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Evaluating carbon emissions in Arctic search and rescue operations

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ABSTRACT

In the Davis Strait and Baffin Bay, in the Canadian eastern Arctic Ocean, fishing vessels are required to conduct search and rescue (SAR) operations in the event of a nearby emergency (Government of Canada, 2023). In this remote region, there are limited SAR capabilities. In performing these Vessel of Opportunity (VOO) operations, fishing vessels have increased fuel consumption and a loss of productivity, leading to added cost and carbon emissions. This is significant to fishery operators in the eastern Arctic Ocean. The goal of this research is to evaluate the dimension of carbon emissions relating to fishing vessels acting as VOOs in an emergency situation. This analysis is performed by use of a case study, focusing on the Canadian Arctic community of Qikiqtarjuaq. The consequences of a dedicated SAR base located within the community are analyzed, focusing on the impact it would have on carbon emissions during emergency situations.

KEY WORDS: Decarbonization; Emission model; Sea ice.

NOMENCLATURE

CCG:	Canadian Coast Guard
CCGS:	Canadian Coast Guard Ship
nm:	Nautical miles
SAR:	Search and Rescue
SFC:	Specific fuel consumption
VOO:	Vessel of Opportunity

INTRODUCTION

A new deep-sea port has been approved in Qikiqtarjuaq, and its construction is expected to start in 2025 (Government of Nunavut, 2023). This new port in Qikiqtarjuaq aims to provide services including refueling stations, resupply stores, and general maintenance support (Government of Nunavut, 2023). Future development of this area could include marine safety infrastructure, such as a SAR station.

Qikiqtarjuaq is located in a sparsely populated region on the eastern shore of Baffin Island. The community sits on the coast of the Davis Strait in Baffin Bay, and is home to almost 600 residents (Statistics Canada, 2021). In the Davis Strait there is marine traffic primarily from fishing vessels, as well as bulk carriers servicing the Mary River Mine in northern Baffin Island (Baffinland, 2025). From approximately November to June, the Davis Strait is covered with sea ice, ending marine operations for the season (DFO, 2019).

Currently in the Canadian Arctic, SAR is fulfilled by the Canadian Coast Guard (CCG) and VOOs (Government of Canada, 2023). A VOO is defined as a vessel that is not a dedicated CCG SAR vessel, and is close enough to provide assistance to a vessel in distress. Under the Canadian Shipping Act, every vessel at sea is required to assist in an emergency situation when possible (Minister of Justice, 2001). Due to the remoteness of the area, and the limited number of dedicated SAR vessels, there are potentially long wait times for distressed vessels to receive help in the Davis Strait and Baffin Bay (NRC, 2019). This is a safety concern for fishery operators. Further, acting as a VOO during an emergency situation can be costly for the responding vessel due to the increased fuel consumption and lost fishing time.

This study investigates the impacts of developing a SAR station in Qikiqtarjuaq and evaluates the decision in terms of fuel consumption and the corresponding carbon emissions. These evaluations are completed using a case study approach, considering three scenarios.

METHODS

To evaluate the carbon emissions from Arctic SAR operations, three scenarios are studied. The vessels and calculation methods used in these scenarios are described in the following subsections, and the scenarios are outlined in the following section.

Vessels

Five vessels are considered: three fishing vessels, the Canadian Coast Guard Ship (CCGS) Henry Larsen, and the CCGS Bay Class Lifeboat. The particulars of each of these vessels are outlined in Table 1 below. For confidentiality, the fishing vessels are listed as Vessels 1, 2, and 3.

The CCGS Henry Larsen is a medium icebreaker, and often operates in the Canadian northeastern Arctic during the summer season (NOAA, 2023).

