ESTIMATING EMISSIONS FROM NON-ROAD ENGINES FOR METRO VANCOUVER

AUGUST, 2024

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability and climate action across the region.

This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

Territorial Acknowledgement

The author acknowledges that the work for this project took place on the unceded ancestral lands of the xwməθkwəy̓əm (Musqueam), Skwxwú7mesh (Squamish), and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) Nations.

Executive Summary

Non road engines (NREs), that include a diverse range of machinery belonging to construction sector, commercial sector, agriculture sector, etc. significantly contribute to air pollution in the Metro Vancouver region. Most NREs in the region are diesel operated and thus their emissions predominantly consist of particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs). These pollutants cause adverse health impacts by exasperating respiratory and cardiovascular diseases. Due to the emission of GHGs and other pollutants, NREs contribute to global warming and deteriorate regional air quality.

To address these adverse health and environmental concerns, a comprehensive emissions inventory for non-road engines in the Metro Vancouver region is imperative. Despite that, there is a lack of accurate, localized data on emissions from NREs required for effective regulations and decision-making. This report thus fills the gap my presenting an emissions inventory for NREs in the Metro Vancouver region. The emissions inventory is developed by spatially disaggregating provincial emissions data provided by Environment and Climate Change Canada (ECCC) for years 2010, 2015, 2019 to 2022. The disaggregation is done using R programing language and the output was generated in the form of an excel spreadsheet.

This report further presents time series trends in emissions of contaminants such as NOx, PM2.5, VOCs, black carbon (BC), CO_2 equivalent, SOx, etc for each sector. The report further investigates the emissions contribution of each tier within a sector for major contaminants. Finally, the report provides limitations of the methodology used to develop the emissions inventory, followed by key recommendations to policymakers.

Estimating Emissions from Non-Road Engines for Metro Vancouver

1. Introduction

Exposure to air pollutants can cause adverse health impacts including respiratory and cardiovascular diseases. Greenhouse gasses (GHGs) such as Carbon Dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) contribute to accelerating climate change. Thus, Metro Vancouver has set priorities for identifying and reducing these emissions. The Clean Air Plan (2021)[1] and Climate 2050 (2019)[2] lay out emissions reduction targets and strategies for various sectors.

Non-road engines (NREs) are a major source of emissions in Metro Vancouver and other urban centres. They are equipment that do not operate on public roads, including a wide range of machinery used in construction, mining, agriculture, commercial, manufacture, airport, railway management, port, yard and garden, and recreational sectors (ICCT, 2019). As most of these engines operate on diesel fuel, emissions from NREs include particulate matter (PM), nitrogen oxides (NOx), and GHGs[3]. The focus pollutants are diesel generated PM 2.5, NOx, volatile organic compounds (VOC)s and GHGs. 8% GHG emissions in the Metro Vancouver region can be traced back to NREs[2]. They also contribute to over 40% of regional diesel PM[1]. Many NREs, particularly construction and yard & garden engines, also operate in dense residential zones and near sensitive receptors such as hospitals, day care, long-term care centres, etc. Emissions from NREs are thus of significant interest to Metro Vancouver for improving health of residents in the region and achieving its climate targets.

Effectively controlling emissions from NREs depends on a thorough understanding of the different types of sources, engine population and type. However, there is minimal accounting of data on the population of NREs in the region, emissions profile, engine types, etc. To track and forecast emissions of air contaminants and greenhouse gas (GHG) emissions in the region, Metro Vancouver prepares emissions inventories, which can be used to measure performance, track progress towards goals and targets, and guide policy and regulatory development. For non-road engines, Metro Vancouver has previously relied on inventory estimates available from Environment and Climate Change Canada (ECCC). This report develops a methodology for disaggregating provincial level NRE emissions inventory to produce an emissions inventory for Metro Vancouver. This methodology can be used by Metro Vancouver, and other jurisdictions in Canada, to develop an understanding of regional NRE emissions. It further reports on emissions of major pollutants in the region, compares emissions from different sectors to 2010 levels and provides in-depth analysis by engine type.

2. Methodology

[1] Metro Vancouver (2021). Clean Air Plan. https://metrovancouver.org/services/air-quality-climate-action/Documents/clean-air-plan-2021.pdf

[2] Metro Vancouver Climate 2050 (2019). https://metrovancouver.org/services/air-quality-climate-action/Documents/climate-2050-strategic-framework-2018.pdf

[3] https://single-market-economy.ec.europa.eu/sectors/automotive-industry/environmental-protection/non-road-mobile-machinery_en

An emissions inventory (EI) for non-road engines (NREs) in the Metro Vancouver region was developed by disaggregating provincial emissions inventory for NREs provided by Environment and Climate Change Canada (ECCC) to regional scale data. The primary data source was the provincial scale NRE emissions inventory derived from the ECCC NONROAD model (V.2012C, ECCC 2023). This data was made provided by ECCC. The provincial emissions inventory for NREs provided by ECCC contains emissions data on NREs for 15 pollutants including GHGs, equipment description, fuel type, engine characteristics, engine power, disaggregation surrogate used (to disaggregate from national to provincial scale), and tech group for years 2010, 2015, 2019, 2020, 2021, and 2022. This provincial emissions inventory was disaggregated from the national emissions inventory using a list of disaggregation surrogates developed by ECCC. We have used the same surrogate for corresponding equipment used by ECCC and calculated our own values as shown in table 1.
The emissions inventory and following data analysis was done using R markdown on R Studio.

