situation brings about an irreversible acceleration of climate change [3].

BC constitutes a crucial element of atmospheric aerosols, originating from incomplete combustion in biomass or fossil fuel processes. BC stands out as the most effective aerosol component in absorbing visible light, thereby exerting a significant impact on Earth's radiative energy equilibrium.

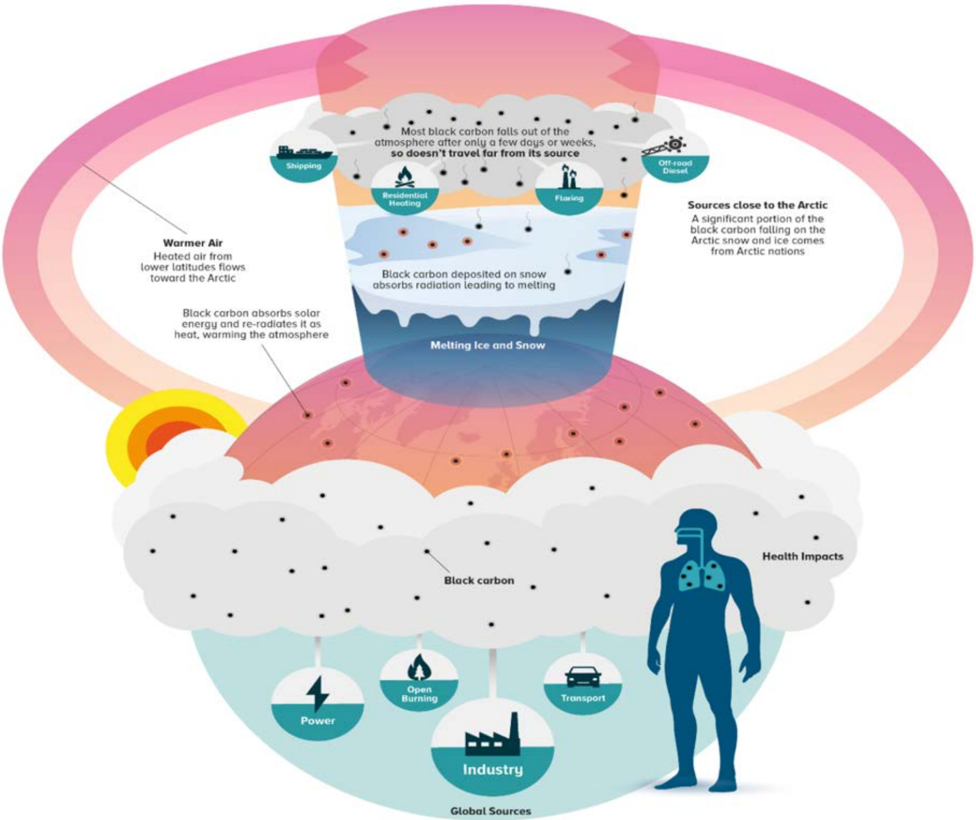


Figure 2. BC's effects [4]

When present in the atmosphere, BC particles exert a direct influence on the Earth's climate system by absorbing and scattering solar radiation. Indirectly, these particles alter the microphysical and optical properties of clouds, contributing to the rapid adjustments initiated by localized atmospheric column heating. Furthermore, when BC particles settle on reflective surfaces such as snow and ice, they can significantly change the local surface albedo, further impacting the surrounding environment [5].

In the Arctic region, BC sources are relatively limited, and the majority of BC observed in this area is a result of long-range transport originating from lower latitudes. Emissions from Eurasia contribute significantly to surface concentrations, and the typical transport times for BC to reach the Arctic span several days. Initially, newly emitted BC particles exhibit hydrophobic characteristics. However, during their transport to the Arctic, the aerosols age and undergo growth through particle coagulation and the condensation of gas-phase species, resulting in an augmentation of their hygroscopic nature [6].

During summer, the slower transport from source regions contributes to the seasonal minimum of BC, intensifying the impact of wet scavenging. This is because the extended duration of BC exposure to precipitation en route from sources to the Arctic, compared to winter, automatically enhances the effectiveness of the wet scavenging process [7].

3 Research Methods and Data Sources

To gather comprehensive insights within the study's scope, qualitative data collection methods were employed, and the outcomes derived from qualitative analyses were subsequently interpreted. Due to the significant role of the maritime industry as a contributor to climate change, it is imperative to scrutinize the impact of maritime trade on environmental pollution. In the context of maritime trade, this perspective has led to the exploration of new routes, such as the Arctic, where ship-sourced BC has been implicated in ecosystem degradation by accelerating ice melt. Annual mean Arctic sea ice ratio data were used to describe the relationship between melting sea ice in the Arctic and the potential for increased maritime traffic. Data on total known maritime incidents in Arctic waters was used to reveal the increasing intensity of use in the Arctic region.

