Major Research Paper

Black carbon emissions related to transportation in Canada:

Sources, impacts, and recommendations

Master of Environmental Sustainability (MES)
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Abstract

The incomplete combustion of fine particulate matter produces black carbon (BC), an atmospheric pollutant that has a major direct and indirect impact on the climate, environment, and human health. The Arctic region is especially impacted by climate change, in part due to BC emissions. Canada has a major obligation to cut its emissions as a key member of the Arctic Council, with its majority of emissions stemming from transportation. Although Canada has been reporting on BC for a number of years, the corresponding regulations to tackle this problem are lacking or not enforced. This paper, through a systematic literature review of academic and grey literature, provides a snapshot of the sources and impacts of BC emissions as well as the current relevant Canadian regulations. These current regulations were analysed for their successes and their gaps pertaining to regulating BC within the transportation sector. Finally, recommendations are provided based on relevant international regulations and the established gaps. These recommendations include urban planning modifications to reduce the impact of BC emissions, increased collaboration with Canada's partners such as the United States, and opportunities for growth inspired by existing projects.

KEYWORDS: Canada, black carbon, Arctic, environmental regulations, transportation

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Ethics Statement

This MRP did not include any field work or human subjects, or require ethical clearance. Ethics guidelines, as outlined by the University of Ottawa, were followed to conduct this research project properly.

Acronyms and Abbreviations

BC	black carbon
CAAQS	Canadian Ambient Air Quality Standards
CEPA	Canadian Environmental Protection Act
CO_2	carbon dioxide
ECCC	Environment and Climate Change Canada
IPCC	Intergovernmental Panel on Climate Change
LRTAP	Convention on Long-Range Transboundary Air Pollution
$PM_{2.5}$	particulate matter less than or equal to 2.5 microns in diameter
UNECE	United Nations Economic Commission for Europe
U.S. EPA	United States Environmental Protection Agency

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1. Introduction

1.1 Background and Context

Air pollution continues to contribute significantly to mortality and morbidity rates around the world despite stringent laws, regulations, and emission programs that have aimed to improve air quality globally (Feng et al., 2024). According to the World Health Organization, air pollution is the leading environmental risk to human health and the natural world (Feng et al., 2024). One significant air pollutant is fine particulate matter ($PM_{2.5}$) and during its incomplete combustion, one important component that arises is black carbon (BC) (UN Environment Programme, n.d.-a).

When fossil fuels and plants are not completely burned (incomplete combustion), BC is created (Ju et al., 2024). During this process, carbon dioxide (CO_2), carbon monoxide, and volatile organic compounds are also produced (UN Environment Programme, n.d.-a). This air pollutant has the third-largest potential for global warming after CO_2 and methane based on potency, according to the Intergovernmental Panel on Climate Change (IPCC) (Kholod & Evans, 2016). According to a recent study, BC may be the second-most potent climatic agent in the world, after CO_2 (Kholod & Evans, 2016). However, other existing research has shown that large emissions of BC have been linked to a greater warming effect than greenhouse gases like CO_2 (Song et al., 2023).

Unlike CO_2 which can persist in the atmosphere for 300 to 1000 years, BC is only in the atmosphere for a few days or weeks, yet BC has a significant effect on the climate, environment, and human health both directly and indirectly (UN Environment Programme, n.d.-a). BC is highly efficient at absorbing light, and then it is able to heat the atmosphere. In

areas where it is concentrated, it intensifies surface and air warming, affects ecosystems, and can alter weather patterns and systems (UN Environment Programme, n.d.-a).

Canada, a member of the Arctic Council, has been reporting on BC to the United Nations (UN) for several years but may lack the corresponding regulations to tackle this issue (ECCC, 2024b). The Arctic region is particularly affected by climate change and has been experiencing four times more warming than any other place in the world (Reddy Muduchuru et al., 2024; Ren et al., 2020). BC emissions worldwide affect Arctic warming, not just localised emissions; hence, it has been suggested that reducing global emissions will reduce Arctic warming as well (Evangeliou et al., 2016; Quinn et al., 2011). While the focus of most climate change conversations and policy debates has been on CO_2, and for good reasons, BC emissions need to be targeted and reduced as well (Evangeliou et al., 2016; Song et al., 2023).

1.2 Research Aim, Question, and Objectives

This Major Research Project (MRP) aims to target the gaps in research and policy and provide recommendations for Canada to reduce its BC emissions, specifically from the transportation sector. In direct response to this aim and to the context outlined problem outlined above, the specific research question that is addressed in this MRP is:

What is the current state of knowledge on the sources, impacts, and recommendations for controlling or reducing black carbon emissions from transportation in Canada?

In order to answer this question, four main objectives have been established and include to: 1) examine the sources of BC emissions in the transportation sector, 2) outline the impacts of these emissions (health, environmental, etc.), 3) analyse current and relevant

national and international policies targeting transportation emissions, and 4) provide recommendations for black carbon policies related to the transportation sector in Canada.

1.3 Significance of Research

The Clean Air Fund's report from December 1st, 2023, contends that although BC poses serious threats to human health and the environment, attention to this issue has "lagged" (Bindman, 2023). Only a few nations included BC objectives in their nationally determined contributions under the Paris Agreement as of 2023 (Bindman, 2023). The report concludes that there is "a significant gap in climate strategy" since BC is not specifically included in any climate agreement, such as the Paris Agreement (Bindman, 2023).

BC is a harmful pollutant that is not often discussed in political or media circles and is mostly kept within the confines of academic and scientific research. The scientific community considers it should be further examined through various lenses of environmental governance and policy to find ways to reduce emissions and protect the Arctic.

Although the combustion of local diesel sources in the Arctic region create some BC emissions, most emissions in the region are transferred from other regions, including Canada (Kholod & Evans, 2016). Thus, it is important to analyse nationwide policies and mechanisms for BC emission reductions. Not only can these policies help reduce the environmental damage that BC causes, but they would also be protecting the Arctic for those who live there and reduce health risks from air pollution Canada-wide (and globally).

2. Design and methods

2.1 Definition of black carbon and fine particulate matter

For the purpose of this major research project, the terms BC and $PM_{2.5}$ will be used interchangeably since BC is a component of $PM_{2.5}$, which is more commonly used in scientific research and air pollution policy.

2.2 Research project components

The approach taken in this study includes an analysis of both quantitative (emissions) data and qualitative (policy and regulation) data and will be evaluated mainly through literature reviews and analytical evaluation. In an article on “Policy Analysis as a Hermeneutic Activity”, Professor John Dryzek describes how several models can be used to analyse policy (Dryzek, 1982). For this MRP, the most realistic one is Model 1, which lists: 1) to define the standards by which policy's outcomes will be assessed; and 2) to list potential policy alternatives (Dryzek, 1982). To define the standards by which to evaluate a policy, Quebec’s National Collaborating Centre for Healthy Public Policy provides a practical guide to analysing public policy and separates it into two categories: effects and implementation (National Collaborating Centre for Healthy Public Policy, 2012). Within effects, there are three elements: effectiveness, unintended effects, and equity (National Collaborating Centre for Healthy Public Policy, 2012). Within implementation, they describe three more elements: cost, feasibility, and acceptability (National Collaborating Centre for Healthy Public Policy, 2012). For the purposes of this MRP, this approach was simplified and the policies identified were evaluated on metrics of enforcement (or lack thereof) and compared to their counterparts on the international scene. This framework, along with

Dryzek's model, is helpful to analyse the existing policies and evaluate how or if they can be improved.