2.1. Developing surrogates

To disaggregate top-down data further from provincial to regional scale, the same surrogates were maintained. Table 1 describes each surrogate and how it was calculated. The ratio equations were obtained from the methodology document shared by ECCC on disaggregating provincial NRE emissions inventory form the national inventory. Most raw data for the calculation was drawn from census data compiled by Statistics Canada for the year 2021.

AIR		$\frac{\sum Movement\ of\ Aircrafts\ within\ MV}{\sum Movement\ of\ Aircrafts\ within\ BC}$	0.79[4,5]
CROP		$\frac{\sum Land\ use\ area\ of\ crop\ (excluding\ Christmas\ trees) in\ MV}{\sum Land\ use\ area\ of\ crop\ (excluding\ Christmas\ trees) in\ BC}$	0.05[6]
IRR		$\frac{\sum Land\ with\ irrigation\ use\ within\ MV}{\sum Land\ with\ irrigation\ use\ within\ BC}$	0.11[7]
CONST		$\frac{\sum Labour\ force\ in\ NAICS\ 23\ in\ MV}{\sum Labour\ force\ in\ NAICS\ 23\ in\ BC}$	0.49[8]
MNFG		$\frac{\sum Labour\ force\ in\ NAICS\ 31-33\ in\ MV}{\sum Labour\ force\ in\ NAICS\ 31-33\ in\ BC}$	0.54[8]
AFFH		$\frac{\sum Labour\ force\ in\ NAICS\ 10/11\ in\ MV}{\sum Labour\ force\ in\ NAICS\ 10/11\ in\ BC}$	0.21[8]

[4] Statistics Canada. Table 23-10-0003-01 Aircraft movements, by civil and military movements, airports with NAV CANADA towers, monthly, inactive
[5] Statistics Canada, Aircraft movements https://www150.statcan.gc.ca/n1/pub/71-607-x/71-607-x2024007-eng.htm
[6] Statistics Canada. Table 32-10-0249-01 Land use, Census of Agriculture, 2021
[7] Statistics Canada. Table 32-10-0368-01 Land inputs, manure and irrigation, Census of Agriculture, 2021
[8] Statistics Canada. 2023. (table). *Census Profile*. 2021 Census of Population. Statistics Canada Catalogue no. 98-316-X2021001. Ottawa. Released November 15, 2023.

HOUSE		$\frac{\sum Single\ detached, semi-detached, and\ row\ houses\ in\ MV}{\sum Single\ detached, semi-detached, and\ row\ houses\ in\ BC}$	0.37[9]
POP		$\frac{\sum Human\ population\ in\ MV}{\sum Human\ population\ in\ BC}$	0.53[9]
WB		$\frac{\sum Length\ of\ shoreline\ and\ coastline\ in\ MV}{\sum Length\ of\ shoreline\ and\ coastline\ in\ BC}$	0.12[10]
RURAL		$\frac{\sum Human\ population\ (urban\ outside\ metropolitan\ area)\ in\ MV}{\sum Human\ population\ (urban\ outside\ metropolitan\ area)\ in\ BC}$	0.02[10]
RAIL		$\frac{\sum Track\ length\ within\ MV}{\sum Track\ length\ within\ BC}$	0.15[10]
GOLF		$\frac{\sum Public\ \&\ semi-private\ 9/18\ holes\ golf\ courses\ in\ MV}{\sum Public\ \&\ semi-private\ 9/18\ holes\ golf\ courses\ in\ BC}$	0.21[10]

Table 1: Equations for calculating surrogates values for disaggregation along with their values

2.2. Developing Emissions Inventory for Metro Vancouver

The two main data inputs are the provincial NRE emissions inventory provided by ECCC and the data for disaggregation compiled from Statics Canada and previous work. The various disaggregation data are used to calculate Surrogate ratios as shown in Table 1. The surrogates used to disaggregate provincial NRE data to MV scale is kept consistent with the surrogates used to disaggregate national level NRE emissions inventory to provincial scale. The values for emissions inventory for NREs in MV region is the product of value in provincial emissions inventory and the corresponding surrogate ratio. Each equipment was further divided into appropriate sectors for analysis and accurate reporting.

3. Emissions Inventory

The emissions inventory has been made available to Metro Vancouver in the form of an Excel sheet along with the R script and all data sets. The inventory contains emissions for all NRE sectors in Metro Vancouver for the years 2010, 2015, 2019, 2020, 2021, and 2022. The following NRE sectors covered in the inventory: construction, manufacture, commercial and industrial, agriculture, mining, oil, railway, marine, yard and garden, and recreational. The sectors and equipment covered by each sector is kept consistent to ECCC classification of NREs and the Provincial emissions inventory prepared by ECCC. Equipment are further divided into sectors based on their application. For example, an agricultural mower is assigned into agricultural sector, a commercial mower is assigned to the commercial sector, and a residential mower is assigned to the yard and garden sector. This categorization is kept consistent with the surrogate type used by ECCC to disaggregate data.

