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Decarbonizing Arctic shipping: governance pathways and future directions

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Arctic shipping is a significant source of greenhouse gas (GHG) emissions, including carbon dioxide and black carbon, which intensify climate risks in the region. While the International Maritime Organization (IMO) has established the International Code for Ships Operating in Polar Waters (Polar Code) to address environmental and safety concerns of polar navigation, it falls short in promoting the decarbonization of Arctic shipping. The collaboration between the IMO and the Arctic Council, along with the contributions of the Arctic Council's task forces, is essential but requires further strengthening. In response to the climate crisis, the IMO has raised environmental standards, leading efforts to promote low-carbon growth in Arctic shipping through measures such as sulfur limits, heavy fuel oil bans, and reductions in black carbon emissions. Despite these initiatives, the governance of Arctic shipping decarbonization remains fragmented. To achieve meaningful decarbonization, the Polar Code must be strengthened and expanded into a unified regulatory framework. Additionally, enhanced collaboration between the IMO and the Arctic Council is crucial to maximize their collective impact. As a key player in Arctic shipping, China must strengthen compliance with international regulations through updated domestic legislation and Arctic policies. By actively engaging in multilateral mechanisms and developing a port state control inspection network, China can play a pivotal role in advancing Arctic shipping governance and IMO energy efficiency standards, contributing to a more coordinated and sustainable approach to the region's environmental challenges and global maritime governance.

KEYWORDS

climate change, arctic shipping, decarbonization, the polar code, governance pathways, China

1 Introduction

Over the past few decades, the Arctic has undergone significant environmental changes due to global warming, including a sharp decline in sea ice, melting permafrost, and an expansion of open water areas. These changes have driven the growth of energy projects, marine tourism, and trade, contributing to a sustained increase in Arctic shipping activities. In 2020, the Arctic Council's Working Group on the Protection of the Arctic Marine Environment (PAME) published the first Arctic Shipping Status Report (ASSR), which documented a notable rise in ship traffic between 2013 and 2019 (PAME, 2020). By 2024,

PAME released a comprehensive 10-year report on Arctic shipping trends, showing a continued increase in both the number of vessels and the distances they travel in the region. The number of ships entering the Arctic rose from 1,298 in 2013 to 1,628 in 2019, and further to 1,782 by 2023 (PAME, 2024a). This upward trend is closely linked to the reduction in Arctic sea ice and the expansion of energy exploration and development projects.

The melting of sea ice has heightened the conflict between the growth of Arctic shipping and the preservation of vulnerable Arctic marine ecosystems, which are highly sensitive to environmental disturbances. Pollution from Arctic shipping primarily takes two forms: primary pollution, which includes degradation of atmospheric and water quality from ship emissions, wastewater, noise, light pollution, and the introduction of invasive species; and man-made or accidental pollution, such as illegal waste discharges, hazardous substances, and accidental oil or chemical spills (Qi et al., 2024). The 2009 Arctic Shipping Assessment Report identifies accidental oil spills and illegal discharges as the most serious threats to the Arctic marine environment (PAME, 2009). These pollutants not only disrupt fragile ecosystems but also pose significant risks to the global climate (Winther et al., 2014), underscoring the urgent need for stricter environmental regulations and more effective management practices in Arctic shipping.

Historically, emission reduction efforts have focused on carbon dioxide, the primary driver of climate change. However, scientific studies have revealed that black carbon—produced by the incomplete combustion of fossil fuels and other carbon-based materials—also has a significant warming effect, approximately 1.1 watts per square meter. This impact is roughly two-thirds that of carbon dioxide and more than double previous estimates. As a result, black carbon has become the second most significant climate forcing agent after carbon dioxide, surpassing methane in its contribution to global warming (Bond et al., 2013).

The growth of Arctic shipping has significantly increased emissions of greenhouse gases, including carbon dioxide and black carbon. Due to the region's amplification effect, the Arctic is warming at a rate 3-4 times faster than the global average (AC, 2023a). Research by Rantanen and colleagues suggests that current climate models may underestimate this effect, with actual warming potentially reaching nearly four times the global average (Rantanen et al., 2022). In 2020, the Arctic recorded its highest temperature of 38°C, and projections indicate that the Arctic Ocean could be ice-free by the mid-21st century (IPCC, 2013; AMAP, 2011). As a critical global climate regulator, the Arctic's rapid warming and ice melt could trigger severe global consequences, including accelerated global warming, rising sea levels, more frequent extreme weather events, and significant biodiversity loss (Liu and Chen, 2010).

The decarbonization of Arctic shipping depends on a collaborative relationship between regional and global governance frameworks. The International Maritime Organization (IMO), a specialized UN agency responsible for the safety and environmental protection of international shipping, reached a key milestone with the development of the International Code for Ships Operating in Polar Waters (Polar Code) over seven years. This code established the first enforceable mandatory standards and recommended measures for Arctic shipping governance. At the same time, the Arctic Council, the leading regulatory body for the Arctic, has worked closely with the IMO to promote greener shipping through various policy initiatives and to strengthen its own governance mechanisms. The Arctic Council's task forces have made significant contributions to this process. Nevertheless, the decarbonization of Arctic shipping remains a major challenge. To address it effectively, greater engagement and cooperation between the IMO, the Arctic Council, and other relevant bodies is crucial.

Effective governance of Arctic shipping depends not only on cooperation among the eight Arctic States but also on the collaboration of port states and flag states. Although China is not an Arctic State, it has become a significant player in shipping, port operations, and shipbuilding. China has consistently shown its commitment to the sustainable development of the Arctic region, actively engaging in scientific research, economic activities, and governance (Chen, 2023). In 2018, China released a white paper on its Arctic Policy, marking the culmination of five years of increasing involvement in Arctic governance as an observer to the Arctic Council. This white paper outlined China's position as a near-Arctic State and Arctic stakeholder, emphasizing its role in the development, utilization, and governance of the Arctic.

This study focuses on the decarbonization and emission reduction of Arctic shipping within the broader context of environmental protection, to analyze governance pathways for decarbonizing Arctic shipping and provide recommendations that could stimulate further measures for sustainable development in the region. The paper is organized as follows: Section 2 reviews past decarbonization policies by the IMO and the Arctic Council, with a particular focus on the Arctic Council's task forces as key initiatives. Section 3 examines recent developments in the IMO's governance of Arctic shipping decarbonization. Section 4 offers recommendations for achieving decarbonization in Arctic shipping and China's contribution in this effort, in line with its dual-carbon target policy. Section 5 concludes the study. By understanding international regulatory mechanisms and policy dynamics, this research aims to promote green and sustainable development in the Arctic while providing a scientific basis for China to enhance its global contribution.