The Bay Class lifeboats are the new class of lifeboats being built by the CCG (Government of Canada, 2024). They are high-speed self-righting semi-displacement vessels, and have a maximum range of 250 nautical miles (nm). They have a fuel capacity of 7 m^3 and an operational limit restricting them from travelling more than 100 nm from base (Government of Canada, 2024). This 100 nm operational limit is displayed using the black circle in Figure 1. The heat map data points represent the location and intensity of the fishing effort in the area (Canadian Geospatial Platform Services, 2019). The vertical line to the right of the fishing effort displays the international border between Canada and Greenland, and the horizontal lines indicate the location of different fishing zones (Government of Canada, 2021).

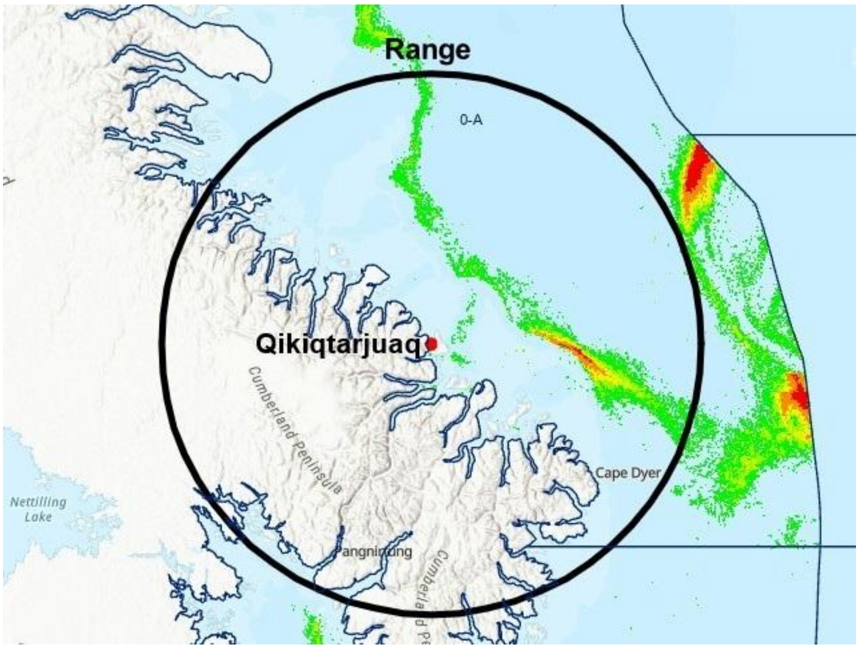

Figure 1. CCGS Bay Class Lifeboat 100 nm operational limit and heatmap of fishing effort

The three fishing vessels are all factory freezer trawler fishing vessels, representative of those that operate in the Davis Strait and Baffin Bay. Their cruising speeds are used in the scenarios.

Table 1. Vessel particulars

Particular	CCGS Henry Larsen	CCGS Bay Class Lifeboat	Vessel 1	Vessel 2	Vessel 3
Length waterline	93.8 m	17.63 m	59.92 m	29.53 m	72.43 m
Beam	19.46 m	5.76 m	14.6 m	7.52 m	13.00 m
Draft	7.24 m	1.61 m	6.10 m	4.65 m	5.62 m
Displacement	8224.4 t	64.85 t	2710 t	544 t	2779 t
Specific fuel consumption	178.8 g/kWh	218.0 g/kwh	178.8 g/kWh	217.4 g/kWh	178.8 g/kWh
Cruising speed (CS)	13.5 knots	15 knots	14 knots	8 knots	11.5 knots
Cruising speed (CS) Froude number	0.229	0.587	0.297	0.242	0.222
Maximum speed (MS)	16 knots	25 knots	-	-	-
Maximum speed (MS) Froude number	0.271	0.782	-	-	-

Kinematics

To calculate the fuel consumption and emissions for each vessel in the scenarios, a series of calculations is followed. Firstly, basic kinematics are used to calculate the vessel's time (t) to reach its intended destination, as shown in Equation (1). This equation relies on the vessel's speed (v) and the distance it travels (x).

$$t = \frac{x}{v} \quad (1)$$

Holtrop and Mennen

The Holtrop and Mennen (1982) method is used to estimate the open water resistance for the CCGS Henry Larsen and for the fishing vessels.