[9] Statistics Canada, 2021 Census of Population. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=Greater%20Vancouver&DGUIDlist=2021A000259,2021A00035915&GENDERlist=1,2,3&STATISTIClist=1&HEADERlist=0

[10] Estimating And Reducing Greenhouse Gas Emissions From Non-Road Engines In The Metro Vancouver Region: A Mixed-Methods Approach, Transdisciplinary Collaborative PhD cohort, 2023

Figure 1 (a) to (f) present emissions by each sectors for major pollutants for years 2010, 2015, 2019 through 2022. Dashed lines indicate that data for years 2011 to 2014 and 2016 to 2018 have not been shown here. The figures show that construction, manufacture, and commercial are some of the highest emitting NRE sectors, followed by yard and garden (and marine for SOX emissions). Thus, focusing on emission reduction efforts in these sectors, especially the construction sector can help overall reduction in emissions from NREs in Metro Vancouver. Figure 1 (a) presents trend in CO2 equivalent emissions, showing an increasing trend for construction, manufacture and commercial sectors. Figures 1 (b), (c), and (d) show a decreasing trend in construction sector emissions for PM2.5, BC, and NOX respectively. Nevertheless, construction remains one of the highest emitting sectors by a huge margin indicating scope for emission reduction initiatives.

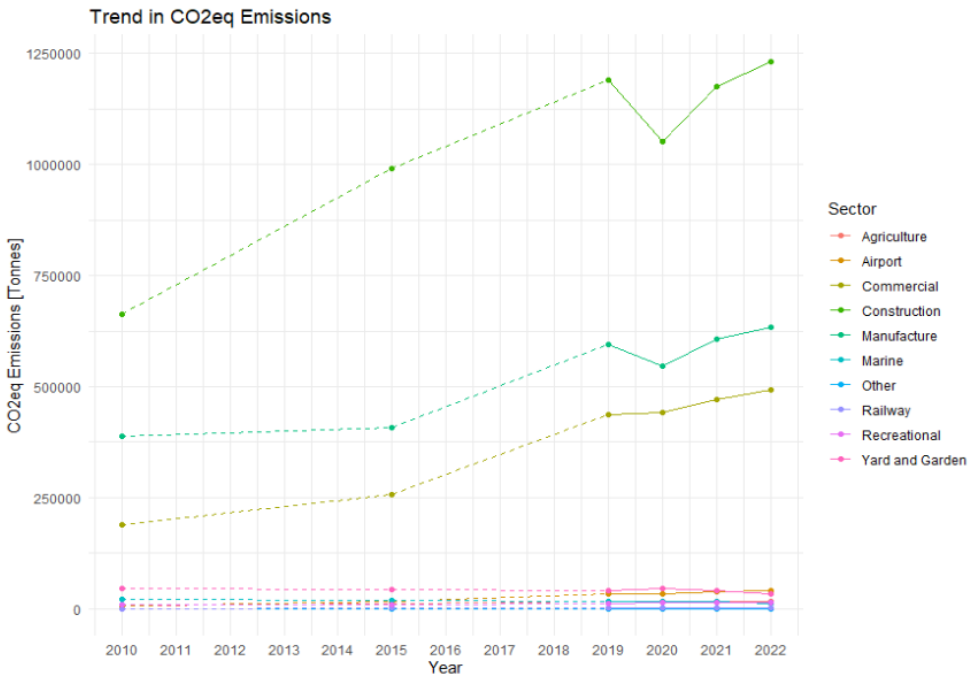

Figure 1 (a) Total CO2 equivalent emissions by each sector

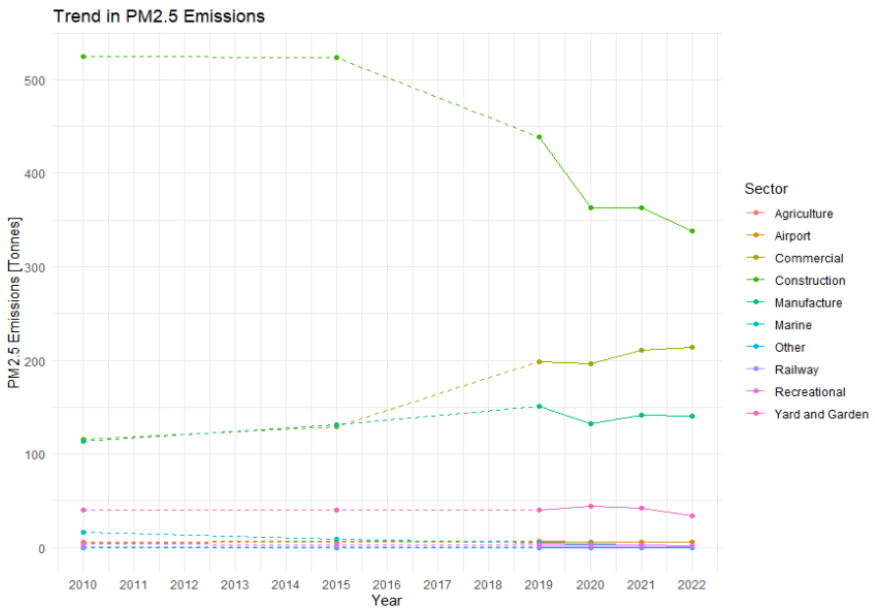

Figure 1 (b) Total PM 2.5 emissions by each sector

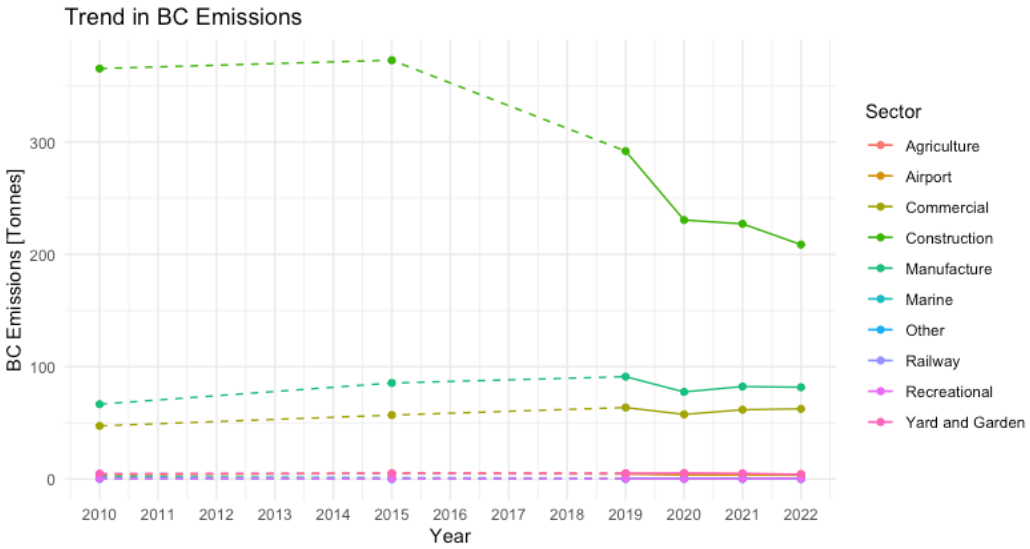

Figure 1 (c) Total black carbon emissions by each sector

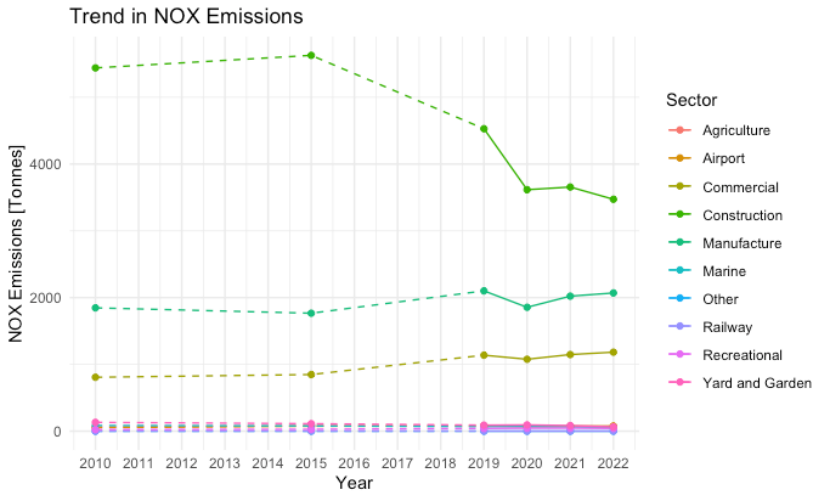

Figure 1 (d) Total NOX emissions by each sector