2 Multilevel governance pathways for decarbonizing Arctic shipping

The escalating crisis of Arctic warming, combined with increasing stakeholder collaboration, has led to the development of a multifaceted governance framework for decarbonizing Arctic shipping (see Table 1). The IMO, operating under the mandate of the United Nations Convention on the Law of the Sea (UNCLOS), addresses the unique challenges of polar shipping through the Polar Code. Regionally, the Arctic Council, alongside international organizations like the IMO and non-governmental organizations (NGOs) like the International Arctic Science Committee (IASC), plays a crucial role in driving initiatives, facilitating negotiations, and supporting policy implementation (Chen and Liu, 2023). This collaborative approach has fostered a dynamic regime complex, characterized by overlapping, non-hierarchical institutional arrangements (Keohane and Victor, 2011).

TABLE 1 Multilevel governance pathways for decarbonizing Arctic shipping.

Governance levels	Actor
International level	United Nations, International Maritime Organization
Regional level	Arctic Council, Non-governmental organizations et al
National level	Arctic states, Non-Arctic States

2.1 IMO's policy on decarbonizing Arctic shipping

2.1.1 Polar Code

The Polar Code, which came into force on January 1, 2017, marks a new era in shipping regulation for polar waters. Structurally, the Polar Code is divided into four main parts: the preamble, the introduction, Part I on safety, and Part II on environmental protection. Part II-A (mandatory measures) consists of five chapters that reflect the standards set by the International Convention on the Prevention of Pollution from Ships (MARPOL), but with more stringent requirements. Notably, the Polar Code does not currently include a specific chapter on the prevention of air pollution from polar ships. The Code's blend of mandatory and non-mandatory measures enhances its acceptance and broadens its applicability (Chen, 2018). By fully embodying the precautionary principle, the Polar Code provides comprehensive norms and standards for Arctic shipping governance, which contribute to reducing environmental and safety risks and significantly contribute to the effective governance of polar shipping (Huntington et al., 2023).

2.1.2 Gaps in Polar Code shipping standards

While the Polar Code represents a significant advancement in the development of safety and environmental standards for polar navigation, it still requires adjustments. Its pollution prevention and environmental protection measures are not comprehensive enough to address all environmental concerns. Since its implementation, criticisms of the Polar Code have primarily centered on its lack of comprehensiveness and the perceived inadequacy of its environmental safeguards (Chen, 2018). One of the most notable shortcomings is the absence of climate governance provisions, particularly in two key areas.

2.1.2.1 Absence of ban on heavy fuel oil usage or carriage

Heavy fuel oil (HFO), a byproduct of the refining process, is commonly used in large vessels such as bulk carriers, cargo ships, and cruise ships. Due to its high toxicity and viscosity, HFO poses significant environmental risks. It is a major source of air pollutants, including sulfur oxides (SOx), nitrogen oxides (NOx), and black carbon, all of which are emitted during its combustion. An accidental spill of HFO in the Arctic would have catastrophic effects on the marine environment and wildlife. Unlike conventional oil, HFO forms a thick, mousse-like substance in seawater that is highly toxic and decomposes very slowly in cold waters, complicating cleanup efforts. The Arctic's remote location, harsh weather conditions, and limited resources for emergency response further hinder effective spill recovery. Additionally, HFO spills threaten the livelihoods and cultures of indigenous communities who depend on marine resources, jeopardizing both their economic stability and traditional ways of life (CAA, 2021).

Although heavy fuel oil (HFO) was banned in Antarctic waters in 2011, ships operating in the Arctic used over 83,000 metric tons of HFO in 2015—double the amount used in 2012. HFO accounts for 57% of the total fuel used in Arctic marine shipping (ICCT, 2017). Given its widespread use, the International Maritime Organization (IMO) acknowledged that enforcing a complete ban on HFO in the Arctic would be difficult. As a result, the final version of the Polar Code only encourages, rather than mandates, the prohibition of HFO use and carriage in Arctic operations.

2.1.2.2 Insufficient measures against black carbon pollution

Black carbon, an aerosol produced by the incomplete combustion of fossil fuels and biomass, exerts a significant warming effect, particularly in the Arctic. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report highlights that the deposition of black carbon on snow and ice contributes to increased Arctic warming (IPCC, 2021). When black carbon settles on Arctic ice, it reduces the ice's albedo (reflectivity), leading to greater heat absorption and accelerated ice melt. This exposes more open water, further decreasing reflectivity and creating a self-reinforcing feedback loop that intensifies warming (IPCC, 2019). Fortunately, black carbon has a short atmospheric lifetime—ranging from a few days to weeks—making its emission control a powerful short-term strategy for mitigating climate warming and achieving immediate decarbonization benefits (EGBCM, 2019).

The primary global sources of black carbon are the combustion of fossil fuels and biomass (Bond et al., 2007). In the Arctic, major contributors to black carbon emissions include fishing vessels (25%), general cargo vessels (19%), and service vessels (12%). In 2015, approximately two-thirds of black carbon emissions from Arctic shipping were linked to heavy fuel oil consumption (ICCT, 2017). The IMO began addressing black carbon emissions in 2008, following advocacy from Friends of the Earth International (FOEI). Initially, the IMO regulated black carbon alongside greenhouse gases (GHGs), but in October 2010, during the 61st session of the Marine Environment Protection Committee (MEPC), black carbon was separated from the broader GHG emissions issue (MEPC, 2010). By 2011, driven by the United States, Norway, and Sweden, MEPC62 focused specifically on the impacts of Arctic black carbon emissions, approving a work plan that initiated research on definitions, measurement methods, and control measures (MEPC, 2011). After several years of discussions, MEPC68 adopted a

definition of black carbon in 2015, and efforts then shifted towards developing control measures (CCS, 2015). Despite these efforts, black carbon remains unaddressed in the final version of the Polar Code or in amendments to the MARPOL Convention.