4 Case Analysis

Transportation plays a significant role in overall greenhouse gas (GHG) emissions, standing as the second-largest sector after electricity production. Maritime transport, responsible for emitting approximately 1000 million tons of CO_2 annually, contributes about 2.5% to global GHG emissions. Projections indicate that shipping emissions could surge between 50% and 250% by 2050, depending on future economic and energy trends. Ships release emissions both into the air and sea, primarily originating from the exhaust gas produced through fuel combustion in ship engines. In recent years, there has been a heightened focus on enhancing shipping efficiency to mitigate global warming by reducing total GHG emissions [8].

International shipping currently accounts for approximately 2.4% of global anthropogenic GHG emissions, and this share is anticipated to rise in the coming years. The primary GHGs emitted from shipping are CO_2, methane (CH_4), and dinitrogen oxide (N_2O), with CO_2 being the predominant contributor to global warming potential. Depending on the type of fuel burned, ships also release other gases with climate implications, including BC, which contributes to warming, and sulfate particles, which have a cooling effect [9].

According to data from the International Energy Agency (Figure 3 - 2023), in 2022, emissions from the international shipping sector increased by 5%, returning to 2017-2018 levels. Innovation is vital to ensuring that ships sailing in zero-emission oceans will be commercially available by the mid-2020s. The existing policies, including operational emissions intensity standards, must be made more stringent to effectively achieve substantial reductions in emissions. This increased stringency is essential to incentivize and promote the widespread adoption of low- and zero-emission fuels and technologies for oceangoing vessels. As emphasized by the Energy Information Administration (www.iea.org), enhancing these policies is crucial for steering the maritime industry towards more sustainable practices and ensuring meaningful contributions to global efforts to reduce overall GHG emissions.

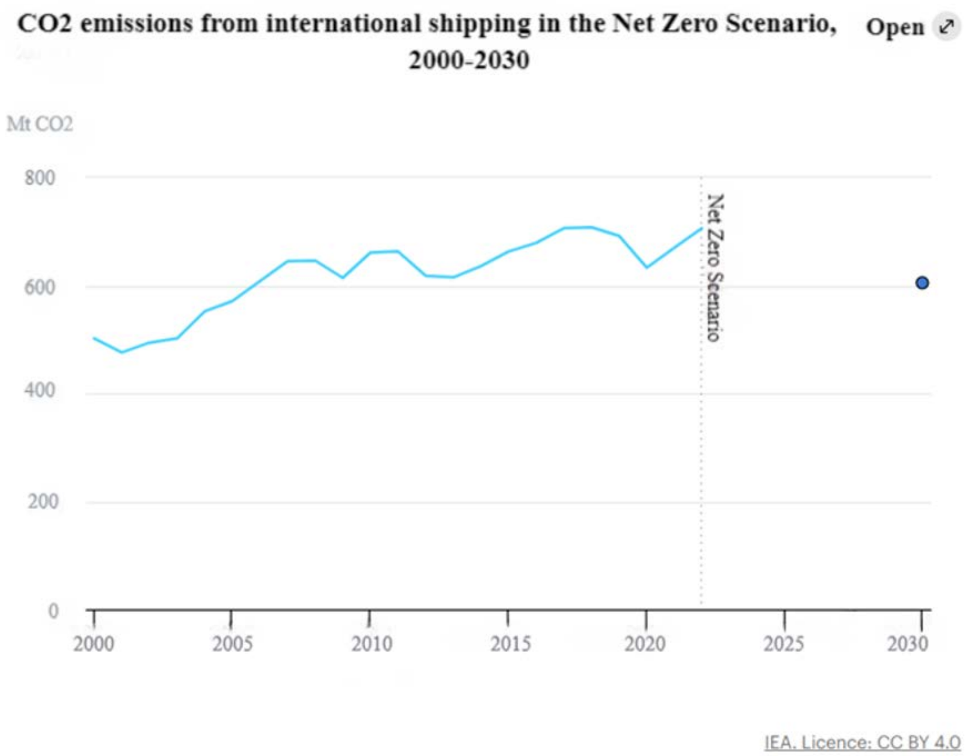


Figure 3. CO_2 emissions from international shipping in the Net Zero Scenario, 2000-2030 [10]

Reducing GHG emissions is crucial to mitigating the most severe consequences of climate change. Despite advancements in operational efficiency in various ship classes, shipping-related GHG emissions are on the rise. This upward trend is primarily attributed to the growing demand for shipping services and the subsequent increase in fossil fuel consumption. Notably, BC emerges as a significant contributor to the climate impact of shipping. Over a 20-year period, BC accounts for 21% of the CO_2 equivalent emissions from ships, underscoring its substantial role in the overall environmental footprint of maritime activities [11].