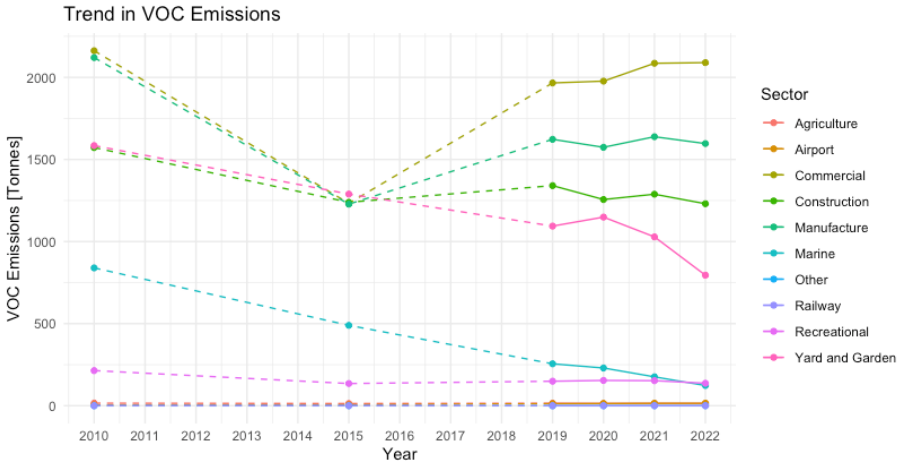

Figure 1 (e) Total VOC emissions by each sector

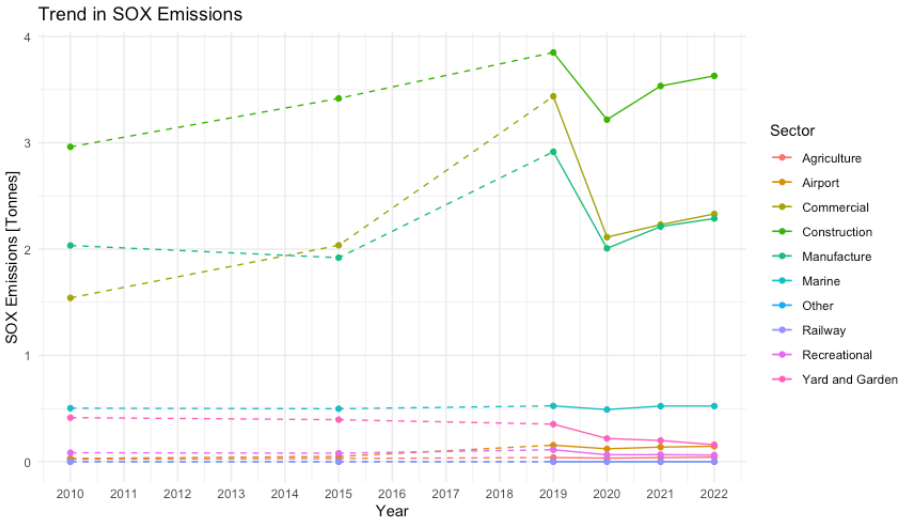

Figure 1 (f) Total SOX emissions by each sector

Figure 2 (a) to (f) present the tier distribution of sector-wise emissions for CO_2, PM2.5, NOX, BC, VOC, and SOX respectively. Figure 2 (a) and (f) show that majority of majority of CO_2 and SOX emissions respectively from construction and manufacture sectors can be attributed to Tier 4 engines. It also shows that CO_2 and SOX emissions from Tier 4 engines used in construction and manufacture is on an increasing trajectory. Whereas Figure 2 (b), (d), and (e) show that engines in tier 0, 1, 2, and 3 all significantly contribute towards PM2.5, BC, and VOC emissions. This highlights the types of engines that need to be better regulated in order to achieve individual emissions targets.