2.2 Arctic Council's decarbonization initiatives for Arctic shipping

2.2.1 Arctic Council and its task forces

2.2.1.1 Strengths and limitations of Arctic Council

At the regional governance level, the Arctic Council is the most influential body in the region. Oran Young describes it as a "decision incubator" with a "generative" function, meaning it plays a key role in shaping decisions rather than making binding decisions itself (Young, 2016). The Arctic Council's operational framework enables greater flexibility than the IMO, allowing it to use informal mechanisms for institutional interaction and policy complementarity with global organizations like the IMO. The Council has actively contributed to Arctic lawmaking, developing a range of soft law regulations (Abbott and Snidal, 2000) and, more recently, three legally binding regional international agreements (Koivurova, 2020). By focusing on areas such as marine environmental protection (AC, 2013), emergency response (AC, 2011) and scientific cooperation (AC, 2017), the Arctic Council has fostered synergies between global and regional mechanisms. Through its scientific assessments and recommendations, the Council has effectively leveraged both hard and soft law to achieve complementary benefits.

However, the Arctic Council faces significant limitations in governing the decarbonization of Arctic shipping. Its membership is confined to the eight Arctic States, which restricts its geographic and political influence. As a high-level intergovernmental forum, the Council's internal instruments are not legally binding. Moreover, the Council lacks independent financial resources and depends heavily on contributions from member states.

2.2.1.2 The task forces and their effectiveness

To effectively leverage its decision-shaping role, the Arctic Council has established six working groups, eleven task forces, and three expert groups to carry out specific tasks, such as scientific assessments. For example, the Working Group on the Protection of the Arctic Marine Environment (PAME) and the Black Carbon and Methane Expert Group (EGBCM) have played pivotal roles in addressing the decarbonization of Arctic shipping.

It is important to recognize that goal-oriented task forces have been crucial, albeit often overlooked, in the Arctic Council's governance framework. Since 2009, the Council has created eleven task forces, each designed to tackle specific issues in Arctic governance. These task forces, composed of experts from the Working Groups and representatives from Arctic States, are appointed for fixed periods to achieve targeted outcomes. Due to their focused mandates and temporary nature, task forces serve as auxiliary bodies to the Arctic Council. Their objectives typically center on addressing environmental and climate challenges, enhancing international cooperation, improving local infrastructure, and promoting sustainable development in the Arctic. All eleven task forces have now completed their original mandates and are currently inactive.

The function and influence of task forces should not be underestimated. These groups are often established to conduct scientific assessments on specific issues and offer feasibility recommendations. They may also develop framework documents or facilitate the negotiation of agreements. For instance, the Task Force on Short-Lived Climate Forcers (SLCF) completed a comprehensive technical assessment of black carbon emissions and abatement options. This task force analyzed black carbon emission trends, reviewed existing policies and programs, and evaluated potential abatement strategies. The feasibility analyses and recommendations provided by the SLCF have served as critical scientific references for the Arctic Council, the IMO, and other decision-makers.

Task forces also play a vital role as platforms that consolidate state interests and support the negotiation of legally binding agreements under the Arctic Council. For example, the Task Force on Search and Rescue facilitated the signing of the Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic in 2011. Similarly, the Task Force on Arctic Marine Oil Pollution Prevention and Response (TFOPP) contributed to the negotiation of the 2013 Agreement on Cooperation on Marine Oil pollution Preparedness and Response, which established a cooperative framework for oil spill response and provided essential legal safeguards. Additionally, the Task Force for Enhancing Scientific Cooperation in the Arctic (SCTF) played a key role in the signing of the Agreement on Enhancing International Arctic Scientific Cooperation in 2017.

The creation and implementation of these three agreements have elevated the Arctic Council's legislative function, marking a significant shift in its role. Unlike science-driven working groups, which typically operate without a political agenda, task forces function as intergovernmental negotiating bodies, where the stakes are higher, and participants are focused on crafting politically sensitive agreements. The task forces' goal-oriented approach—centered on securing legal agreements or establishing clear timelines for program implementation—has strengthened the political will of states to address pressing issues effectively.

The task forces have been pivotal in establishing key mechanisms within the Arctic Council and the broader Arctic governance framework. For example, the Task Force on Black Carbon and Methane (TFBCM) directly contributed to the creation of the Expert Group on Black Carbon and Methane (EGBCM). The effectiveness of these task forces, as evidenced by their achievements, highlights their critical role within the Arctic Council. Not only have they helped transform the Council's function and broaden its influence, but they have also strengthened the scientific foundation of the Council's decision-

making and law-making processes. Their ongoing impact underscores their essential contribution to Arctic governance.

2.2.2 Arctic Council's Initiative for decarbonizing Arctic shipping

Even before the Polar Code came into force, the Arctic Council had been actively advancing climate governance policies. In 2004, the Council published the Arctic Climate Impact Assessment (ACIA), which highlighted the environmental and socio-economic consequences of Arctic climate change. The findings were subsequently incorporated into the IPCC's Fourth Assessment Report. In 2009, the Council established the Task Force on Short-Lived Climate Forcers (SLCF), focusing on black carbon reduction. Its report, Black Carbon Impacts on the Arctic Climate, suggested that reducing black carbon emissions could be an effective short-term strategy for mitigating climate change. That same year, the Council released the Arctic Maritime Shipping Assessment (AMSA), which identified opportunities for black carbon emission reductions in Arctic shipping (PAME, 2009).

In 2015, the Council adopted the Enhanced Framework for Action on Black Carbon and Methane Emissions Reduction, calling for regional and collective action among Member States. This framework emphasized the importance of scientific research, the implementation of a black carbon emissions reporting system, and strengthened collaboration between Member and observer States to accelerate emissions reductions. The following year, in celebration of its 20th anniversary, the Council adopted the 20th Anniversary Joint Declaration—The Arctic Council: A Forum for Peace and Cooperation. This declaration urged member states to protect the Arctic environment in line with the Paris Agreement and commit to reducing GHG emissions to combat climate change and promote sustainable development. Empirical studies have found that the Declaration's policy initiatives have positively impacted GHG emission reductions in the Arctic, particularly in raising awareness about black carbon (Wang et al., 2023). Despite its limited authority and capacity, the Arctic Council has significantly elevated the profile of Arctic climate change within the global governance framework.

Following the entry into force of the Polar Code, Arctic States, observers, industry stakeholders, NGOs, and other parties, through the Arctic Council, have developed various measures to mitigate the climate impacts of Arctic shipping. These initiatives include establishing a database on Arctic shipping traffic, exchanging best practices in Arctic shipping, publishing reports on the state of Arctic shipping and the use of heavy fuel oil, participating in the governance of black carbon, and creating low-impact shipping corridors. Throughout this process, the Arctic Council has closely collaborated with the IMO, supporting the implementation of the Polar Code while also addressing its shortcomings. By leveraging its unique position to coordinate the interests of Arctic States, the Arctic Council has systematically worked to fill the gaps left by the Polar Code.