Table 1 links the identified research objectives with specific research methods that will be used to achieve those objectives.

Table 1: Research objectives and related research methods

Research Objectives:	Research Methods:
1. To analyse BC emissions from transportation in Canada and identify the main sources and trends 2. To outline the impacts of BC on health and the environment (Arctic) 3. To evaluate current policies and regulations targeting transportation in Canada, then at the international level. 4. To provide recommendations for future BC transport regulations based on all research acquired.	1. Review of the BC report for Canada (2024 edition) and available statistics regarding transportation (quantitative data) 2. Literature review (academic, grey) of implications of BC 3. Literature review (academic, grey) of: a. Relevant Canadian air pollution regulations b. Relevant international air pollution regulations 4. Literature review (academic, grey) of policies targeting the transportation sector (air pollution)

2.3 Search strategy

For this MRP, a careful literature review was conducted through May 2024 of the scientific literature gathered in the Web of Science and the University of Ottawa's OMNI databases. To determine which studies may be used in this paper, the entire texts of the possibly relevant publications were examined in comparison to the inclusion and exclusion criteria. Using the program Zotero, about 100 papers were extracted into the database, tagged for the relevant sections of the paper (Sources, Impacts, Recommendations...), and re-read for usefulness, which narrowed down the total to 89 papers. The initial searches yielded numerous results (in the tens of thousands), however, most of them were found irrelevant to the field of study of this paper. Finally, looking through official papers, policies, and other publications from the EU, Canada, and others for this review was done by visiting

websites such as that of the European Union, the Government of Canada, and the United Nations.

As shown in Table 1, this involved several research objectives with their related research methods, mainly consisting of literature reviews. Each of these literature reviews requires a search string used to guide the research (Table 2), as well as overall inclusion/exclusion criteria (Table 3). The University of Melbourne outlines some helpful common inclusion and exclusion criteria such as date, peer review, or setting (The University of Melbourne, 2024). This guide was used to make decisions regarding narrowing down research and excluding certain topics.

The research from these literature reviews on those databases was limited to academic, peer-reviewed articles in English. Since most of the relevant data from BC only dates back to 2013, that was decided to be the start year for all of the research. Data older than 2013 was ignored to narrow down the research and focus on the most up-to-date information.

Other relevant research includes using the Arctic Council repository, existing government legislation, academic studies related to BC as well as emissions data collected from the Canadian BC Report, and Arctic Council databases. A mix of types of literature is important to gather all perspectives (academic/scientific, policy, governmental, etc.). The goal is for the quantitative data to support or disprove the qualitative data (for example, have existing air pollutant regulations reduced BC emissions in Canada?).

Table 2: Search strings for online research

Search String A: Impacts of BC	Search string B: Current air pollution regulation (Canada, international, Arctic Council)	Search String C: Policies targeting transportation
[“black carbon” OR “particulate matter” OR “soot”] AND [“impact*” OR “environment*” OR “health”]	1) [“air pollut*” OR "sulfur oxide*” or “sulphur oxide*” OR “nitrous oxide*” OR “methane” OR “particulate matter” OR “PM*”] AND [“polic*” OR “govern*” OR “regulat*” OR “legislat*” OR “protocol*” OR “framework*”] AND [“transport*” OR “vehicle” OR “on-road”] 2) Same as 1) but include “Canad*”	1) [“polic*” OR “govern*” OR “regulat*” OR “legislat*” OR “protocol*” OR “framework*”] AND [“transport*” OR “vehicle” OR “on-road”] 2) Same as 1) but include “Canad*”

Table 3 displays some of the inclusion/exclusion criteria for the research objectives. The decisions to include certain topics, such as municipal regulations or climate models are for simplicity’s sake in order to narrow the scope of this MRP. A literature analysis was used for all of the outlined objectives and the methods here relate to all aspects of this MRP.

Table 3: Inclusion/exclusion criteria

Included	Excluded
Canadian (federal) policies and regulations regarding black carbon, particulate matter, or air pollutants in general related to transportation	Provincial, territorial, or municipal regulations
International policies and regulations regarding black carbon, particulate matter, or air pollutants in general specifically for transportation	Economic considerations, etc.
Impacts (health, climate, etc.) of BC	Greenhouse gas regulations and removal technologies
The Canadian Black Carbon Report	Calculations and/or equations as to how the emissions are calculated

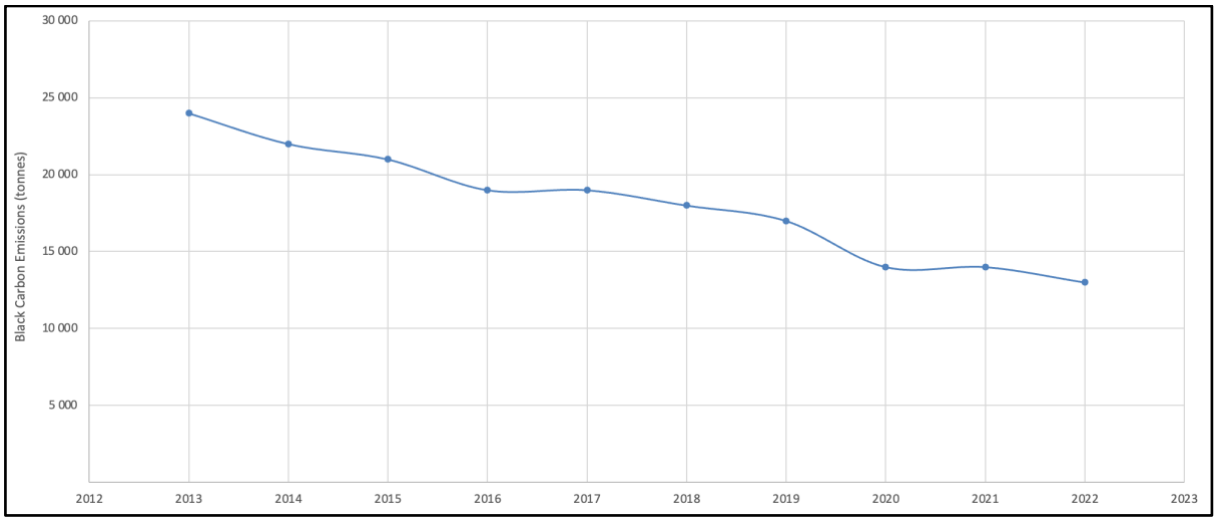
3. Results and Discussion

3.1 Sources of black carbon emissions in transportation

One of the main sources of emissions of BC in the Arctic is diesel engines, both stationary and mobile (US EPA, 2024). According to the Canadian BC report, transportation is “by far” the most significant source of BC emissions in Canada, one of the main culprits being diesel engines for on-road transport (ECCC, 2024b). Diesel fuel is used by locomotives, ships, construction trucks, and farming equipment, among other off-road mobility sources (US EPA, 2024). Automobiles, buses, and trucks are examples of on-road mobility sources (US EPA, 2024).