Mercier

To estimate the resistance of the CCGS Bay Class Lifeboat, the Mercier (1973) method is used. This method was selected due to the semi-displacement hull form of the Bay Class lifeboats. The Mercier (1973) method is based on a regression analysis of the smooth-water resistance data from seven transom stern hull series vessels.

To use the Mercier (1973) method, several requirements should be met. First, the volume Froude number (F_{nv}) must be between 1.0 and 2.0. Equation (2) below is used to calculate the F_{nv}, relying on the speed of the vessel (v), the acceleration due to gravity (g), and the vessel's volumetric displacement (∇). This calculation yields that a F_{nv} of 1.0 corresponds to a speed of 12 knots, and a F_{nv} of 2.0 corresponds to a speed of 24 knots. The Bay Class lifeboat operates within this range.

$$F_{nv} = \frac{v}{\sqrt{g\nabla^{\frac{1}{3}}}} \tag{2}$$

The transom area to maximum section area ratio is also checked against the slenderness ratio to ensure it falls within the range of appropriate vessels used in the Mercier (1973) method. The slenderness ratio for the Bay Class lifeboat is calculated using Equation (3), and it is equal to 4.42. This equation depends solely on the length (L) and volumetric displacement (∇) of the vessel. The ratio of transom area to maximum section area is equal to 0.66. From comparison with figures in Mercier's (1973) paper, these values show that the Bay Class lifeboat is within the bounds of applicability for the Mercier method.

$$Slenderness\ Ratio = \frac{L}{\nabla^{\frac{1}{3}}} \tag{3}$$

A final check can be performed to evaluate the suitability of the Mercier (1973) method. This check compares the half entrance angle of the vessel to the transom area to maximum section area ratio. The half entrance angle of the Bay Class lifeboat is 31°, which puts it slightly outside the bounds of applicability for this method.

Modified Keinonen

Keinonen's method is used to estimate the resistance due to sailing ice (Keinonen et al., 1996). A modified version of this estimation method, proposed by Veber (2023), is used in the third scenario of this paper to estimate the ice resistance encountered by the CCGS Henry Larsen. The foundation for the modified method is outlined in Equation (4), and requires the speed (v), length (L), and draft (T) of the vessel, as well as the resistance calculated from the Keinonen (1996) method ($R_{i(Keinonen)}$). The modified Keinonen method has been validated by full scale trials on the CCSG Henry Larsen (Veber et al., 2024).

$$R_i = R_{i(Keinonen)}(1.199 - 0.0273v - 0.0017L + 0.0246T)^2 \tag{4}$$

Powering

The brake power (P_B) requirements for the three fishing vessels and the CCGS Bay Class Lifeboat are estimated by first considering the total resistance (R_T) estimated by the Holtrop and Mennen (1982) method. The effective power requirements (P_E) for these four vessels are calculated using Equation (5). An assumed total efficiency (η), considering hull efficiency ($\eta_H = 1.04$), behind ship propeller efficiency ($\eta_B = 0.65$), shaft efficiency ($\eta_S = 0.99$), and gearbox efficiency ($\eta_M = 0.96$), of 0.64 is used to calculate the brake power from the effective power for the fishing vessels and lifeboat using Equation (6).

$$P_E = R_T \times v \quad (5)$$

$$P_B = \frac{P_E}{\eta} \quad (6)$$

The brake power (P_B) requirement for the CCGS Henry Larsen is estimated by first determining the thrust requirements based on the total resistance. The thrust power is calculated using a thrust deduction formula based on a regression analysis of full-scale data from the CCGS Henry Larsen (Veber, 2023). From the thrust power, the delivered power is calculated using a behind ship propeller efficiency of 0.69. The brake power is calculated from the delivered power based on estimated shaft and transmission efficiencies of 0.99 and 0.84, respectively.