2.2.2.1 Artic shipping status report

PAME's Arctic Shipping Status Reports (ASSR), based on the Arctic Ship Traffic Data (ASTD) system, analyze key trends in Arctic shipping. The first report (2020) covered trends from 2013 to 2019, while the second report (2021) noted an 82% increase in fuel consumption since 2016, with 10% of ships using hazardous heavy fuel oil (HFO). The third report (2021) highlighted a rise in both ship numbers and distances traveled in the Northwest Passage (PAME, 2021). In 2023, the fourth report analyzed 1,661 vessels, 1,349 flagged by Arctic States and 96 by observer states, with Russia leading at 885 ships (PAME, 2023). The fifth report (2024) showed that fishing vessels (44%) were the most common, followed by general cargo ships (11%) and bulk carriers (7%), with natural resource exploration driving much of the growth (PAME, 2024b).

In January 2024, PAME updated its 2013-2019 report to include data for 2020-2023, revealing a continuous increase in Arctic shipping. In 2023, 1,782 ships entered Arctic waters, a 37% increase from 2013. Shipping distance grew by 111%, reaching 12.9 million nautical miles. Bulk carriers rose sharply from 71 in 2013 to 119 in 2023, linked to energy projects like Mary River Mine and Yamal Gas (PAME, 2024a). This rise in shipping coincides with a decline in Arctic Sea ice, shrinking from 6.1 million square kilometers in September 1999 to 4.3 million in 2019. While the report does not directly address shipping impacts, it has drawn attention to the growth of Arctic shipping among policymakers.

2.2.2.2 Arctic heavy oil research report

Since 2011, PAME has published four reports on the use and transport of heavy fuel oil (HFO) in Arctic shipping, focusing on black carbon emissions and technologies for their reduction. In October 2020, PAME's report on HFO use in 2019 noted that 61% of Arctic ships used distillate marine fuel. Although the number of ships in the Arctic increased by only 2% from 2016 to 2019, the use of HFO rose significantly, from 117 to 165 ships—an increase of over 40%, with bulk carriers leading the rise (PAME, 2019). The report also highlighted environmental risks such as HFO spills and black carbon emissions, bridging the knowledge gap at the IMO and serving as an early warning, urging action toward a potential HFO ban.

2.2.2.3 Black Carbon Governance

In April 2015, the Arctic Council adopted the Framework for Action to Enhance Black Carbon and Methane Emission Reductions, overseen by the EGBCM. This framework aimed to evaluate progress based on national reports, Working Group outputs, and other relevant data. The EGBCM's first progress report led to the 2017 Fairbanks Declaration, calling for a 25-33%

reduction in black carbon emissions by 2025. Recognizing the global impact of black carbon and methane, the Arctic Council invited observer states to join these efforts.

This initiative marked the first coordinated effort by Arctic States to set climate reduction targets and propose national measures for mitigating short-term climate forcers. However, the targets are non-mandatory and modest—EGBCM projects a 24% reduction with minimal action. While groundbreaking, the Arctic Council's work on black carbon governance requires further strengthening.

The Council's contributions to Arctic shipping decarbonization include conducting scientific assessments, raising awareness, issuing recommendations, formulating new rules, generating flexible soft law, and fostering collaboration. Task forces have played a key role in bridging knowledge gaps, offering assessments, and providing negotiation platforms, representing a potential new model for decarbonization governance.

3 IMO's latest efforts to decarbonize Arctic shipping

In response to global shipping emissions reduction goals, the IMO has issued work plans and measures to strengthen environmental standards and enhance the mandatory nature of its regulations. These efforts include provisions specifically targeting the Arctic, aimed at addressing gaps in the Polar Code to maximize its effectiveness. The IMO's proactive approach is paving the way for a low-carbon Arctic shipping industry and offers hope for a more environmentally sustainable future in Arctic shipping.

3.1 Timely revision of the GHG mitigation strategy for global shipping

To combat global warming, the IMO has developed and continuously refined its GHG emission reduction strategy for international shipping, marking a new era in green shipping governance. These initiatives also impact Arctic shipping.

The IMO has long recognized the air pollution caused by international shipping, amending the MARPOL Convention in 1997 to include air pollution prevention in Annex VI. This annex has been updated several times, including in 2011 when the mandatory Ship Energy Efficiency Code was adopted, introducing the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Program (SEEMP). These measures formed the first global mandatory GHG reduction mechanism for international transport. However, while Annex VI encourages innovative energy technologies and mandates their application, its technical requirements have raised concerns about limiting the rights of developing countries, conflicting with the "common but differentiated responsibilities" principle (Liu et al., 2023).

In 2018, the IMO introduced its Initial Strategy for GHG Emission Reduction from Ships, setting carbon reduction targets: a 40% reduction in carbon intensity by 2030 and a 50% reduction in total GHG emissions by 2050 (IMO, 2018). The strategy supports developing countries through technology transfer and research cooperation, balancing the needs of both developed and developing nations (Doelle and Chircop, 2019), but it notably excludes black carbon from its targets.

In June 2021, the IMO's Marine Environment Protection Committee (MEPC76) adopted amendments to Annex VI of the MARPOL Convention. These amendments introduced the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), effective from January 1, 2023. Ships over 5,000 gross tons must calculate and verify their CII, with those receiving a D or E rating for three consecutive years required to develop an energy efficiency improvement plan. This marked the first formal ship rating mechanism to improve energy efficiency and reduce GHG emissions.

The IMO's updated GHG Emission Reduction Strategy, adopted at MEPC80 in 2023, sets a long-term net-zero target for international shipping by 2050, aligning with the Paris Agreement's goals (IMO, 2023). As shown in Figure 1, the strategy includes targets for alternative fuel adoption, aiming for 5-10% of international shipping to use zero or near-zero GHG technologies by 2030. It also sets GHG reduction milestones: 20-30% by 2030 and 70-80% by 2040, compared to 2008 levels.

Medium-term measures are being developed, including GHG intensity standards for bunker fuels and a carbon pricing mechanism. In March 2024, MEPC81 adopted revised Guidelines on the life cycle GHG intensity of marine fuels and discussed a draft net-zero framework, which includes GHG fuel intensity (GFI) targets and flexible implementation mechanisms. Future interim measures will be based on this framework (IMO, 2024).