5 Policy Analysis

In April 2018, the International Maritime Organization (IMO) agreed to the climate strategy, which aims to cut GHG emissions at least 50% below 2008 levels by 2050. However, this climate strategy ignored a major pollutant that is second only to CO_2 and drives global warming: BC. BC is a dark, tiny particle that is produced when fuel is incompletely burned. About 100 times smaller than the width of a human hair, the BC is small enough to penetrate deep into the lungs. Therefore, it causes lung and heart diseases and premature death [1].

Besides its negative effects on health, BC is a powerful climate change actor. Although it remains in the atmosphere for only a few days as a "short-lived climate pollutant," it can have an extraordinary effect on the climate in a short time. Moreover, BC strongly absorbs sunlight and directly heats the atmosphere. Figure 4 shows the BC Particle under an Electron Microscope. When it falls on snow and ice, it accelerates its melting and reveals the darker lands or waters below. While there are other sources of BC, shipping in and near the Arctic emits BC that can build up directly on sea ice, and icebreakers are the only sources that emit BC in the ice pack [1].

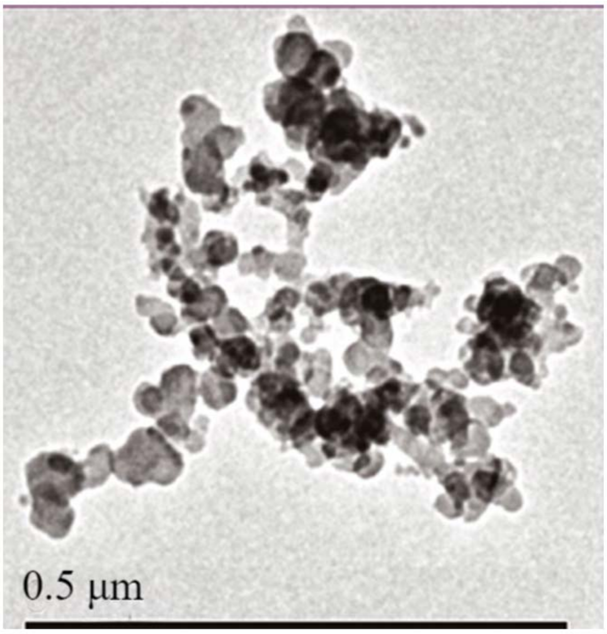


Figure 4. BC particle under an electron microscope [1]

Because of all these polluting effects on the world, IMO has taken new decisions on climate change. As of January 1, 2020, the use of very low-sulfur fuel oil (VLSFO) in maritime transport has been made mandatory by the IMO. In fact, this regulation is part of the main objective of IMO's 2020 program, which aims to reduce sulfur emissions from shipping by 80 percent [12].

Two years after this decision, in November 2022, IMO took new decisions to reduce the effects of ship-borne BC emissions in the Arctic on climate change. Adopting new resolutions in this direction after tackling pollution-related problems for a long time is an important development to move away from the dirtiest marine fuels. As an important part of all these processes, the IMO decision, which was agreed upon at a meeting of the Marine Environment Protection Committee (MEPC 77), strongly encourages governments to reduce ship-sourced BC emissions in the Arctic, giving governments both regional and national action, and it also offers a new way. Not only that, IMO resolutions also urge ship operators to reduce BC emissions by switching to distillate or other cleaner alternative fuels or propulsion methods when passing through the Arctic [13].

Despite IMO's efforts to address emissions, the relatively slow progress has prompted the European Union (EU) to take action. The inclusion of the shipping industry in the European Green Deal (EGD) signals a commitment to expedite solutions for controlling and limiting emissions. With an ambitious goal to become the world's first climate-neutral continent by 2050, the European Commission launched the EGD as a comprehensive initiative, encompassing various sectors in a collective effort toward transformation. Released in December 2019, the EGD serves as a roadmap for achieving climate neutrality. In response to climate and environmental emergencies, the EGD policies aim to minimize harm to nature, biodiversity, and humans. The plan advocates a sustainable transition by reducing carbon emissions, embracing cleaner energy sources, and adopting green technologies to mitigate adverse effects on health and the environment [14].