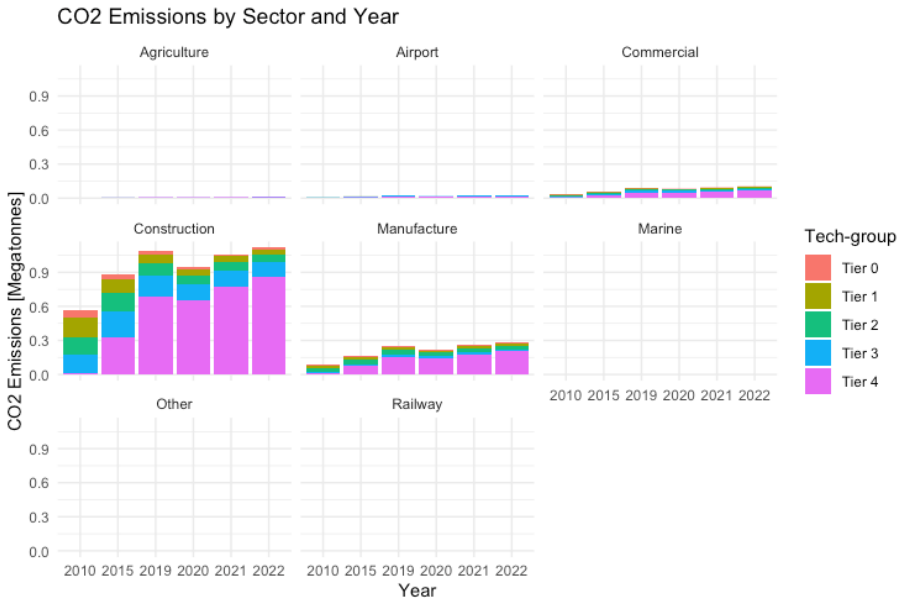

Figure 2 (a) Tier distribution for CO_2 emissions

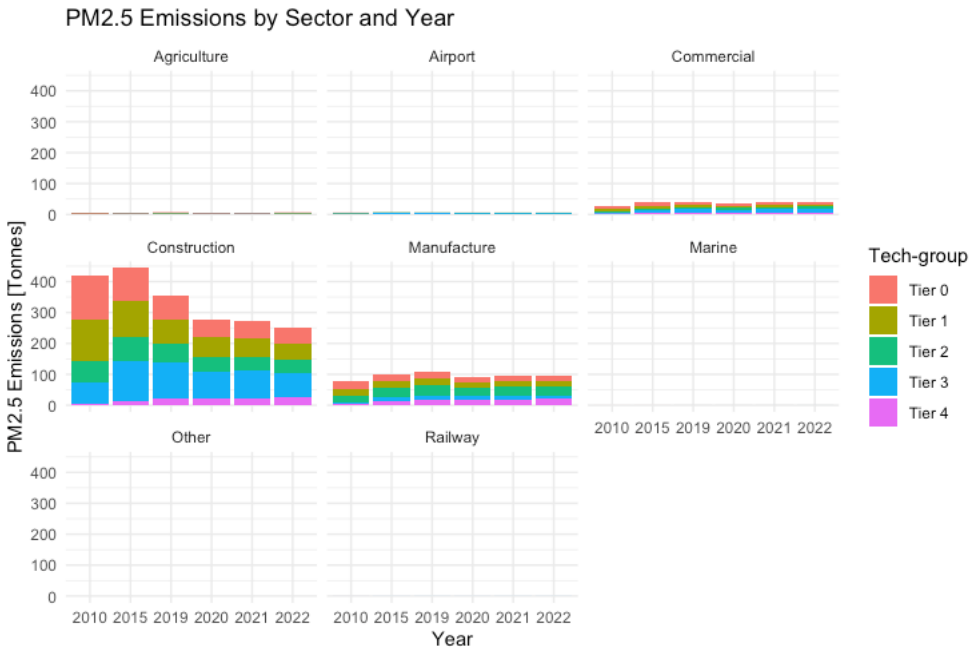

Figure 2 (b) Tier distribution for PM 2.5 emissions

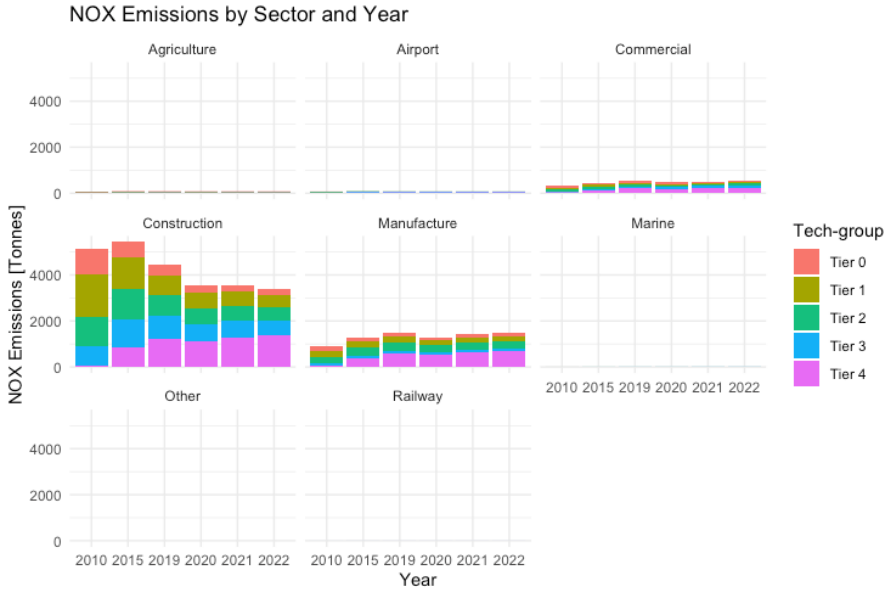

Figure 2 (c) Tier distribution for NOX emissions

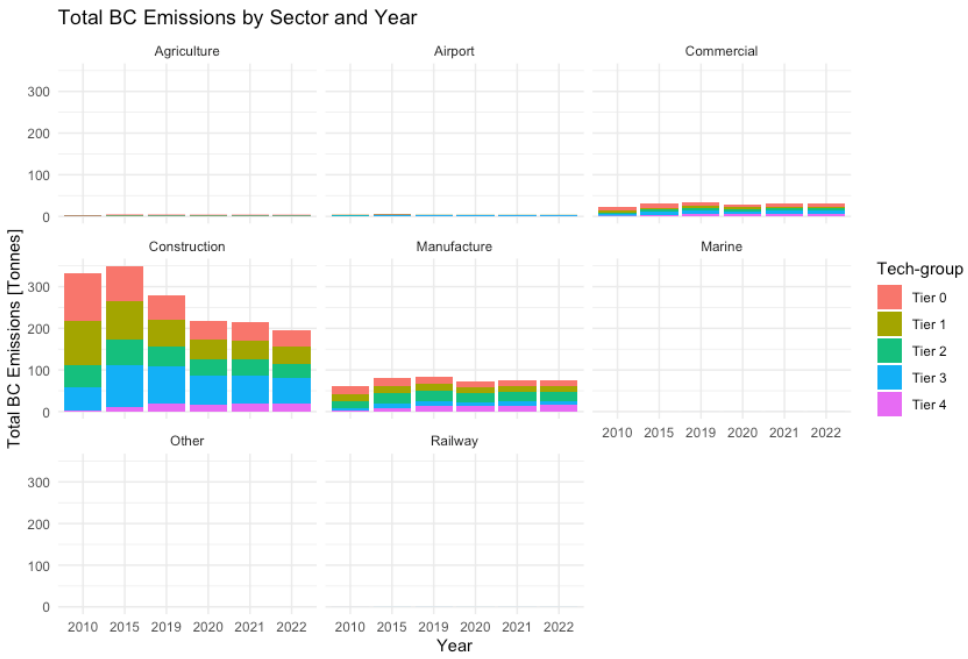

Figure 2 (d) Tier distribution for BC emissions

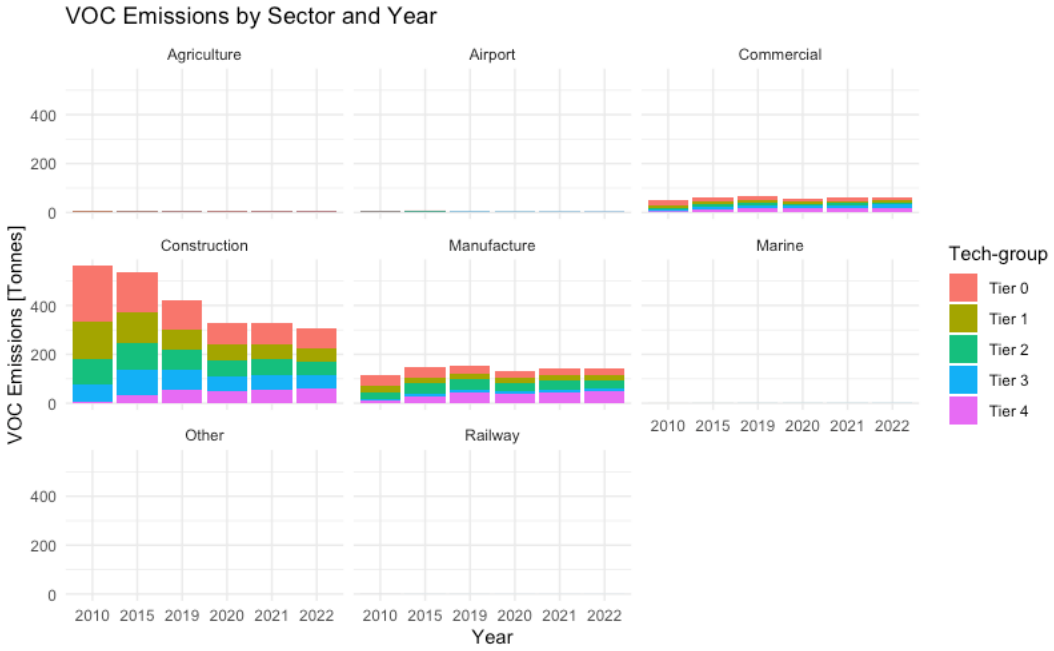

Figure 2 (e) Tier distribution for VOC emissions

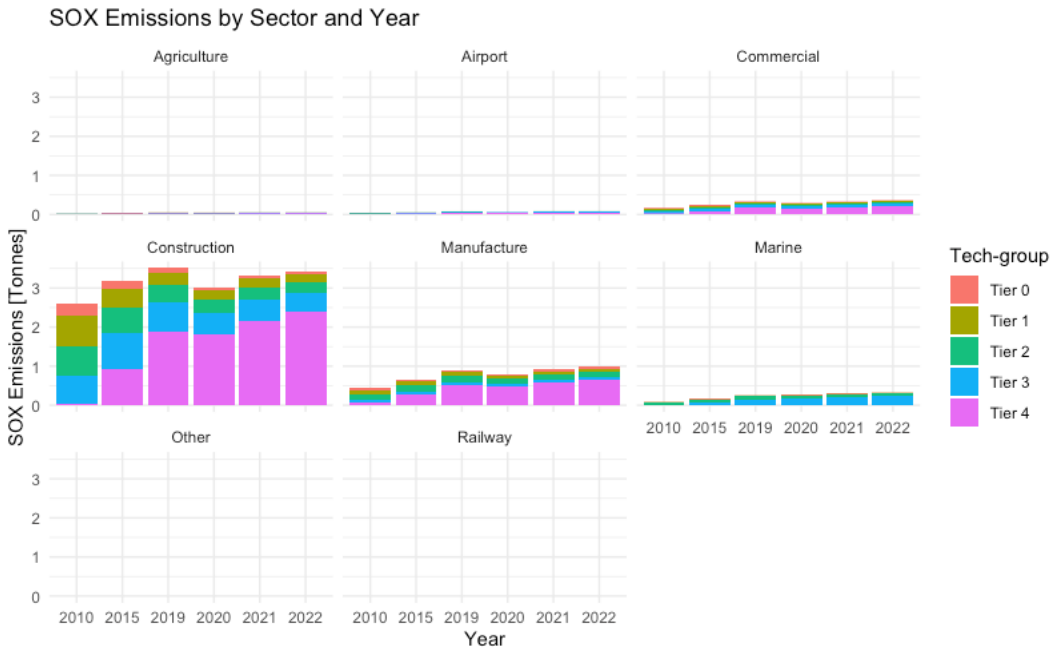

Figure 2 (f) Tier distribution for SOX emissions