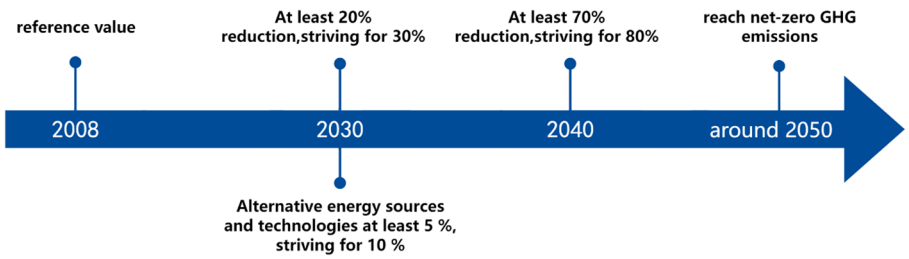

FIGURE 1
Timeline for the IMO ship greenhouse gas emission reduction strategy (2023).

3.2 New sulfur limit regulations

The IMO's sulfur and carbon restriction measures work in tandem to promote cleaner shipping practices. Effective from January 1, 2020, the IMO 2020 sulfur regulations mandate that ships transition from high-sulfur fuel oil (HSFO) with 3.5% sulfur content to very low sulfur fuel oil (VLSFO) with a 0.5% sulfur content. Only ships equipped with desulfurization systems (scrubbers) are allowed to continue using HSFO. This regulation has significantly impacted the global shipping industry, including in the Arctic, marking a shift to cleaner marine fuels. However, the transition has resulted in higher fuel costs, required modifications to ships (e.g., installing scrubbers), and operational challenges due to the less stable quality of VLSFO. Despite these challenges, most of the world's trading ships have already switched to VLSFO.

The IMO has also examined the impact of VLSFO on carbon emissions to ensure sulfur restrictions align with carbon reduction goals. However, the sulfur restrictions have sparked concerns due to their potential unintended climate effects. Although the reduction in sulfate aerosols from low-sulfur fuels benefits human health, it also alters atmospheric light-scattering properties, indirectly influencing climate change (Sofiev et al., 2018). VLSFO, which often contains high levels of aromatic compounds like benzene and toluene, can significantly increase black carbon emissions (ICCT, 2017). Refiners have developed various fuel blends to reduce compliance costs, but these could lead to a sharp rise in black carbon emissions (IMO, 2019a). Research funded by Germany and Finland indicates that the switch from HFO to VLSFO could increase black carbon emissions by up to 85% (IMO, 2019b), potentially undermining the IMO's efforts to reduce GHG emissions and worsening global climate change (High North News, 2020).

3.3 Initial actions on Arctic Black Carbon Governance

To address the warming effects of Arctic shipping, the IMO has introduced measures targeting black carbon, the second most significant contributor to climate warming. In November 2021, during MEPC77, the IMO adopted a decision encouraging the voluntary use of cleaner fuels in the Arctic to reduce black carbon emissions. The resolution urges member states and ship operators to voluntarily adopt distillate fuels, alternative cleaner fuels, or other propulsion methods that minimize black carbon emissions in or near the Arctic (MEPC, 2021). However, the resolution is not mandatory and relies on voluntary compliance, leading to limited enthusiasm from ship operators due to the increased operating costs. In response, the Clean Arctic Alliance (CAA) has called for mandatory rules to enforce this approach.

The IMO has identified several methods for reducing black carbon emissions, including transitioning from HFO to distillates or LNG, using diesel particulate filters or electrostatic precipitators to remove black carbon from exhaust gases, and adopting zero-emission technologies such as batteries and hydrogen fuel cells (ICCT, 2019a). However, the practical implementation of these technologies into substantive policy remains contentious, primarily due to high conversion costs. The absence of mandatory black carbon regulations has drawn criticism from environmental organizations, who argue that reducing black carbon emissions is feasible and urge the IMO to expedite the transition to distillate fuels in all Arctic shipping. They also call for global regulations to ban high black carbon emissions, with Arctic countries taking the lead in supporting and enforcing these initiatives (High North News, 2022; ICCT, 2019b).

3.4 Formal ban on Arctic heavy oil

The combustion of heavy fuel oil (HFO) contributes significantly to black carbon, carbon dioxide, and sulfur dioxide emissions, all of which accelerate Arctic and global warming. Additionally, the risk of HFO spills during transport poses a severe threat to the Arctic environment (PAME, 2009). At MEPC72, a proposal to ban the use and transport of HFO in Arctic waters gained widespread support, and after years of consultation, the ban was formalized.

In June 2021, MEPC76 adopted an amendment to MARPOL Annex I, introducing the Arctic HFO ban. The ban will be implemented in three phases: an initial period, a transition period, and full implementation. Starting July 1, 2024, the ban will prohibit the use and carriage of HFO in Arctic waters, with exceptions for ships involved in safety, search and rescue, or maritime oil spill response. Some vessels can continue using and carrying HFO until July 1, 2029, after which the ban will be fully enforced.

The phased implementation has sparked controversy, particularly over exemptions for certain ships during the transition period. The Clean Arctic Alliance (CAA) has called for a more stringent ban, arguing that the gradual phase-out allows ships to continue burning significant quantities of HFO, prolonging black carbon emissions and spill risks (CAA, 2021). In 2022, the CAA proposed that Nordic countries enforce a 12-nautical-mile HFO ban within their territorial waters to strengthen Arctic protection and ensure equal enforcement of the ban.

Given that HFO accounted for 60% of fuel consumption in Arctic shipping (High North News, 2019), the IMO's HFO ban represents a significant shift. The phased implementation, tailored to specific countries and timelines, makes compliance and enforcement more feasible (Chen and Wang, 2019). Many shipping operators are already moving away from HFO, with companies like Maersk pledging carbon-neutral shipping by 2050 and Ponant discontinuing HFO use in its cruise fleet (High North News, 2019).

At MEPC81, the IMO approved a proposal by Norway and Canada to establish Emission Control Areas (ECAs) in the Arctic, further accelerating HFO controls. ECAs aim to reduce pollutants like sulfur oxides (SOx), particulate matter, and nitrogen oxides (NOx), with new rules reducing fuel sulfur content from 0.5% to 0.1%. Environmental groups welcomed this move, as the Norwegian Sea ECA is expected to cut particulate matter, including black carbon, by 58% by 2030 compared to 2020 levels (High North News, 2024).