Within the “Transportation and Mobile Equipment” sector, the Canadian BC report outlines various subsections, including Off-Road Transport and On-Road Transport (diesel, gasoline, liquid petroleum gas, and natural gas), and Rail Transportation (Environment And Climate Change Canada, 2024a). Transportation accounts for 51% of total BC emissions in Canada, with off-road diesel engines responsible for 7.7 kilotonnes (kt), or 30% of the total emissions in this category (ECCC, 2024b). The COVID-19 pandemic occurred in 2020 and 2021 and since transportation was quite limited during that period due to distancing and lockdowns, there were considerable declines in emissions (ECCC, 2024b). In fact, emissions from transportation fell by 3.8 kt, or 22%, between 2019 and 2022. Figure 1 below shows a summary of emissions in the transportation and mobile equipment sector, from 2013 to 2022 (ECCC, 2024a).

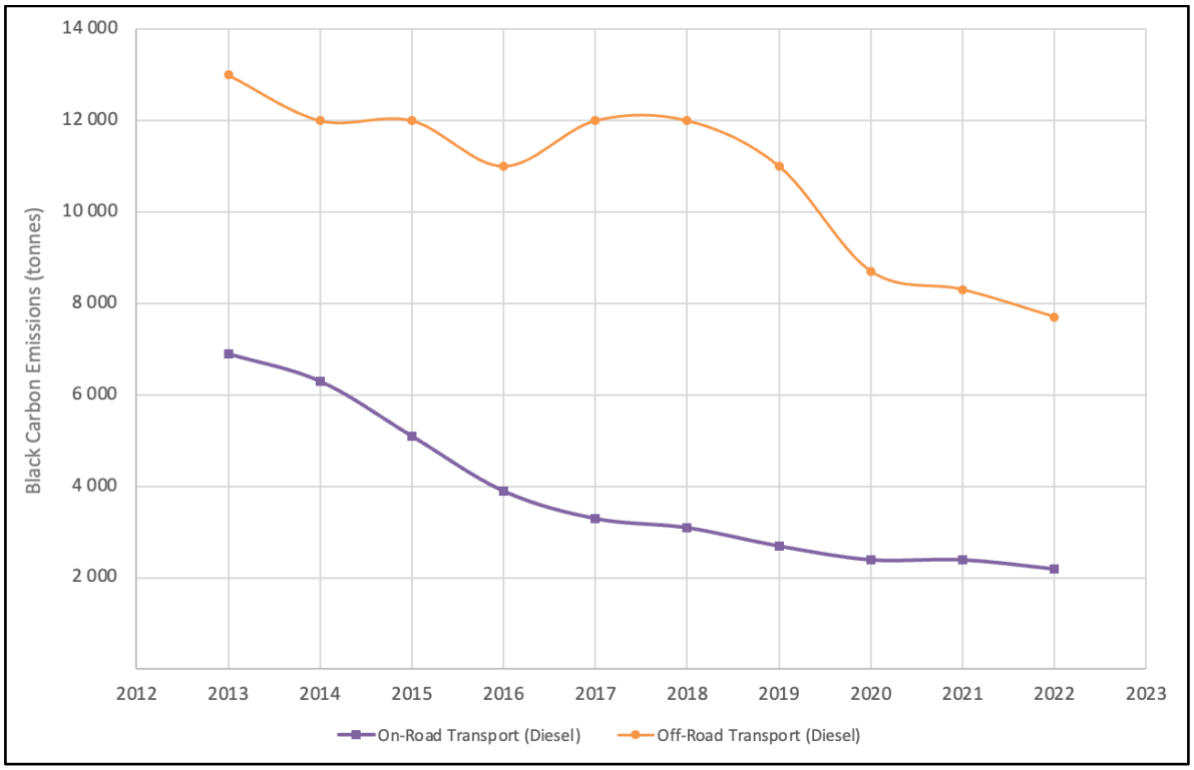
Figure 1: Black Carbon Emissions (tonnes) from Transportation in Canada (2013-2022)



As can be seen in Figure 1, emissions in this category seem to be decreasing, particularly since the COVID-19 period. It is important to mention that even with the economy bouncing back 2022, the decrease in emissions is still notable post-pandemic and will likely rise back unless other changes are made. There is a significant amount of passenger cars in Canada—roughly 18 million—and they contribute significantly to air pollution, especially in cities (ECCC, 2017). Some of the nation's transportation-related emissions are attributed to passenger automobiles, roughly 4% of $PM_{2.5}$ emissions (ECCC, 2017).

In Canada, trucks and buses are examples of heavy-duty automobiles. According to regulations, an on-road vehicle is considered heavy-duty if its gross vehicle weight rating is greater than 3,856 kilograms, its curb weight is greater than 2,722 kilograms, or its basic vehicle frontal area is greater than 4.2 square metres (ECCC, 2013). Diesel engines power the majority of heavy-duty vehicles, which include vehicles used for mining, construction, and farming (ECCC, 2013). Figure 2 below displays BC emissions from on and off-road diesel transportation from 2013 to 2022 (ECCC, 2024a).

Figure 2: Black Carbon Emissions (tonnes) from On and Off-Road Transport (Diesel) in Canada (2013-2022)



As shown in Figure 2 above, off-road diesel emissions are considerably higher than those of on-road diesel vehicles. As shown in Section 3 of this MRP, most policies and regulations in Canada are more stringent on on-road vehicles and less so on off-road vehicles that remain diesel-heavy, which could explain the difference in trends. As diesel vehicles contribute significantly to road transport emissions, significant reductions in this industry and other harmful diesel engines would be advantageous for public health and climate change mitigation (UN Environment Programme, n.d.-b).

3.2 Impacts: health and climate

3.2.1 Human health

Air pollution exposure is a leading cause of disease and mortality worldwide (ECCC, 2024c). According to Health Canada, "air pollution represents the largest environmental risk to health" (EcoJustice, 2023). A staggering 15,300 premature deaths in Canada are attributed to air pollution each year (ECCC, 2024b). With current projections of 4 million to 9 million annual deaths globally attributed to $PM_{2.5}$ emissions, it has been acknowledged as the primary environmental risk factor for the global burden of illness according to a study by Jun Meng et al. evaluating the health effects related to low-level $PM_{2.5}$ in Canada (2019).

BC and $PM_{2.5}$ particles, sometimes smaller than a grain of salt, can enter the lungs and transfer harmful substances into the bloodstream (UN Environment Programme, n.d.-a). $PM_{2.5}$ pollution has been associated with several adverse health effects, such as increased heart and lung disease-related mortality in adults, heart attacks, strokes, and chronic respiratory conditions including bronchitis (UN Environment Programme, n.d.-a). It has also been connected to worsened asthma symptoms and other cardio-respiratory symptoms (UN Environment Programme, n.d.-a).

Additionally, following a rigorous analysis of the epidemiological and toxicological literature on ambient PM, Grahame et al. (2014) determined that BC is "causally involved" in all-cause mortality, cardiovascular disease, and lung cancer. Similarly, Janssen et al. (2012) presented epidemiological evidence that connected BC to hospital admissions for cardiopulmonary conditions as well as all-cause, cardiopulmonary, and cardiovascular death in a World Health Organization (WHO) study on the health impacts of BC. Based on more robust and persistent relationships from epidemiological research, these thorough assessments have indicated that BC is a better biomarker of the health impacts of air

pollution than ambient $PM_{2.5}$ (Briggs & Long, 2016; Grahame et al., 2014; Janssen et al., 2012;).