It is a well-known fact that BC from the exhausts of ships accelerates the melting and loss of reflection when it settles into snow and ice. What really matters is what happens next. The threat of BC to the Arctic has been known for a long time, and unfortunately, what happens in the Arctic on this global Earth does not just stay in the Arctic. These temperature changes in the Arctic climate are expected to have serious repercussions in the south. BC, which is responsible for about 20% of the climate impact of maritime transport, is emitted from the exhausts of ships and settles in snow and ice. This creates a cycle that exacerbates local and global warming [13].

Figure 5 shows that melting sea ice in the Arctic also reveals the potential for increased maritime traffic. While this creates difficulties for insurers, it also increases tensions between government interests and environmental concerns.

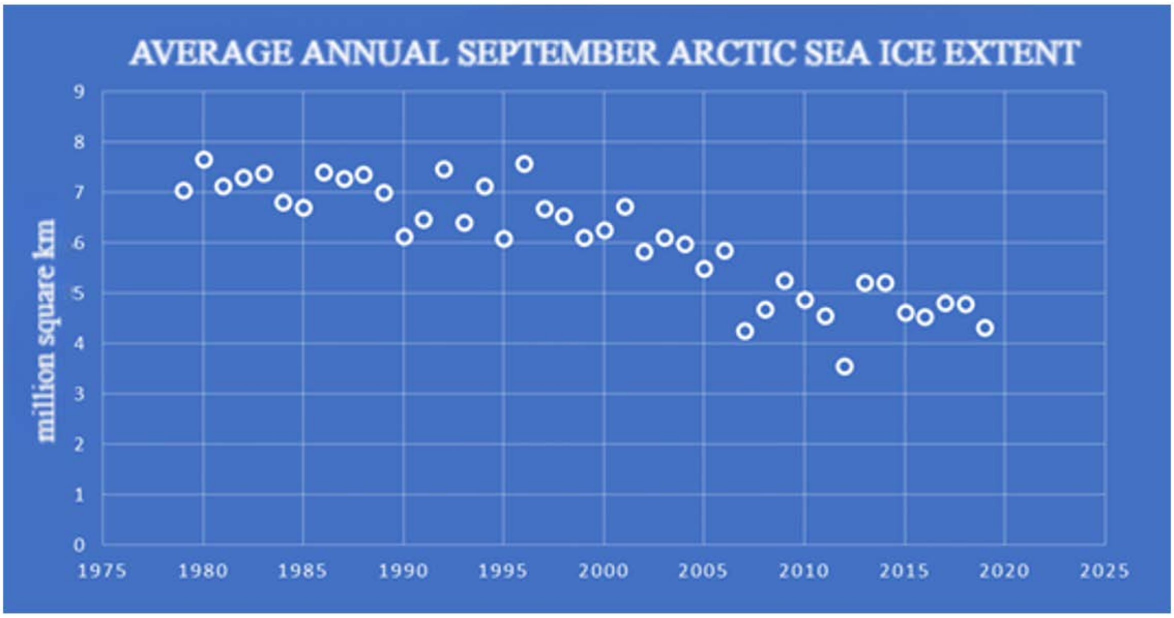


Figure 5. Average annual September Arctic Sea ice extent [15]

6 Arctic Maritime Traffic and the Effects of Ships on Global Warming

Arctic waters refer to the internal waters of Canada, including the territorial sea and exclusive economic zone. These encompass the area enclosed by the 60th parallel of north latitude and the 141st meridian of west longitude and extend to the outer limit of the exclusive economic zone. The definition applies unless interrupted by the international boundary [16]. The main Arctic shipping routes are shown in Figure 6.