The combination of the Polar Code, sulfur restrictions, and the HFO ban signals a transformative shift toward cleaner Arctic shipping. These measures, alongside industry-led initiatives, align with the broader goal of achieving net-zero GHG emissions by 2050, marking a new era in Arctic green shipping.

4 Governance pathways for decarbonization of Arctic shipping and China's contribution

Given the growing complexity of the Arctic environment and the increasing volume of shipping, it is critical to implement effective strategies to address the emerging risks and challenges. First, the Polar Code should be revised and strengthened to serve as the central framework for Arctic shipping governance. Second, greater collaboration between the IMO and the Arctic Council is needed to create a synergistic governance structure that facilitates the green transformation of Arctic shipping. This collaboration should also highlight the strategic role of the Arctic Council's task forces. Finally, China, as a major shipping nation with a dual role in both Arctic and global shipping, is pivotal in shaping policies for the decarbonization of Arctic shipping.

4.1 Revise and strengthen the Polar Code as a unified core guideline for Arctic shipping governance

The fragmented governance of Arctic shipping reflects broader global governance challenges, such as the competing priorities of developed and developing countries and the differing approaches to ocean governance (Chen and Liu, 2023). Given the Arctic's fragile ecosystem and the urgent climate crisis, it is critical to overcome diverse political divides and reach a consensus on a unified and more stricter international agreement.

The Polar Code, as the first international legal framework governing Arctic shipping, offers a foundation for such an agreement. With broad participation from member states and the authority of the IMO as the global regulator of maritime affairs, the Polar Code can expedite the process of decarbonizing Arctic shipping. By refining and strengthening the existing framework, the Code can facilitate quicker and more cost-effective implementation.

To address critical regulatory gaps, particularly concerning black carbon emissions, it is essential to incorporate insights from the Arctic Council, and other relevant bodies into the Polar Code. Establishing stringent emission standards, alongside appropriate incentives, will be essential for progress. Black carbon, like other air pollutants and greenhouse gases (GHGs), should be regulated in tandem with GHGs and other emissions from ships. Given the unique sensitivity of the Arctic environment, a new section on "Prevention of Air Pollution" could be added to the Polar Code, addressing pollutants such as carbon dioxide, sulfur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), and black carbon.

The revision process should involve not only Arctic states but also non-Arctic countries, non-governmental organizations, and Indigenous peoples, ensuring that the updated Polar Code is comprehensive, inclusive, and relevant for all stakeholders. The ultimate goal should be to establish the Polar Code as the central, binding framework for Arctic shipping governance.

4.2 Enhance collaboration between the Arctic Council and IMO, emphasizing the role of Arctic Council task forces

Global issues such as climate governance, marine environment protection, and biodiversity often involve diverse national interests, making coordination challenging and leading to fragmented legal frameworks. This complex landscape of overlapping and non-hierarchical regimes is referred to as a "regime complex" (Raustiala and Victor, 2004). Oran Young further refines this concept, defining regime interaction as the dynamic relationships within a regime complex, where rules, institutions, and operations from different legal regimes influence one another (Orsini et al., 2013; Trevisanut et al., 2020). These interactions can result in either conflict and regulatory chaos or synergies with neutral outcomes (Young, 1996).

In the case of Arctic shipping decarbonization, the interaction between the IMO and the Arctic Council closely mirrors a "nested regime" interaction, where specific arrangements are embedded within a broader institutional framework. This dynamic is particularly marked by the coexistence of hard law (IMO regulations) and soft law (Arctic Council initiatives). The IMO, as the global regulator of international shipping, has led the charge in shipping decarbonization, including initiatives specific to Arctic shipping. However, the Polar Code, while an important step, has yet to fully address the urgent and comprehensive decarbonization needs of Arctic shipping.

The Arctic Council, while a high-level intergovernmental forum rather than a formal treaty-based organization, offers considerable flexibility in governance. It plays a critical role in Arctic shipping decarbonization by producing knowledge, fostering consensus among Arctic States, promoting political will, and engaging with other relevant international bodies (Chen and Gao, 2020). The IMO's observer status in the Arctic Council, granted in 2019, further strengthens the collaboration between these two bodies, facilitating more integrated and effective governance efforts (Bai, 2021).

As shown in Figure 2, the synergistic interaction between hard and soft law within the regime complex governing Arctic shipping

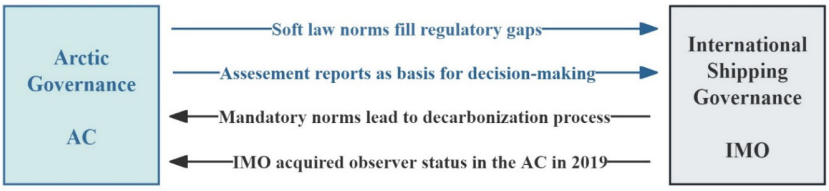

FIGURE 2
Regime interaction between IMO and the Arctic Council.

decarbonization can yield positive outcomes by mitigating regulatory conflicts. Specifically, the Arctic Council's soft law norms help address gaps in the IMO's polar shipping standards, contributing to a more comprehensive approach to low-carbon development in Arctic shipping. For example, the Arctic Shipping Assessment Report by PAME in 2009 provided crucial data and practical solutions that informed the development of the IMO's Polar Code. These interactions also foster enhanced collaboration among states, facilitating the sharing of resources such as funds, technology, and expertise, thereby supporting sustainable Arctic shipping governance (Huntington et al., 2023).

Effective decarbonization management requires strengthened cooperation between the IMO and Arctic Council to enhance these synergies. Both organizations should share knowledge, information, and development plans at each other's meetings, reducing research costs, resolving conflicts, and filling regulatory gaps. Additionally, aligning principles such as the precautionary principle and harmonizing the scope of agreements can further streamline efforts. Simplifying monitoring and reporting obligations to avoid duplication would ease the burden on countries and improve the efficiency of data collection and reporting. Further, linking measures like capacity-building, scientific cooperation, and technology transfer across mechanisms will increase effectiveness and transparency (Van Asselt, 2014). Establishing a common green shipping fund and facilitating the sharing of best practices through the Arctic Shipping Best Practices Forum will also promote collective learning and progress.