Lung inflammation brought on by $PM_{2.5}$ exposure has the potential to cause systemic inflammation (Kirrane et al., 2019). The liver may produce more proteins and coagulation factors in response to circulating inflammatory cytokines, which might change haemostasis (the process of keeping blood within a damaged blood vessel) and raise the risk of thrombosis, or blood clots (Kirrane et al., 2019). Aside from its impact on haemostasis, systemic inflammation can also cause vascular dysfunction, which can result in the development of new atherosclerotic plaques (hardening of the arteries), the rupture of pre-existing plaques, blockage of the heart's blood supply (ischemic heart disease), and an increase of risk of heart failure (Kirrane et al., 2019). Additionally, an increasing amount of research has assessed the correlation between pre-eclampsia (a condition involving high blood pressure in pregnant women) and long-term exposure to ambient air pollution, namely BC and PM (Harvard Health, 2023; Zhu et al., 2024).

Children and infants are also impacted by $PM_{2.5}$, as it is responsible for premature fatalities from acute lower respiratory illnesses like pneumonia (UN Environment Programme, n.d.-a). In one study by Cunha-Lopes et al, the exposure of kids to black carbon and sized-fractionated particulate matter in an urban setting was assessed (2019). The study found that while performing their regular commute only took up 5% of the time they spent outside, children who commuted during rush hour to school breathed 23% of their daily intake of BC (Cunha-Lopes et al., 2019). The authors of the study emphasize the significance of urban design in minimizing children's exposure to traffic emissions, in conjunction with public awareness-raising initiatives on the effects of indoor sources (Cunha-Lopes et al., 2019).

According to information on census block points and the National Road Network, around 10 million Canadians, or 32% of the country's population, reside in "exposure zones," which are places where they are subject to air pollution from traffic (Brauer et al., 2013). One study on “Traffic-related air pollution and health in Canada” found that 500 meters on either side of a highway or 100 meters on either side of a major urban road are considered to be these heightened exposure zones (Brauer et al., 2013). An upper-bound estimate of 16.9 million people (54% of the Canadian population) and a lower-bound estimate of 4.1 million people (13% of the Canadian population) respectively indicate how many people live in these high-exposure locations (Brauer et al., 2013). Given the elevated level of exposure and the evidence of connected health issues, it is clear that traffic-related air pollution poses a serious threat to public health in Canada and that population exposure has to be reduced via regulations and policy (Brauer et al., 2013).

3.2.2 Climate: The Arctic

BC contributes to global warming because of its exceptional ability to absorb light and heat its surroundings (UN Environment Programme, n.d.-a). The impacts of BC are not evenly distributed around the world due to significant spatial and temporal variations in its concentrations (UN Environment Programme, n.d.-a). Recent studies indicate that BC is the second major cause of climate change after CO_2 (Cheek, 2018). One of the first climate modelers at Stanford University, Doctor Mark Jacobson, suggests that the BC emissions from fossil fuels and biofuels combined may be responsible for roughly 16% of gross global warming (Cheek, 2018).

BC, which is suspended in the atmosphere, warms the planet by turning solar energy into heat, just as asphalt surfaces in cities produce heat islands (UN Environment Programme, n.d.-a). In addition to influencing cloud formation, BC also affects local weather

and rainfall patterns (UN Environment Programme, n.d.-a). Particles of BC heat the surface of ice and snow by decreasing its albedo, or capacity to reflect sunlight (US EPA, 2024). Since 1750, this impact is thought to have contributed 0.04 degrees Celsius to global warming (UN Environment Programme, n.d.-a). Particularly susceptible to melting are areas with glaciers and the Arctic (UN Environment Programme, n.d.-a). The mean annual surface temperature is predicted to rise by around 2 degrees Celsius by 2050 compared to current levels (US EPA, 2013).

Indirect effects are caused by BC altering the distribution and characteristics of clouds, which impacts their longevity and reflectance (US EPA, 2013). The semi-direct action of BC has an impact on cloud stability as well (US EPA, 2013). The indirect and semi-direct impacts of black carbon have unknown net influences on climate since these cloud effects can be both warming and cooling (US EPA, 2013). These are not the impacts of greenhouse gases (US EPA, 2013). Methane and BC provide more radiative forcing than CO_2 for each additional metric ton in the atmosphere (US EPA, 2013).

The Arctic is also particularly sensitive to the effects of BC since it deposits as a black surface on snow, which accelerates melting (also known as the albedo effect) (Makarova et al., 2021; Reddy Muduchuru et al., 2024; Ren et al., 2020). It is important to consider the co-benefits of these factors when evaluating the significance of BC mitigation (Kühn et al., 2020). Only a minor portion of global emissions originate from the Arctic region; most effects are caused by BC that is imported and emitted from beyond the region (Kühn et al., 2020). Indeed, recent research has shown that BC's major contribution to the warming of the Arctic is the movement of warm air masses from outside the region, including Canada (Kühn et al., 2020).

Approximately 40% of Canada's total land area is classified as Arctic and Northern (Arctic Council Secretariat, 2024). As an important member of the Arctic Council, Canada bears a heavy responsibility for reducing its emissions (ECCC, 2024b). Environment and Climate Change Canada's (ECCC) first BC inventory report, covering the year 2013, was published in 2015 and is submitted yearly to the United Nation's Economic Commission for Europe as part of Canada's Arctic Council obligations and as a voluntary responsibility under the Gothenburg Protocol, which includes a commitment to reducing $PM_{2.5}$ emissions (UN Environment Programme, n.d.-b). It provides a better understanding of the importance of various emission sources by quantifying BC emissions (UN Environment Programme, n.d.-c).

The duration of a pollutant's impact on temperature and radiative forcing is determined by its atmospheric lifespan. The faster atmospheric concentrations (and hence consequences) may be decreased by emissions abatement, the shorter the lifespan (US EPA, 2013). Doctor Charles Zender of the Earth System Modelling Facility at the University of California stated that it would take decades before there were any benefits from a halt to zero CO_2 emissions today (Cheek, 2018). Conversely, if BC emissions were reduced today, benefits may be felt almost instantly in the Arctic (Cheek, 2018). The possibility of BC mitigation to cause Arctic warming to slow down on a short timeline has been extensively covered in the literature (Kühn et al., 2020).

In addition to the reductions predicted as a result of current regulations, case studies on emissions mitigation indicate that targeted mitigation strategies might significantly lower global black carbon emissions (US EPA, 2013). Emissions of BC might be lowered by 70 to 80% by 2030 (US EPA, 2013). Excluding the indirect cloud impacts of particles, worldwide implementation of the highest technologically possible mitigation techniques for BC and co-

emitted pollutants might reduce Arctic warming by around 0.25 degrees Celsius by 2050 (US EPA, 2013).

3.3 Regulations

3.3.1 Canada: current state of relevant policies

Current and ongoing Canadian air pollution regulations

ECCC is the federal agency responsible for overseeing air pollution regulations in Canada (Anggadol, 2024). In particular, by restricting the quantity of pollutants released into the atmosphere annually, the Government of Canada, empowered under the Canadian Environmental Protection Act (CEPA), 1999, creates and carries out regulations to assist in lowering overall levels of air pollution (ECCC, 2024b). The most prevalent air pollutants with established health risks are governed by CEPA and are referred to as "criteria air contaminants" (Ewing et al., 2024). Nitrogen dioxide, sulphur dioxide, carbon monoxide, ammonia, PM, and volatile organic compounds are among the common air contaminants (Ewing et al., 2024).