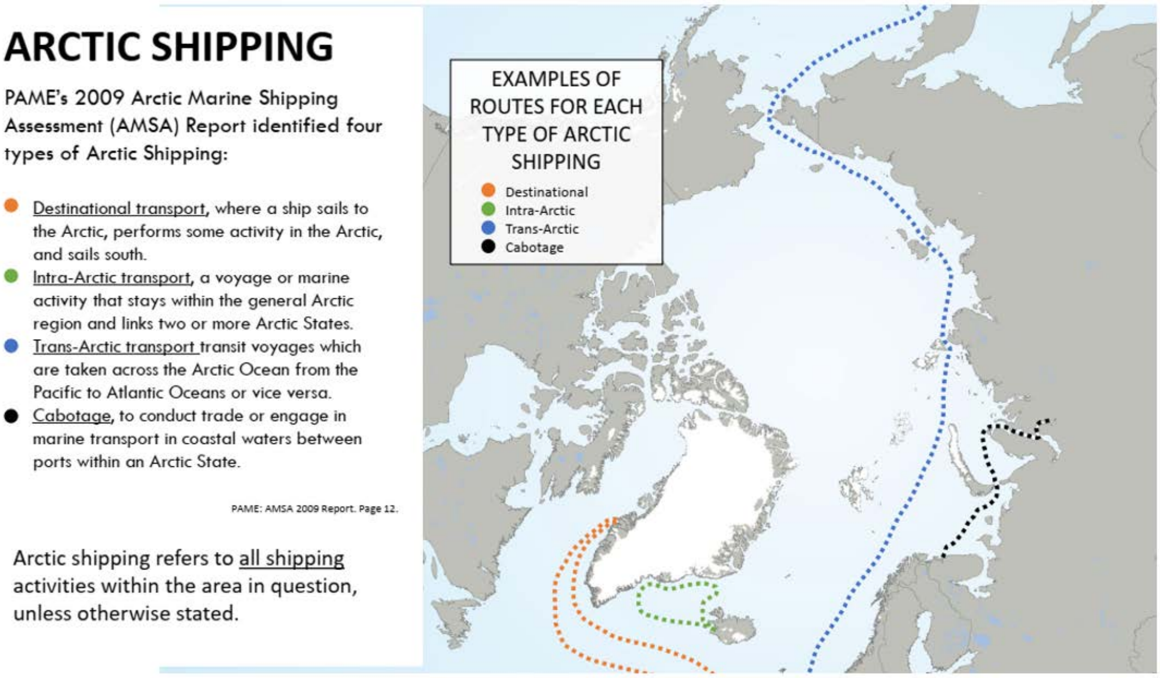


Figure 6. Examples of routes for each type of Arctic shipping [16]

The navigational distance for containers from a Northwest European port to East Asia can be shortened by around 40% when opting for the Northern Sea Route (NSR) as opposed to using the Suez Canal. However, factors such as uncertainty in travel speed, icebreaker fees, navigational hazards, and increased insurance fees can reduce the attractiveness of the distance covered. While cost-benefit analysis does not care about most of the new routes, some companies and governments have been experimenting recently to explore the potential of different regions. For the first time in 2017, a Russian tanker crossed the NSR without the aid of an icebreaker. In 2018, China announced new plans to develop a "Polar Silk Road" through new Arctic routes. In 2018, Russian natural gas producer Novatek completed its first liquefied natural gas (LNG) cargo voyage to China using the NSR. A month later, Maersk sent a container ship via the NSR [17].

BC, which is formed as a result of incomplete combustion of fuel, is considered the most effective emission in terms of climate change after CO_2. Although it is a short-lived emission that stays in the atmosphere for up to two weeks, it has a significant impact, especially as it settles into ice in the Arctic region. The effects of BC emissions in the Arctic region are known to increase global warming [12]. Because of the BC's hazards, the increasing maritime activities in this region also raise environmental concerns. With the increase in the number of ships, emissions and BC emissions in this region will increase, and this will exacerbate the melting. At this time, even MARPOL's mandate to replace heavy fuel oil with very low-sulfur fuel oil for Arctic ships does not fully address BC concerns. Although the data for previous periods is not sufficient, the total known maritime events in Arctic waters reveal an increase in the intensity of use of this region [18]. The Total Known Shipping Events in Arctic Waters, shown in Table 1, is an indicator that supports this situation.

Table 1. Total Known Shipping Incidents in Arctic Waters, 2009-2018 [18]

Cause	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Hull damage	6	2	2	1	2	1	1	2	2	0	19
Collision with vessel	4	10	4	4	2	0	3	2	4	2	35
Wrecked/grounded	14	9	9	8	10	14	6	11	9	8	98
Machinery	14	16	12	13	20	27	45	32	46	24	249
Other	10	14	12	11	16	13	15	8	10	12	121
Total	48	51	39	37	50	55	70	55	71	46	522

Research into the Arctic predicts that overall maritime activity in the region will increase by more than 50% between 2012 and 2050. Unfortunately, this will mean that sea ice in the Arctic is constantly shrinking. Global warming has led to the thinning of polar ice to the point where increasing numbers of ships use Arctic shipping routes (particularly the Northwest Passage in northern Canada and the Northeast Passage, which includes the NSR in northern Russia). At the same time, these routes significantly shorten cruising times. These routes are generally only open during the summer months, unless a ship is escorted by an icebreaker. Shipping companies are investing more and more in ships that can break through thin ice. However, the voyages of these ships are generally limited to the summer months. But as previously mentioned, for the first time in 2018, the ships survived the winter without an icebreaker [18].