Emissions

The carbon dioxide emissions (CO_2) from the vessels are estimated using Equation (7). This equation uses engine SFC, brake power (P_B), and a conversion factor (C_F) based on fuel type for carbon dioxide emissions, as outlined in MARPOL Annex 5 (IMO, 2018). Equation (7) also considers the emissions due to hotel load. The fuel consumption due to hotel load (FC_H) for the CCGS Henry Larsen is known based on full scale trials and fuel consumption monitoring. The fuel consumption due to hotel load of the other four vessels is estimated.

$$CO_2 = [(P_B \times t \times SFC) + (FC_H \times t)] \times C_F \quad (7)$$

SCENARIOS

In the three scenarios, the fishing vessels act as VOOs or vessels in distress, and the CCG vessels respond to incidents. Each scenario is developed to represent a plausible event, based on an understanding of fishing hotspots in the region (Canadian Geospatial Platform Services, 2019) and marine incident occurrence data, showing where accidents have occurred in the past (Frampton, 2023). The incidents responded to in these scenarios can be used to represent any emergency that could plausibly happen at sea. These emergencies include engine failure, medical emergency, and loss of vessel.

One limitation of these scenarios is the assumption of calm seas. In the event of rough sea conditions, it is unlikely that the SAR lifeboat is capable of sailing at maximum speed. To account for this, the maximum speed used for the lifeboat in these scenarios is 20 knots, instead of 25 knots as listed in Table 1. This limitation is further considered in the discussion section.

Scenario 1

A fishing vessel is in distress 62 nm from Qikiqtarjuaq. There is a fishing vessel operating in the region that could respond as a VOO, the CCGS Henry Larsen is available, and the SAR station in Qikiqtarjuaq can also respond using the SAR lifeboat. All responding vessels are equidistant from the vessel in distress, 62 nm away, making this scenario a baseline. This scenario also accounts for a 62 nm return, for a total of 124 nm travelled by each vessel.

Scenario 2

A fishing vessel is in distress 100 nm from Qikiqtarjuaq, the operational limit for the CCGS Bay Class Lifeboats. The lifeboat will return to the SAR station after it responds to the incident. The CCGS Henry Larsen is located 200 nm southwest of the vessel in distress, and will not return to its original position after responding. All other fishing vessels are too far away to assist. Both the lifeboat and icebreaker will travel 200 nm in this scenario. This scenario is designed to compare CCGS response options.

Scenario 3

The CCGS Henry Larsen is in 0.10 m thick ice at the north of Baffin Island. The ice coverage extends for 215 nm, after which it will have to sail 65 nm in open water to reach the vessel in distress. While in ice, the icebreaker will sail at 12 knots. When sailing in open water, the icebreaker will sail at its maximum speed of 16 knots. There is a fishing vessel that can act as a VOO located 130 nm away from the vessel in distress, sailing in open water. In this scenario, the lifeboat is too far away from the incident to respond, due to its 100 nm range limit. This scenario highlights a limitation of the lifeboat, showing that it cannot respond in all incidents.

RESULTS AND ANALYSIS

Scenario 1

The results from the first scenario, the baseline study, are shown in Table 2. In this scenario, each of the fishing vessels is considered as a VOO in turn, and the lifeboat and icebreaker are also considered.

Fishing Vessel 2 emits the smallest quantity of carbon in this scenario, of 2.6 t. The SAR lifeboat has the next lowest carbon emissions, of 5.4 t at cruising speed, and 5.9 t at a maximum speed of 20 knots. The CCGS Henry Larsen emits the most carbon in this scenario, 25.0 t at cruising speed and 41.4 t at maximum speed.

The fuel burnt in this scenario can also be quantified in terms of cost, by assuming an approximate fuel cost of $600 USD per ton (Ship & Bunker, 2025). The resultant fuel expenditure for each vessel, listed in USD, is included in Table 2.