In order to promote improvements in air quality across the nation, the Canadian government is still working to establish stricter Canadian Ambient Air Quality Standards (CAAQS) (ECCC, 2024b). More precisely, since 2015, more stringent $PM_{2.5}$ regulations have been in place (ECCC, 2024b). The CAAQS are voluntary targets, nevertheless, and as such are neither legally enforceable nor binding (Ewing et al., 2024). Although CEPA's components provide the foundational policy tools needed to lower emissions and enhance environmental outcomes, their implementation and enforcement have fallen short of expectations, part of the reason being a lack of resources and funding (Ewing et al., 2024).

Furthermore, the Canada-United States Air Quality Agreement was signed in 1991 by the two countries (US EPA, 2023). A particulate matter annex was included in the Agreement in 2004 to address the transboundary migration of $PM_{2.5}$ that happens over the border between Canada and the United States (US EPA, 2023). Since 1991, both the US and Canada have achieved notable strides in lowering their emissions of the pollutants that result in ground-level ozone and acid rain (ECCC, 2024d). To guarantee that transboundary air pollution does not interfere with a nation's capacity to achieve and uphold its national ambient air quality criteria for pollutants like $PM_{2.5}$, both countries must continue their bilateral efforts (ECCC, 2024d).

Additionally, the development and use of clean fuels, technologies, and procedures are encouraged more by the Clean Fuel Regulations (ECCC, 2022a). According to the regulations, providers of liquid fossil fuels (diesel and gasoline) must progressively lower the carbon intensity of the fuels they manufacture and distribute for use in Canada, to achieve a 15% reduction (below 2016 levels) by 2030 (ECCC, 2022a). The Canadian government is adopting laws that emphasize emissions across the fuel lifecycle, mirroring the strategies that are now in place in California, and Oregon (ECCC, 2022a). Because of these rules, several jurisdictions have profited from the growth of the clean technology industry (ECCC, 2022a). A credit market is established under the Clean Fuel Regulations (ECCC, 2022a). To meet the reduction criteria, regulated parties—manufacturers and importers of gasoline and diesel—must either create or purchase credits. Extra credits may be sold or deposited for usage in future years by interested parties (ECCC, 2022a). The purpose of regulations is to increase the economy's use of low-carbon fuels and to *incentivize* innovation and the use of clean technology (ECCC, 2024e). While this regulation is a great step in the right direction and provides a smart opportunity to lower emissions through fuels, it is only an incentive

and is not enforced. As the Clean Fuel Regulations are under CEPA (which contains ‘enforcement powers’), a breach of the Regulations could result in monetary fines and convictions (Adam Chamberlain, 2023), it will be interesting to see the follow-through with this enforcement as time progresses. There "is room for improvement" in the Clean Fuel Regulations, according to Sander Duncanson, co-chair of Osler's regulatory, Indigenous, and environmental division (Macnab, 2023). Duncanson states that certain groups in Ottawa believe that the fastest path to net zero is eliminating fossil fuels from the economy and that developing "low carbon fuels" entails substituting fossil fuels with an alternative (Macnab, 2023).

Research indicates that 90% of Canadians' daily driving demands are satisfied by commercially accessible electric vehicles (EVs), especially in metropolitan areas where driving ranges are often shorter and there is more potential to cut emissions (Lopez-Behar et al., 2019). As such, a national Zero-Emissions Vehicle Strategy with an unbinding aim is being developed by the federal, provincial, and territorial governments of Canada (Lopez-Behar et al., 2019). Additionally, to achieve 100% new light-duty zero-emission vehicle sales by 2035, the 2030 Emissions Reduction Plan is committed to developing a light-duty zero-emission vehicle sales regulation that would set annual requirements (ECCC, 2022c). Within the regulation, they define vehicles that are capable of running without emitting any emissions from their exhaust are classified as zero-emission vehicles. This category includes fuel cell, plug-in hybrid, and battery electric vehicles (ECCC, 2023). This regulation would also require the mandatory periodic goals of a minimum of 20% of all new light-duty vehicles sold by 2026 and a minimum of 60% by 2030, with the ultimate goal of reaching 35% of all new medium- and heavy-duty vehicle sales being zero-emission vehicles by 2030 (ECCC, 2022c). Furthermore, by 2040, all new sales of medium- and heavy-duty vehicles

must be zero-emission cars, according to legislation that the government is developing (ECCC, 2022c).

The government's strategy entails ensuring the accessibility and affordability of zero-emission vehicles, constructing charging and refuelling facilities, and fostering public knowledge and trust in zero-emission vehicles (ECCC, 2022c). To facilitate the safe implementation of medium- and heavy-duty zero-emission vehicles on Canadian roadways, Transport Canada initiated the $75.8 million Zero-Emission Trucking Program (ECCC, 2022c). Funding for the program will go toward safety evaluations, developing and updating guidelines, codes, and standards in partnership with provinces and territories, setting up trucking testbeds to facilitate early deployments, and renovating the Government's Motor Vehicle Test Centre to facilitate upcoming heavy-duty zero-emission vehicle compliance evaluations and studies (ECCC, 2022c). As the regulation is still very recent and therefore it is hard to determine its success as of yet, although, through knowledge of how Canadian environmental regulations operate under CEPA, it is easy to see how implementation and enforcement will be challenging for the government. This is further explained in Section 6.1 under general recommendations.

Gaps in Canadian air pollution regulations for black carbon within transportation

One 2015 study states that in terms of per capita emissions of different criteria air contaminants, Canada "consistently ranks among the three worst industrialized nations" (Boyd, 2015). An ECCC report from 2021 describes how Canada is ranked second highest in $PM_{2.5}$ emissions and had "had the highest ratio of PM2.5 emissions to gross domestic product" among the Organisation for Economic Co-operation and Development countries (ECCC, 2021). Some contend that a portion of the problem stems from consumer habits and

production issues, the underutilization of CEPA, and ineffective administration and enforcement at various levels of government (Ewing et al., 2024).

1. Passenger vehicles

Due in part to an increasing desire for sports utility vehicles and trucks (SUVs), Canadians drive some of the most polluting automobiles in the world; over the previous 20 years, domestic transportation-related carbon emissions have climbed by about 30% (Clean Energy Canada, 2020). When it comes to their next vehicle purchase, the majority of Canadians lean toward buying an electric car, yet very few auto dealerships in the nation have even one EV available for test drive or purchase (Clean Energy Canada, 2020). Although it is the world's 12th-largest car manufacturer, Canada lags behind other nations in the production of electric cars (Clean Energy Canada, 2020). Just 0.4% of EVs are produced in Canada, compared to 2.2% of light-duty cars produced worldwide (Clean Energy Canada, 2020). The sales targets for light-duty zero-emission vehicles in Canada are 10% by 2025, 30% by 2030, and 100% by 2040; however, the current policies have been deemed insufficient to achieve these goals (Clean Energy Canada, 2020). At 8.9 litres of gasoline per 100 kilometres (L/100km), Canada's typical car was the least fuel-efficient in 2017 (Canada Energy Regulator, 2023). By contrast, the average gasoline usage in the US was 8.6 L/100 km, in Germany it was 5.9 L/100 km, and in Portugal it was 4.9 L/100 km (Canada Energy Regulator, 2023). Car manufacturers in North America build bigger automobiles than their competitors in Europe and Asia (*When It Comes to Vehicles, Canada Tops the Charts for Poor Fuel Economy*, 2019). This is due in part to marketing efforts and production economies of scale, but it also reflects customer preferences that drive consumers toward SUVs (*When It Comes to Vehicles, Canada Tops the Charts for Poor Fuel Economy*, 2019). Cost is by far the main factor behind Canada's fleet of fuel-inefficient automobiles (*When It Comes to*