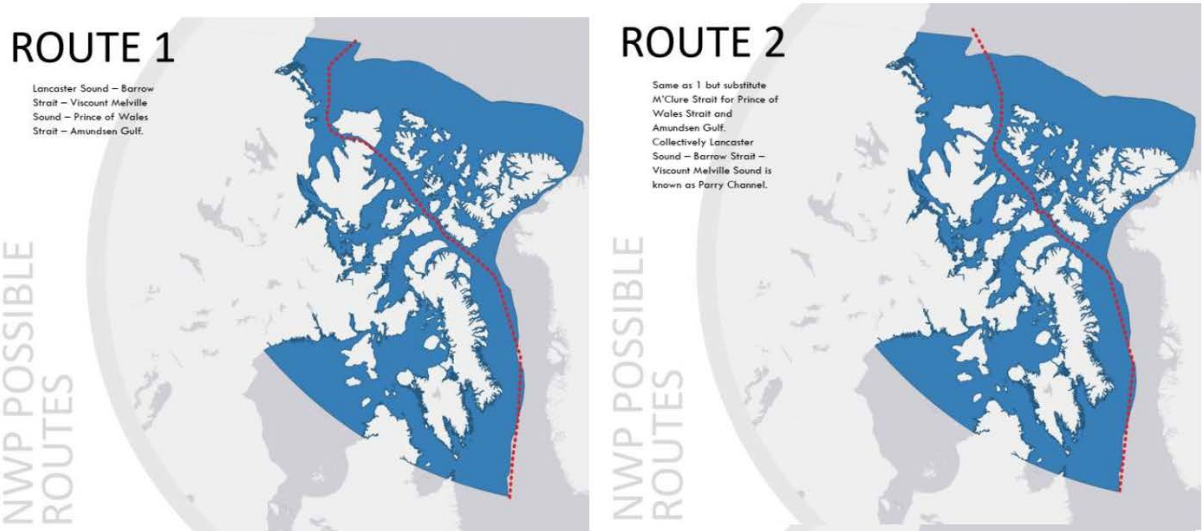
According to PAME's 2009 Arctic Marine Shipping Assessment report, there are six main routes for the northwest pass, as indicated in Figure 7.

The rapid shrinkage of Arctic Sea ice, attributed to global warming, is evident in the annual minimum size, decreasing by 12.58% per decade compared to the 1981-2010 average. This reduction, along with the extended ice-free periods, has led to a significant rise in maritime traffic in the region. Notably, the total number of ships entering the Arctic has seen a 25% increase since 2013, and the overall distance covered by all ships in the area has surged by 75% [17].

As a matter of fact, the Arctic Shipping Status Report dated 2021 supports this situation (Figure 8). Compared to 2013 and 2019, there was a 44% increase in the number of ships. On the other hand, the distance traveled by ships in this region increased by 107% from 2013 to 2019.

There was an 85% increase in BC from ships due to the increase in oil tankers and bulk carriers, particularly between 2015 and 2019. Because of this increase, environmentalists constantly draw attention to this issue in the Arctic, which is warming four times faster than the global average. According to a report by shipbroker Simpson Spence Young, pollution from global shipping increased by 4.9% in 2021 [19].

Apart from those, Dr. Sian Prior, chief adviser to the Clean Arctic Alliance warned IMO member states about taking immediate global action for reducing ship-sourced BC for mitigating the climate crisis in the Arctic. According to the Alliance, if all ships using heavy fuel oil in the Arctic switched to cleaner distilled fuel, it would reduce BC emissions by 44%. BC could be reduced by an additional 90% if all ships also install diesel particulate filters, which capture and store soot, reducing emissions [10].