As Arctic governance evolves, the increasing complexity of institutional arrangements will necessitate careful management of these interactions to ensure the regime complex remains effective. Interplay management refers to coordinated efforts to improve institutional interactions, whether through legal frameworks, institutional coordination, or autonomous management (Oberthür, 2009; Van Asselt, 2014). Proper management of these interactions will help prevent fragmentation and conflict, enhance synergies, and address existing gaps within the governance network.

Oran Young argues that it is unrealistic to expect a comprehensive Arctic Ocean Convention to address the coordination needs of the Arctic Ocean regime complex. Even if the SMM (SAO-based marine mechanism) under the Arctic Council's framework evolves into a permanent body, it will still fall short of addressing the broad challenges posed by the increasingly dense and complex governance structures in the Arctic Ocean (Young and Kim, 2021). To address these challenges, it is essential to engage in joint discussions on coordinating regime interactions for Arctic shipping decarbonization, involving Arctic and non-Arctic states as well as non-state actors.

Although the Arctic Council lacks the legal capacity to act as the primary coordinator, it can leverage its convening power and meeting venues to organize informal international workshops. These workshops could bring together key stakeholders, including representatives from the IMO, the Arctic Council, and other relevant bodies, to exchange information on recent developments, resolve conflicts, enhance synergies, and fill regulatory gaps. Such a collaborative approach would foster a unified, comprehensive regulatory framework for Arctic shipping decarbonization, integrating efforts across global, regional, and national levels.

While task forces under the Arctic Council have been pivotal in Arctic shipping governance, their current work plans often underutilize their potential contributions. Although all 11 task forces have completed their mandates and ceased operations, the urgency of the Arctic climate crisis calls for renewed focus. The Arctic Council should consider reactivating the Task Force on Black Carbon and Methane (TFBCM) or establishing a new task force dedicated to Arctic decarbonization. This task force could serve as a platform for convening meetings, sharing information, technology, and capacity, and providing scientific evaluations on key pollutants such as black carbon, methane, carbon dioxide, and other greenhouse gases.

Furthermore, this task force could play a pivotal role in aligning national efforts and supporting the negotiation of a new Arctic decarbonization agreement. It is crucial for all countries to continue supporting and actively participating in the Arctic Council's work, revitalizing its task forces. This involvement would not only enhance their influence within the Arctic Council but also inject new momentum into the green transformation of Arctic shipping, contributing to innovative solutions for climate governance in the region.

4.3 Pathways for China's contribution to decarbonization of Arctic shipping

China plays a pivotal role in the decarbonization of Arctic shipping, holding dual positions as a Category A member of the IMO and an official observer state of the Arctic Council. As a global leader in both shipping and shipbuilding, China significantly influences Arctic shipping routes. Maritime transport accounts for approximately 95% of China's international trade, and in 2023, China's shipping import and export trade represented over 30% of global shipping volumes. Furthermore, China surpassed Greece in August 2023 to become the world's largest ship-owning nation by gross tonnage (Clarkson Research, 2023).

While pursuing the Maritime Silk Road, China is also concerned with carbon emissions from international shipping, including Arctic shipping. China has actively supported the IMO's strategy to reduce greenhouse gas emissions from ships. In 2020, China set dual carbon goals: carbon peaking by 2030 and carbon neutrality by 2060. "Carbon peaking" refers to the point at which CO2 emissions stop growing and begin to decline, while "carbon neutrality" aims to offset emissions through measures such as afforestation, energy conservation, and emission reduction (People's Daily, 2021). Under these dual-carbon goals, China can make significant strides in reducing emissions in the shipping industry through policies, legislation, technological innovation, and international cooperation, contributing to global efforts, including in the Arctic shipping sector. China's actions could thus positively impact Arctic shipping governance and the development of international law in this area. Furthermore, in November 2024, China and Russia convened the first meeting of the Sub-Committee on Arctic Shipping Route Cooperation to discuss the development

of Arctic shipping routes. This new mechanism aims to advance polar ship construction, ensure the safety of Arctic navigation, and protect the Arctic ecosystem, demonstrating China's commitment to Arctic shipping governance (Ministry of Transport of the People's Republic of China, 2024).

China has made significant strides in applying green technologies within the shipping industry. Notably, the "Three Gorges 1," a new-energy electric cruise ship powered by clean hydropower, is the world's largest and most advanced electric cruise ship in terms of capacity and intelligence. It can replace 530 tons of fuel oil annually and reduce harmful gas emissions by over 1,600 tons (People's Daily Online, 2022). Additionally, China Yangtze River Shipping Group (CSCG) is constructing river-sea vessels with LNG-for-tanks technology, and the "Chuanjiang 130-meter standard ship" under development will feature methanol dual-fuel power. CSCG plans to launch these vessels soon, with a target of building 80 new energy ships over the next three years to create a clean energy fleet and support large-scale green operations (Chongqing Municipal People's Government, 2024).

China is committed to responsible maritime practices and has set ambitious "carbon peak" and "carbon neutrality" targets, supported by a range of policy measures to achieve these goals. China's involvement in the green development of Arctic shipping is expected to positively influence the IMO, Arctic shipping governance, and the evolution of international law in this domain (Bai and Li, 2021; Bai and Zhu, 2023). China's contributions to this process can unfold in several key ways.

4.3.1 Enhance compliance through domestic legislation and policy updates

The Arctic shipping route offers significant economic and environmental advantages by shortening the distance between Europe and Asia, reducing both transport costs and carbon emissions. As a key user of these routes and an active participant in relevant governance mechanisms, China must closely monitor and adapt to evolving Arctic shipping policies, strengthening domestic compliance through legislation and policy updates. As climate change accelerates, Arctic shipping policies will likely tighten, and China should prepare for the impact of the IMO's evolving regulations on Arctic operations.

In the short term, China's Green Ship Rules, developed by the China Classification Society (CCS), already integrate the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP). As the IMO tightens energy efficiency standards and promotes the adoption of green technologies and alternative fuels, China should continue to invest in research and development in these areas. This includes innovations in green ship technologies, promoting nuclear-powered icebreakers, and introducing financial policies such as subsidies, tax incentives, and low-interest loans to facilitate their practical application.

In the medium to long term, China has begun establishing a shipping carbon emissions trading market (China Financial News, 2024). This initiative requires the timely implementation of supporting policies and regulations to ensure its effectiveness and sustainability. To align with international efforts, China should also regularly update its Arctic policy. Since the release of its 2018 Arctic Policy white paper, the region's climate, environment, and geopolitical landscape have evolved significantly. In comparison, countries like the UK, a "near-Arctic" nation, have been more agile in adapting their policies to these changes. By regularly revising its Arctic policy, China can ensure its approach remains relevant, strategic, and responsive to shifting dynamics in the region. Moreover, continuous review and follow-up on policy implementation will help China navigate and influence Arctic governance more effectively.