Vehicles, Canada Tops the Charts for Poor Fuel Economy, 2019). Compared to the rest of the globe, it is significantly less expensive to buy and run a less-efficient in Canada or the United States (*When It Comes to Vehicles, Canada Tops the Charts for Poor Fuel Economy*, 2019). Vehicle registrations in Europe are frequently determined by the vehicle's emissions or fuel efficiency. For instance, automobile buyers in France deal with a sliding "bonus-malus" scale (*When It Comes to Vehicles, Canada Tops the Charts for Poor Fuel Economy*, 2019). Zero-emission cars are eligible for a €6,000 refund, whereas high-emitting vehicles may be subject to a registration fee of up to €10,000 (*When It Comes to Vehicles, Canada Tops the Charts for Poor Fuel Economy*, 2019). Canada also ranks lowest for CO_2 emissions per kilometre driven, perhaps due to the close correlation between CO_2 emissions and fuel efficiency (Canada Energy Regulator, 2023).

2. Trucks

In 2023, three non-governmental organisations–Canadian Physicians for the Environment, Friends of the Earth Canada, and Ecojustice–addressed a letter to the Commissioner for the Environment and Sustainable Development (EcoJustice, 2023). Within this letter, the authors cite a study from the University of Toronto which states that the bulk of emissions were caused by a small percentage of vehicles and trucks (EcoJustice, 2023). Hence, the study explains how there are significant advantages to policies and initiatives could be that are put in place to get rid of this tiny percentage of the dirtiest cars from communities (EcoJustice, 2023). Additionally, the letter states that the most significant recommendation from Canada's premier research on near-road air pollution is for governments to "reduce near-road diesel exhaust concentrations" (EcoJustice, 2023). The researchers also emphasized how critical it is to identify and remove the most polluting trucks in order to effectively and quickly reduce diesel emissions (EcoJustice, 2023). For

truck models made in 2007 and after, new federal vehicle emissions requirements are implemented (EcoJustice, 2023). However, older vehicles are exempt from these more recent, health-protective regulations (EcoJustice, 2023). In fact, compared to their more modern equivalents, older heavy-duty diesel engines are legally allowed to release ten times as much particulate pollution (EcoJustice, 2023). This is a significant divergence from emissions regulations based on health (EcoJustice, 2023). Nonetheless, the majority of the diesel engines currently in operation in Canada are older than the most modern pollution regulations (EcoJustice, 2023).

3. Trains

In 1977, Prime Minister Pierre Elliott Trudeau launched VIA Rail as a Crown Corporation and the country's first national passenger rail corporation, deeming intercity train transportation indispensable throughout Canada (VIA Rail, n.d.-b). These trains are all diesel or diesel-electric (VIA Rail, n.d.-a).

Canada is still the only G7 nation without any high-speed rail (Chiasson, 2023). The installation of a high-speed rail network for the Quebec City–Windsor line has been the subject of much discussion (Chiasson, 2023). The corridor is home to 16 large cities with over 100,000 population, including the Niagara municipal region, and three metropolitan regions, all of which are almost exactly in a straight line (Chiasson, 2023). It is the most densely inhabited region in all of Canada (Chiasson, 2023). Given that more than half of all Canadians—94% of those in Ontario and 65% of those in Quebec—live inside the corridor, it is illogical that there hasn't been a significant effort to build a high-speed rail network along it (Chiasson, 2023). According to a new Canadian high-speed rail firm, trips from Toronto to Montreal, which take five hours by car, might take less than an hour by high-speed train

(Chiasson, 2023). There have been 26 studies conducted since 1970 regarding the installation of a rapid transit network in Ontario, but none of them have resulted in any action (Chiasson, 2023).

3.3.2 Relevant international policies

Gothenburg and the Arctic Council

Internationally, there are no enforceable actions to limit BC emissions, except for the promises to decrease BC as a component of $PM_{2.5}$ outlined in the Gothenburg Protocol to the Convention on Long-Range Transboundary Air Pollution (Kühn et al., 2020).

By addressing foreign contaminants that nevertheless have an impact on Canadian air quality, the Gothenburg Protocol helps Canada address the contaminants that lead to ground-level ozone and acidification (ECCC, 2022b). It establishes limitations on air pollutants that are harmful to both human health and the environment, such as ammonia, nitrogen oxide, sulphur dioxide, and volatile organic compounds (ECCC, 2022b). It was revised in 2012 to incorporate new pledges for 2020 as well as PM and BC (as a PM component) (ECCC, 2022b).

The only legally enforceable international agreement addressing air pollutants is the Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution (LRTAP) (ECCC, 2022b). With the exception of the Geneva Protocol on volatile organic compounds, Canada is a Party to every protocol (ECCC, 2022b). The addition of BC as part of PM to the modified Protocol requires nations to put an emphasis on $PM_{2.5}$ reductions from sources with considerable BC content (ECCC, 2022b). In compliance with these protocols, the Air Pollutant Emissions Inventory report for Canada contains a variety of emission sources for $PM_{2.5}$ (ECCC, 2022b). However, dust sources (not from combustion) such as road construction and agricultural crop production are not included in Canada's $PM_{2.5}$ emission

reduction commitment (ECCC, 2022b). In addition, the Protocol requires Parties to voluntarily publish BC emissions and predictions (ECCC, 2022b). Canada has always met its submission commitments, as well as all the air pollution targets and is in a good position to meet its future goals emissions-wise (ECCC, 2022b). It is interesting to note that the UNECE hosts working groups through the "Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe", which monitors and reports the compliance of the "Parties to the Convention" (a total of 51 countries, which includes Canada) (UNECE, 2022). These annual reports provide detailed information as to which Parties report their PM emissions in accordance with the Convention and which ones are lacking (UNECE, 2022). By speaking to someone at ECCC I learned that countries that are found to not comply are contacted by the UNECE through a letter which details the non-compliance and requests an answer detailing whether or not the Party agrees with this assessment. Should the country not provide substantial proof or not respond, the matter is 'escalated' to an investigation led by a committee. However, there is no literature to suggest whether a non-complying Party is reprimanded in consequence.

The Arctic Council also oversees significant non-binding procedures that expedite regional action. Enhanced Black Carbon and Methane Emissions Reductions, An Arctic Council Framework for Action, is one of the primary examples that the Arctic Council approved during its 2015 conference (Kühn et al., 2020). The document declares that the member states of the Arctic Council are dedicated to quickening the decrease in BC emissions and invite the observer governments of the Arctic Council to join in the endeavour (Kühn et al., 2020). Furthermore, an aspirational collective objective of decreasing BC emissions between 25 and 33 percent below 2013 levels by 2025 was

accepted at the 10th Arctic Council Ministerial Meeting in May 2017 (Kühn et al., 2020). Again, these regulations, as well as those under the Gothenburg Protocol, are voluntary.

The European Union

In the European Union (EU), fuels used for road transportation must adhere to stringent quality standards to safeguard public health, the environment, and vehicles' ability to safely cross national borders (European Commission, n.d.). The member states must disclose the quantity and quality of gasoline and diesel fuels sold inside national borders (European Commission, n.d.). These states have to analyse fuel samples every year to make sure they meet Fuel Quality Directive standards (European Commission, n.d.).