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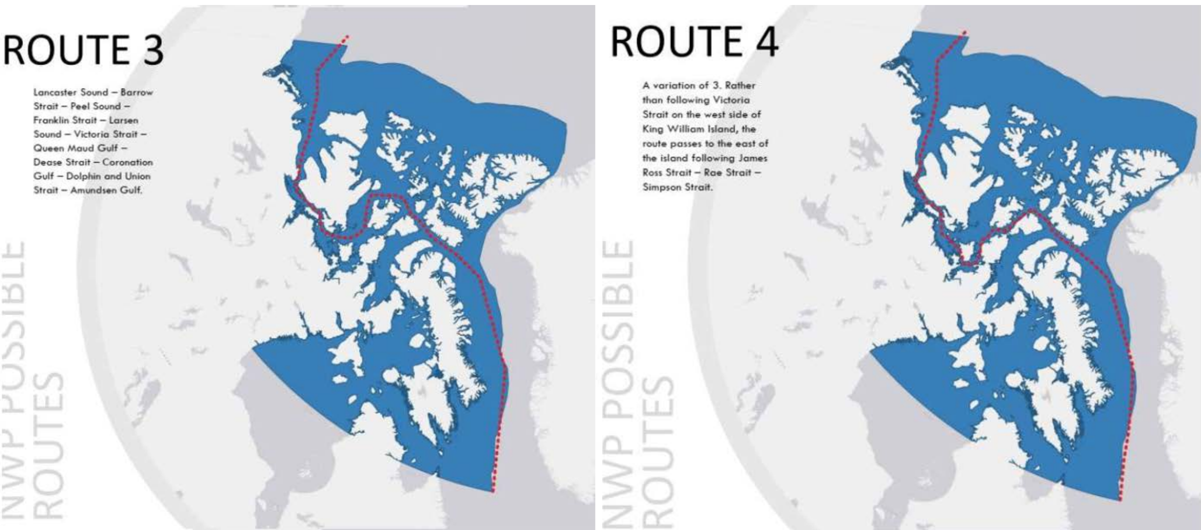

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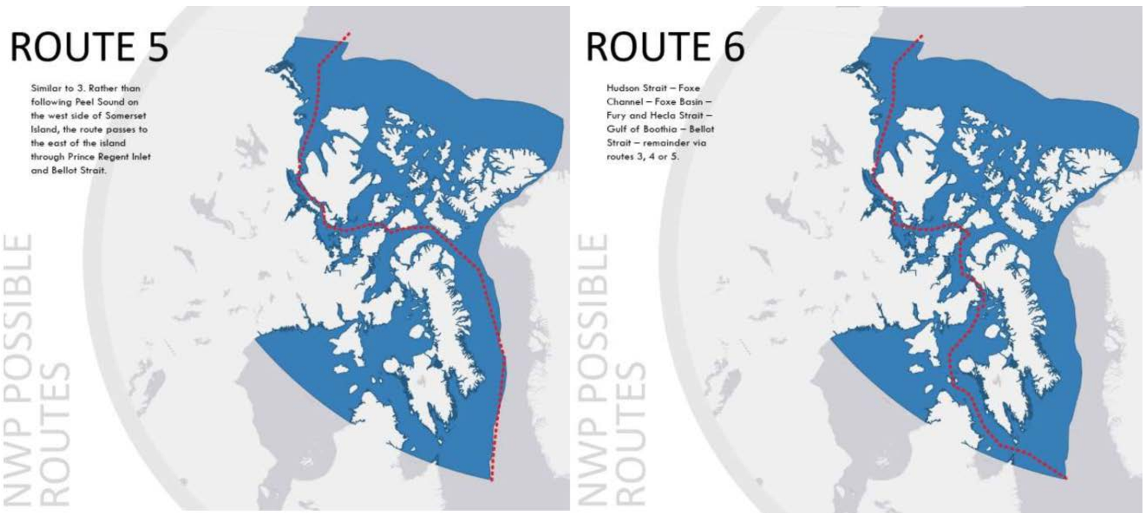

(c)

Figure 7. Six main Arctic routes for northwest pass [16]

Figure 8. Unique ships and distance sailed in Arctic between 2013 and 2019 [16]

7 Discussion

International maritime transport serves as the backbone of the global economy; nonetheless, the emissions released by vessels pose a significant threat by polluting the air and contributing substantially to global warming. With the anticipated growth of shipping activities, the urgency to reduce these emissions is paramount. This is essential not only to prevent undermining efforts aimed at reducing emissions in other sectors but also to safeguard human health, preserve the environment, and mitigate the impacts of climate change [20].

The melting of ice due to global warming has reshaped maritime routes worldwide, leading to the emergence of new pathways. One such route traverses the Arctic, providing maritime traffic with shorter distances and reduced costs. However, the increased utilization of the Arctic route poses a threat to the ecosystem, primarily due to the emission of BC from ships. This BC has an accelerating effect on global warming, raising concerns about its environmental impact and the need for sustainable practices in the changing maritime landscape.