4.3.2 Promote port state control inspection network for Arctic shipping

To strengthen governance in Arctic shipping, it is essential to expedite domestic policy updates and leverage the critical role of port state control. Port state control extends beyond territorial sovereignty, incorporating rights and obligations under international conventions and national regulations. Through vessel inspections and detentions, port states uphold maritime safety and support flag states in their jurisdictional responsibilities.

As both a destination port for Arctic shipping and a key port state at the Asian end of the Arctic route, China plays a pivotal role in port state control inspection. As one of the world's leading port nations, China has actively participated in international efforts to oversee port state inspection and eliminate substandard ships, contributing to global maritime safety.

Given the absence of a unified port state control organization, regional cooperation through memorandums of understanding (MoUs) is crucial. China can continue its participation in regional port state control agreements across the Asia-Pacific, Indian Ocean, and South Pacific. By collaborating with Arctic coastal states and other port nations, China can exchange policies, share information, promote technological cooperation, and jointly enforce regulations. These actions would explore a port state control inspection network specifically for Arctic shipping. Establishing unified inspection standards with other nations would enhance safety and environmental protection in Arctic waters, compensating for the limitations of flag state oversight.

4.3.3 Proactive engagement in improving Arctic shipping governance and IMO energy efficiency standards

As the Arctic shipping governance system, centered around the Polar Code, undergoes revision, China has an opportunity to play a constructive role. As an Arctic stakeholder, China should leverage its observer status to actively engage with task forces, working groups, and expert groups. By doing so, China can ensure that the perspectives of developing countries are represented, seek opportunities for international cooperation, and propose initiatives that align with its national interests while reflecting the broader goals of countries using Arctic shipping routes.

In recent years, the IMO has placed increasing emphasis on higher energy efficiency standards for ships. A significant milestone in this effort was the release of the ISO 23453:2022 standard in December 2022, which provides "Guidelines on the Design and Manufacture of Vortex Reducing Fins for Fixed-Pitch Propellers for

Ships and Marine Technology Vessels" (ISO, 2022). Led by China's No. 702 Institute of the China Shipbuilding Group Corporation (CSSC) and supported by other domestic institutions, this standard exemplifies China's contribution to meeting IMO's stringent energy efficiency requirements.

China has previously made significant contributions to the IMO, including proposals to improve the Energy Efficiency Design Index (EEDI) formula, the establishment of an International Maritime Sustainable Fund, and the development of incentive mechanisms (IMO, 2016, IMO, 2022). Moving forward, China should deepen its engagement with multilateral mechanisms such as the IMO and the Arctic Council, continue submitting proposals on shipping emission reductions, and contribute to global public goods. Additionally, China should strengthen bilateral and multilateral cooperation to reduce misunderstandings, bridge differences, and achieve mutual benefits (Pan and Huntington, 2024). This proactive involvement will not only safeguard China's shipping interests but also contribute positively to Arctic and global maritime governance (Chen, 2017).

5 Conclusions and prospects

Global warming and the accelerated melting of Arctic sea ice are intensifying climate risks, with greenhouse gases like carbon dioxide and particulate matter such as black carbon posing severe threats. The IMO and the Arctic Council, as central bodies in maritime and Arctic governance, have taken effective actions through coordinated regime interactions. The integration of both soft and hard law is essential for establishing robust governance. In this framework, the Arctic Council's task forces play a critical but often underappreciated role. These task forces conduct scientific assessments, provide feasibility recommendations, draft framework documents, and facilitate agreements, enhancing the scientific rigor and influence of the Council's decisions. Given their vital role in Arctic governance and sustainable development, there is a compelling case for reactivating or establishing new task forces to address the climate risks posed by Arctic shipping more effectively.

Since the Ukraine crisis, the Arctic Council has effectively suspended its operations, halting official meetings and multilateral cooperation on Arctic governance (Chen and Wang, 2022). Russia, as the largest Arctic nation and a key player in the Northern Sea Route, has long been central to global shipping activities in the region. Arctic shipping, which significantly impacts the environment through emissions such as black carbon, exhaust gases, and waste, has been further complicated by Russia's absence from the Council. This highlights the geopolitical tensions that have spilled over into Arctic governance, impeding progress on crucial environmental issues. Meanwhile, the impacts of global warming on Arctic ecosystems and biodiversity are accelerating at an alarming rate (Kim et al., 2023). This underscores the urgent need to restore and strengthen Arctic governance, particularly through the resumption of the Arctic Council's activities and enhanced international cooperation.

On May 11, 2023, Norway assumed the rotating chairmanship of the Arctic Council from Russia, a role it will hold until 2025. Norway's chairmanship prioritizes Arctic stability and constructive cooperation, focusing on four key areas: oceans, climate and environment, sustainable economic development, and the well-being of Arctic peoples. In the climate and environment domain, Norway will highlight the impacts of climate change on the Arctic, advocate for adapting management systems, and address environmental challenges arising from increased human activity. Special attention will be given to short-term climate factors such as methane and black carbon, with the aim of reducing their emissions by 2030 to slow Arctic warming. Norway also plans to support efforts to mitigate the environmental impact of Arctic shipping, including the exploration of green shipping corridors as pilot projects.

Since taking on the chairmanship, Norway has adopted an active governance approach, focusing on the gradual resumption of the Council's operations, particularly its working groups (AC, 2023b). A key priority has been placing the issue of worsening Arctic wildfires on the Arctic Council's agenda, reflecting a commitment to addressing climate change and enhancing governance. Norway's leadership in shaping Arctic shipping policies aligns with its broader climate goals.

Given the severity of the Arctic climate crisis, it is essential for Arctic nations, international organizations, non-governmental organizations, and other stakeholders to collaborate effectively to push for a revised Polar Code for decarbonization of Arctic shipping. This revised code should aim to become the most authoritative, comprehensive, and mandatory legal framework for polar waters. As a major Arctic stakeholder, China has a responsibility to take proactive measures, including strengthening its domestic compliance through legislative updates and enhancing its role in port state control. China should actively work with other nations, Arctic Council, and the IMO, to build a robust regulatory network for decarbonizing Arctic shipping and sustainable future.

Author contributions

YC: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. KC: Data curation, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing.

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