The air pollutant emissions restrictions set by the previous European standards are tightened by the Euro 6/VI vehicle emissions standards, which also mandate the use of the most advanced vehicle emissions control equipment available (Williams & Minjares, 2016). The European plan consists of six phases with progressively stricter emission control regulations, beginning in 1992 with Euro 1/I and continuing until 2015 with Euro 6/VI (Williams & Minjares, 2016). With modifications to the heavy-duty vehicle test procedure in favour of the World Harmonized Transient Cycle, a new particle number restriction, and stricter on-board diagnostic requirements (computer programs that oversee emission-related elements), the heavy-duty Euro VI standards address high real-world PM emissions from diesel trucks (US EPA, 2024b; Williams & Minjares, 2016).

California

The California Air Resources Board (CARB) authorised the California Low Carbon Fuel Standard (LCFS) in 2009; it was put into effect in 2011, revised in 2013, and re-adopted in 2015 (Witcover et al., 2022). The program primarily generates deficits and credits for fuel volumes based on their carbon intensity ratings, which must be balanced by credits to

achieve compliance (Witcover et al., 2022). In addition to lowering the carbon intensity of transportation fuel, other anticipated advantages include diversifying the fuel supply, lowering reliance on petroleum, and lowering emissions of other air pollutants (Witcover et al., 2022). Electricity, ethanol, and renewable diesel were the primary fuels that produced credits in 2021 (Witcover et al., 2022). As of the end of 2020, the program has produced shortfalls totalling 69.4 million MT and credits totalling a reduction of 77.5 million MT of greenhouse gases (Seymour, 2021). This translates to an over-compliance of 8.1 million MT, indicating that the program's GHG reductions have been happening earlier than anticipated (Seymour, 2021).

Oregon

Following the passage of HB 2186 by the Oregon Legislature, which gave the Environmental Quality Commission the authority to establish regulations aimed at lowering the carbon intensity of Oregon's transportation fuels, the Oregon Clean Fuels Program got underway in 2009 (Witcover et al., 2022). Similar in structure and basic objectives to the California LCFS, the Oregon Clean Fuels Program aims to reduce carbon intensity by 20% by 2020 compared to 2015 levels (Witcover et al., 2022). Since the program's inception, Oregon has seen a decrease in carbon intensity and an increase in the volume of available fuels that replace gasoline and diesel (Witcover et al., 2022).

According to a study done by the University of Quebec in Montreal, Canada’s Clean Fuel Regulations percent carbon intensity reductions relative to their baseline year are consistently lower than those observed in California and Oregon (Witcover et al., 2022).

4. Recommendations for Canada

4.1 General recommendations

To preserve air quality, controlling emissions sources is a key component of air pollution management at the policy level (Ewing et al., 2024). Laws and regulations by themselves, however, are not sufficient to improve the environment; to discourage rule-breaking and promote compliance, the effectiveness of these laws and their enforcement are equally important (Ewing et al., 2024). Different countries have different approaches to enforcing regulations; some are more direct and combative (like the United States) while others are more cooperative (like Canada) (Ewing et al., 2024). According to studies conducted by academics and commercial organisations, Canada has typically loose regulations and relatively low fines for environmental infractions when compared to other countries (Ewing et al., 2024). The ability of regulators to assess the veracity of the industry's self-reported data is constrained (Ewing et al., 2024). As stated by the Canadian Auditor General, "Environment Canada does not have adequate systems and practices in place to verify that all facilities required to report their emissions are doing so and that the information they provide is accurate" (Ewing et al., 2024).

According to Konisky et al. (2021), enforcement agencies—particularly those operating in the United States—have the flexibility to establish priorities, allocate funds, and modify the severity of their enforcement, giving them a substantial advantage in matching enforcement tactics with environmental priorities. In Canada, this does not seem to be the case (Konisky et al., 2021). It is possible to make several potentially significant changes within the parameters of the current policies and the budget, either slightly increased or the same (Konisky et al., 2021).

Performing random inspections (instead of or in addition to planned inspections) is another suggestion (Zou, 2021). In order to study businesses on an "average" working day over time and increase the likelihood of finding noncompliance, random inspections will be helpful (Zou, 2021). Furthermore, a rise in administrative penalties would be beneficial (Zou, 2021). Agencies have the option to utilize this tool more frequently, even if some are constrained by low maximums for the maximum amount a punishment for a particular offense can be (and raising this limit is a policy matter) (Zou, 2021).

Pollution reductions have improved more in countries that use a more direct enforcement strategy (Ewing et al., 2024). Cooperative methods of enforcing regulations might not be enough to discourage infringers (Ewing et al., 2024). It has also been demonstrated that voluntary programs are not very effective (Ewing et al., 2024). It is important to think about how a more direct enforcement approach might be implemented in Canada in light of these earlier discoveries and the study's findings, which lend credence to the cooperative description of enforcement in the country (Ewing et al., 2024). Provinces could separately raise fines and implement stricter enforcement measures, but this would probably work best under a more aggressive implementation of CEPA (Ewing et al., 2024). One study investigating "Patterns of air pollution enforcement in Canada" recommends strengthening CEPA to make the CAAQS legally binding (Ewing et al., 2024). Additionally, they suggest bolstering ECCC or establishing a separate organization to look into and enforce environmental laws and regulations (Ewing et al., 2024).

Furthermore, it would be advantageous to concentrate on high-risk infractions, particularly those involving possible large polluters, and use them as an example (Alm and Shimshack, 2014; Collins et al., 2016). As enforcement targets, specific high-risk categories could be chosen, such as repeat offenders, cross-provincial offenders, facilities close to

vulnerable neighbourhoods, and so forth (Ewing et al., 2024). Here, "focus" refers to dedicating resources for enforcement and modifying the enforcement strategy (Ewing et al., 2024). Random inspections might be assigned to these institutions more frequently (Ewing et al., 2024). More direct enforcement techniques, such as tickets, orders, administrative fines, and prosecutions, could be applied to non-compliant actors (Ewing et al., 2024).

Theoretically, it is conceivable to regulate most noncompliant emissions and dissuade violators through enforcement, yet still have a large air pollution problem, given that Canada lacks strict national air quality standards (Ewing et al., 2024). If this is the case, then better enforcement has the potential to benefit the environment but is inherently constrained by the laws it upholds (Ewing et al., 2024). Since lax laws and policies cannot be made up for by enforcement, legislation reform may be the most crucial instrument for enhancing compliance and environmental results (Ewing et al., 2024).

4.1.1 Urban planning

The demand for efficient approaches to reduce near-road air pollution is growing as data linking poor health outcomes to near-road air quality increases (Brantley et al., 2014). One such technique is the building of barriers—either vegetative or solid—between highways and communities where people may be exposed to traffic pollution (Brantley et al., 2014). These structures can be built quickly (Brantley et al., 2014). Constant sampling showed decreases in BC behind the vegetation barrier in both parallel and downwind wind circumstances (12.4% and 7.8%, respectively), with maximal reductions reaching 22% in the late afternoon when breezes from the road were present (Brantley et al., 2014). Urban vegetation has several advantages, such as regulating drainage and temperature, reducing noise, and enhancing aesthetics (Brantley et al., 2014). The study's findings suggest that

vegetal barriers, which are predominantly released by traffic sources, may somewhat reduce near-road BC concentrations (Brantley et al., 2014).