Additionally, a report in 2012 published by T&E emphasized that human activities in the Arctic had the potential to inflict severe ecological damage on the region unless proactive measures were implemented. At the same time, the report noted that BC emitted by shipping activities has potentially devastating effects; the heavy fuel used is the dirtiest fuel and should be banned; and ships without ice-class can have dire ecological consequences [18].

Due to the various polluting effects on the environment, the IMO has implemented new decisions to address climate change. One significant measure is the mandatory use of very low sulfur fuel oil in maritime transport, effective from January 1, 2020. This regulation is a crucial component of the IMO's 2020 program, which has the primary goal of reducing sulfur emissions from shipping by 80 percent. This initiative reflects the maritime industry's commitment to mitigating its environmental impact and aligning with global efforts to combat climate change [12].

On the EU front, the European Commission, as part of the EGD, has declared an ambitious target to reduce GHG emissions from EU transport by 90% by the year 2050. The EGD outlines a comprehensive strategy detailing how this reduction goal will be achieved, encompassing various sectors, including shipping. This initiative reflects the EU's commitment to significantly mitigate the environmental impact of transport and contribute to broader climate change mitigation efforts.

The EGD targets the decarbonization of the continent within three decades, placing a significant emphasis on energy efficiency and decarbonizing the economy through the energy union. The European Commission has set specific milestones for 2030, including reducing GHG emissions by at least 40% from 1990 levels, improving energy efficiency by at least 32.5%, and increasing the share of renewable energy by at least 32%. Recognizing the urgency of curbing emissions, the shipping industry is actively engaged in efforts to reduce its carbon footprint. The shipping sector is actively adopting a range of technical and operational measures to cost-effectively reduce emissions. These include the implementation of weather routing, the use of contra-rotating propellers, the integration of propulsion efficiency devices, and the practice of slow steaming. These measures collectively contribute to the industry's efforts to decrease emissions while maintaining a focus on economic viability [14].

8 Conclusion and Future Research Directions

Maritime trade remains the most efficient and cost-effective mode of transporting goods over longer distances, despite market fluctuations and supply-demand dynamics. It continues to serve as the backbone of international trade. In the face of challenges such as volatile market conditions and rising fuel costs, maritime companies are exploring new routes to optimize their routes, aiming to reach destination ports quickly and economically. However, the global concern over climate change has brought heightened attention to the environmental impact of the maritime industry. Recognizing that maritime activities contribute significantly to climate change, it is imperative to thoroughly investigate the effects of maritime trade on environmental pollution. This inquiry is essential for understanding the industry's role in the broader context of climate change and its implications for both the environment and human health. On the flip side, the melting of ice due to global warming has led to a transformation of maritime routes worldwide, ushering in the utilization of new pathways. One notable route is through the Arctic, offering shorter and more cost-effective options for maritime traffic. However, the heightened utilization of the Arctic route poses a significant threat to the ecosystem, primarily due to the release of BC from ships, which, in turn, accelerates global warming.

In this study, the effects of ships using the Arctic route on global warming were investigated. The research highlights the potential consequences of increased traffic, particularly from oil tankers and bulk carriers in the region, leading to elevated BC emissions. The study suggests that such a scenario may act as a catalyst for global warming, emphasizing the need for comprehensive assessments and sustainable practices in navigating the evolving maritime landscape. The priority of both IMO and the EU Green Deal decisions is the prevention of carbon emissions caused by ships. These decisions are expected to give results in the long term when applied in a healthy way. On the other hand, previous studies show that the use of the Arctic route just to reduce costs triggers climate change caused by BC emissions.

In these days when our world is under a new threat regarding climate change, both individuals, businesses, and governments should think twice when making commercial decisions. As a result, the frequent use of the Arctic route by ships will adversely affect not only that region but also its surroundings in the long run for climate change. It is quite tragic that this situation is due to ship and maritime pollution. In this case, countries and those dealing with maritime transportation and maritime trade are faced with a single dilemma. Will ship owners and ship operators continue to cause global warming through BC to make really huge profits, or will they take longer routes, incurring higher fuel costs and sacrificing their profitability? Of course, this raises other questions as well. Is it worth it for businesses to make high profits when, albeit indirectly, caused by global warming to accelerate the coming of the end of the world? What good will these high profits and money do if there is no healthy world left to live in one day? The main aim of this paper is to raise awareness about this issue. Of course, maritime trade is a field of activity aimed at achieving high profits. However, the cost of these gains to the future of our world should be evaluated very well by ship operators, owners and countries. As indicated in American Indian proverb "We do not inherit the Earth from our ancestors; we borrow it from our children".

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflict of interest.

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