Table 2. Scenario 1 results

	Total Time		Fuel Consumption		Emissions	
CCG Vessel	CS	MS	CS	MS	CS	MS
CCGS Bay Class Lifeboat	8.3 h	6.2 h	1.7 t [$1,020]	1.9 t [$1,110]	5.4 t	5.9 t
CCGS Henry Larsen	9.2 h	7.8 h	7.8 t [$4,690]	12.9 t [$7,750]	25.0 t	41.4 t
Fishing Vessel	CS		CS		CS	
Vessel 1	8.9 h		4.4 t [$2,610]		14.0 t	
Vessel 2	15.5 h		0.8 t [$490]		2.6 t	
Vessel 3	10.8 h		2.8 t [$1,700]		9.1 t	

Scenario 2

The results of the second scenario are shown in Table 3. This scenario compares the emergency response of the CCGS Bay Class Lifeboat to that of the CCGS Henry Larsen over a 200 nm trip. In this scenario, the lifeboat responds quicker, burns less fuel, and emits less carbon than the icebreaker at both cruising speed and a maximum speed of 20 knots. The fuel cost associated with this response is also included in Table 3. The cost of the fuel burnt by the lifeboat is approximately five times less than that of the icebreaker at cruising speed, and seven times less at maximum speed.

Table 3. Scenario 2 results

	Total Time		Fuel Consumption		Emissions	
CCG Vessel	CS	MS	CS	MS	CS	MS
CCGS Bay Class Lifeboat	13.3 h	10.0 h	2.7 t [$1,630]	3.0 t [$1,790]	8.7 t	9.6 t
CCGS Henry Larsen	14.8 h	12.5 h	12.6 t [$7,550]	20.8 t [$12,500]	40.4 t	66.8 t

Scenario 3

In the third scenario, the response of the icebreaker is compared to that of the three fishing vessels. Similar to Scenario 1, each of the three fishing vessels is considered as a VOO in turn. The results in Table 4 show that the emissions from the fishing vessels responding as VOOs are lower than that of the CCGS Henry Larsen. The fishing vessels emit between 2.7 and 14.6 t of carbon, whereas the icebreaker emits 65.7 t. The results also show that each of the fishing vessels can respond faster than the icebreaker.

The fuel cost associated with this emergency response shows that it is also cheaper for the fishing vessels to respond to the emergency than the icebreaker.

Table 4. Scenario 3 results

Vessel	Total Time	Fuel Consumption	Emissions
CCGS Henry Larsen	22.0 h (17.9 h in ice, 4.1 h in open water)	20.5 t (13.7 t in ice, 6.8 t in open water) [$12,300]	65.7 t (44.0 t in ice, 21.7 t in open water)
Vessel 1	9.3 h	4.5 t [$2,730]	14.6 t
Vessel 2	16.3 h	0.9 t [$510]	2.7 t
Vessel 3	11.3 h	3.0 t [$1,780]	9.5 t

DISCUSSION

As shown in the three scenarios, the development of a SAR base in Qikiqtarjuaq has the potential to reduce carbon emissions in certain cases. In Scenario 1, the benefits of using a SAR lifeboat compared to an icebreaker are demonstrated by a reduction in carbon emissions. However, the SAR lifeboat was not better than all of the fishing vessels, as shown by a comparison of fuel consumption and carbon emissions in Table 2. Ultimately, the best possible response option for this scenario, based on carbon emissions, is Vessel 2 or the SAR Lifeboat. This response option is also supported by the fuel cost associated with the response of these two vessels. It should be noted that in this scenario, the lifeboat is a better option than the majority of the fishing vessels at both cruising speed and a maximum speed of 20 knots.