4.1.2 Collaboration with the United States

Benefits from international cooperation are implied by the significant $PM_{2.5}$ emissions from the United States (about 30%) (Meng et al., 2019). There may be reciprocal advantages to lowering the emissions from the major U.S. contributors to $PM_{2.5}$ in the country, which include the agriculture, transportation, and power generation sectors (Meng et al., 2019). According to a White House statement from 2023, a joint technical study and assessment is being conducted by the US and Canada to determine if the 1991 U.S.-Canada Air Quality Agreement is accomplishing its environmental goals and is adequate in controlling transboundary air pollution (The White House, 2023). Collaboration between these two Arctic Council members and neighbouring countries is essential in reducing emissions jointly.

4.2 Opportunities for growth

Despite observed gaps in Canadian air pollution regulation and a lack of enforcement, there are some innovative opportunities for growth within the transportation sector in Canada which could provide significant emission reductions for that sector.

An experiment that began in 2023 illustrates how hydrogen-stored power may take the place of diesel fuel on railroads where it would be difficult to install overhead wires or electrified tracks (Chung, 2023). Each day, the train utilizes around 50 kg of hydrogen (Chung, 2023). This takes the place of around 500 litres of diesel that would be used for the trip (Chung, 2023). According to the Quebec government, the $8 million project would get $3 million in funding (Chung, 2023). According to Environment Minister Benoit Charette, it is

a component of the province's 2030 green economic strategy (Chung, 2023). When the train draws hydrogen gas from its tank and mixes it with atmospheric oxygen to create power in a fuel cell, the vapour is produced (Chung, 2023). The hydrogen is produced by Quebec City-based Harnois Énergies using an electrolyser, which uses electricity to split water into hydrogen and oxygen (Chung, 2023). The resultant hydrogen is regarded as green since the electricity comes from Hydro-Quebec, which generates 94% of its electricity from hydropower, 5% from wind, and practically all of it through decarbonization (Chung, 2023). This is a fantastic use of renewable energy and zero-emissions technology that also facilitates inter-city public transportation, which is lacking in Canada.

A rapid passenger rail project between Québec City and Toronto was introduced by VIA High-Frequency Rail CEO Martin Imbleau in February 2024 during a speech to the Chamber of Commerce of Metropolitan Montréal (Bourdeau, 2024). Since then, the project has undergone significant changes, including the establishment of a new federal Crown corporation that is solely focused on its development (Bourdeau, 2024). Since the St. Lawrence Seaway's completion more than 60 years ago, this project represents Canada's greatest transportation infrastructure undertaking (Bourdeau, 2024). The projected network will have stations in Québec City, Trois-Rivières, Laval, Montréal, Ottawa, Peterborough, and Toronto across a distance of around 1,000 kilometres on dedicated, electrified lines (Bourdeau, 2024). The rapid rail project in addition to the hydrogen project brings Canada to the forefront of zero-emission transportation and no longer trailing behind its G7 partners, as identified in Section 5.1.

Additionally, one of Canada’s largest trucking and transportation companies, TFI, is looking for innovative, affordable ways to increase the fleet's efficiency, including the use of emission-free cars (TFI International, 2020). Some operating firms, like their company ICS

Courrier, have already begun investigating electric cars, with test versions scheduled for 2022 (TFI International, 2020). Similarly, a significant first step toward its goal of having 100% of its fleet driven by alternative energy sources, Walmart Canada's first electric semi-trucks hit the road in British Columbia in 2023 (Walmart Canada, 2023). By using these cars, we can reduce the amount of gasoline used annually—more than 100,000 litres. With only one charge, the Freightliner eCascadia is an all-electric, zero-emission semi-truck that can go about 400 km (Walmart Canada, 2023). These vehicles will each be utilised for about 110,000 km of annual travel at Walmart (Walmart Canada, 2023). These cars are made to keep drivers comfortable and the roads safe, thanks to their ergonomic seats and cutting-edge safety systems (Walmart Canada, 2023). It is inspiring to have large transportation companies starting the trend of EVs that hopefully will inspire other Canadian companies to do the same.

5. Conclusion

The importance of environmental policies targeting BC and PM emissions cannot be overstated. Within Canada, those emission sources mainly stem from the transportation sector, both from on and off-road vehicles (ECCC, 2024b). These emissions travel north and also have a catastrophic impact on the Arctic climate and its environment Reddy Muduchuru et al., 2024; Ren et al., 2020). These consequences make the Arctic one of the planet's most vulnerable regions (Makarova et al., 2021). The impacts on human health are more than worrying, resulting in a plethora of potential diseases, complications, and even death that affect humans at all stages of life (EcoJustice, 2023). As a member of the Arctic Council, Canada has a responsibility to act through strict and enforced environmental regulations (ECCC, 2024b).

Although current and ongoing Canadian regulations in the transportation sector have begun to add BC or PM within their requirements for compliance and even developed a national Zero-Emissions Vehicle Strategy, these regulations are in stark contrast with the Canadian public's increasing desire to purchase high-emitting and less fuel-efficient vehicles (Clean Energy Canada, 2020; Lopez-Behar et al., 2019). These gaps in Canadian air pollution regulations within transportation also relate to trucks and trains, which are still mainly diesel-powered (EcoJustice, 2023).

The EU and certain US states have achieved great strides in regulating fuels, which Canada should use as examples and models in order to become more stringent with on and off-road vehicles, particularly by incentivizing individuals and corporations to lead by example.

This MRP has argued that Canada has already made quite some progress in terms of these regulations and that it should continue to aim higher in order to significantly reduce

the impacts of BC on our environment and health. There are some interesting opportunities stemming from the transportation sector, both at the government and corporation level that offer glimmers of hope in terms of emissions reductions and efficiency. Most importantly, BC has the distinctive trait of being a short-lived pollutant; therefore, reducing these emissions quickly and thoroughly will show immediate and beneficial impacts not only for Canada and Canadians but for the Arctic as a whole.

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7. Appendix

7.1 Integration of second reader's comments

Table 4 below shows a summary of the comments the second reader, Raphaelle Pelland St-Pierre, provided to the final proposal in the first column, as well as how these comments were addressed in the final major research project in the second column.

Table 3: Integration of Second Reader's Comments

Second reader's comments	Integration of comments into MRP
Would add why these regions [the Arctic] are of specific interest (i.e. BC accelerates the melting of the snow, black on white surface / the albedo effect).	Included a statement in the impacts section on the albedo effect caused by BC.
Maybe not needed in this proposal, but for the whole thing I'd go in details on the commitment that is targeting PM2.5 and how it's applicable to BC as well indirectly.	A section was added under relevant international policies to describe the Gothenburg Protocol and its added commitment to targeting particulate matter.
What fit in that category [zero-emission vehicles]? Vehicle can be pretty wide as a term.	Included statements from ECCC defining zero-emission vehicles and what that means.
It's possible that what's already in place will be enough and that the recommendations will be wider not just on regulating. To be safer and to offer more flexibility, I'd go with 'recommendation for controlling or reducing BC emissions'	Altered the research question to "controlling and reducing" instead of "regulating".
Wondering if there is an add-on value to also look at PM2.5.	A section was added on the definitions of BC and PM2.5 to state that they are often used interchangeably in the research.