The second scenario also demonstrates the benefits of using a CCGS Bay Class Lifeboat instead of the CCGS Henry Larsen for emergency response when possible. This is shown by the lifeboat outperforming the icebreaker in all metrics: response time, fuel consumption, fuel cost, and carbon emissions. In this scenario, the lifeboat consumes approximately 46% of its fuel capacity at a maximum speed of 20 knots, proving that it has sufficient fuel to complete this response.

The third scenario highlights a situation where the lifeboat cannot respond due to its limited range. In this situation, the three fishing vessels outperform the icebreaker in all metrics. The fishing vessels burn less fuel, emit less carbon, and can execute the response long before the icebreaker can arrive at the vessel in distress. This shows that it makes more sense for the fishing vessels to respond instead of the icebreaker.

The CCGS Bay Class Lifeboat emits less carbon than all but one of the fishing vessels, meaning it is generally a better option than a fishing vessel acting as a VOO. The one caveat of this conclusion is that these lifeboats have a limited range that only allows them to travel 100 nm from their base.

In cases when the accident occurs outside of the 100 nm range of the lifeboat, it is concluded that the fishing vessels should respond to the incident as a VOO if possible. This conclusion is supported by the fishing vessels responding quicker, burning less fuel, and emitting less carbon than the CCG icebreaker.

It should also be noted that this study is only focused on the carbon aspect of the problem, with a brief investigation of fuel cost. The scope of this case study analysis could be expanded in the future to include factors such as cost due to lost fishing time from the fishing vessels acting as VOOs. The scope of this case study could be further expanded to consider the impact of other SAR assets operating out of this SAR base, such as helicopters. Further, a permanent SAR base would also have an associated carbon footprint from its year-round operation, the magnitude of which is outside the scope of this study. All of these factors could be considered when evaluating the development of a SAR base in Qikiqtarjuaq. Ultimately, there is always a cost associated with a SAR response. The development of a SAR base in Qikiqtarjuaq has the potential to alleviate some of that cost from the fishing vessels, transferring it to the CCG.

The severity and specifics of the incident being responded to also impact the response. It is possible that for larger incidents, a larger response vessel, such as an icebreaker, would be required. In other incidents, it is possible that lives may depend on rescue time, in which case the high speed of the CCGS Bay Class Lifeboat would be valuable.

Limitations

There are several limitations of this study. Firstly, the random nature of incidents is impossible to replicate using just three scenarios. To mitigate this limitation, the three scenarios considered were developed based on heat maps showing the location of the fishing effort, published by the Canadian Geospatial Platform Services (2019), as well as marine incident occurrence data published by the Transportation Safety Board of Canada (Frampton, 2023).

A second limitation of this study is associated with the application of the Mercier (1973) method to estimate the resistance of the CCGS Bay Class Lifeboat. As described in the methods section, the Mercier (1973) resistance estimation method should only be applied to vessels which meet three criteria. The CCGS Bay Class Lifeboat meets two of these criteria, but falls just outside of the third.

The scenarios considered in this study assume calm sea conditions. This is a limitation of the study, especially for the scenarios involving the CCGS Bay Class Lifeboat. If the sea conditions were not calm, the lifeboat would have to go much slower than its maximum speed to avoid adverse slamming of the semi-displacement hull. To account for this limitation, a maximum speed of 20 knots was used in the scenarios instead of 25 knots, which is the maximum speed published by the CCG for this vessel (Government of Canada, 2025). The average sea conditions in the Davis Strait and Baffin Bay vary by month throughout the operational window of June to November. During this operational window, the monthly average significant wave height is lowest in June (at 0.3 m) and highest in October (at 1.8 m) (ECCC Data Catalogue, 2018).

The scenarios presented in this case study involving the SAR lifeboat assume that the waters are free of ice. This assumption was made because the CCGS Bay Class Lifeboat has extremely limited capability in ice. This is a limitation because at the beginning and end of the operational window in the Davis Strait and Baffin Bay, it is expected that there will be some quantity of sea ice.

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