Figures 3 (a) to (f) show change in emissions for each sector compared to 2010 baseline. We have chosen the year 2010 as baseline year as many Metro Vancouver emissions reduction targets are set compared to 2010. These graphs show us the emissions trend of each sector compared to 2010 for major pollutants, highlighting sectors that require more emissions reduction efforts and sectors that are seeing considerable improvements. Emissions from commercial sector for most pollutants, with the exception of VOCs, have been on a rise compared to 2010 levels. In Figure 3 (c) we see that NOX emissions from yard and garden have decreased by about 50% in 2022 compared to the 2010 baseline.

The sudden increase in CO_2 emissions from agriculture sector as seen in Figure 3 (a) could be due to change in reporting methods.

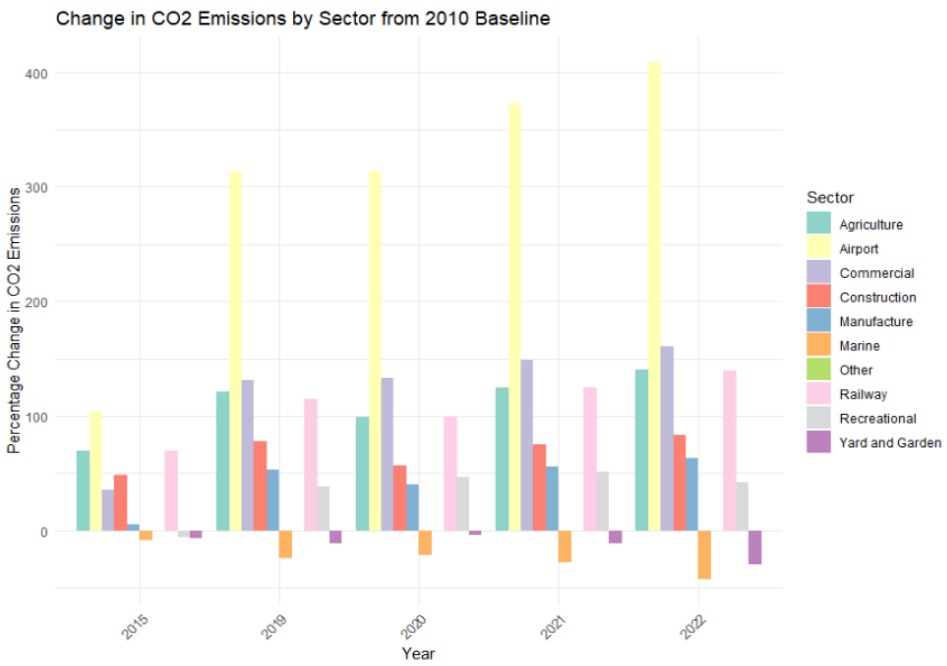

Figure 3 (a) Change in CO2 emissions for each sector compared to 2010 baseline

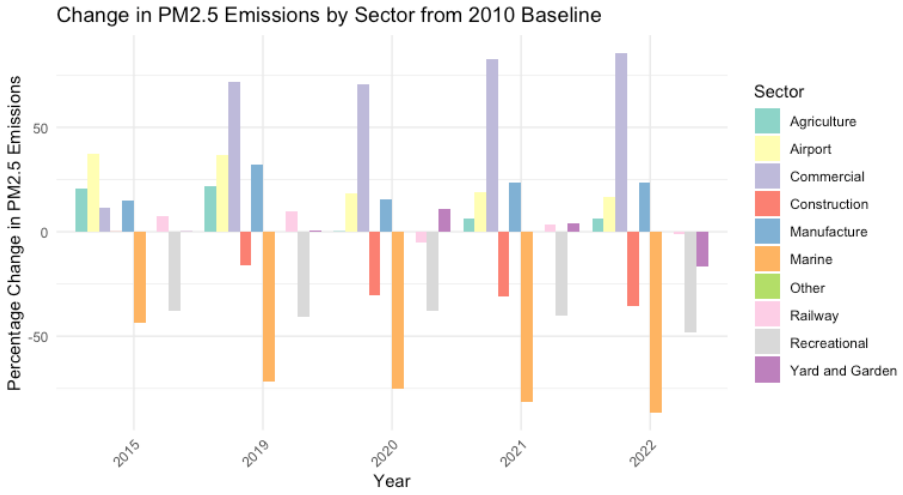

Figure 3 (b) Change in PM2.5 emissions for each sector compared to 2010 baseline

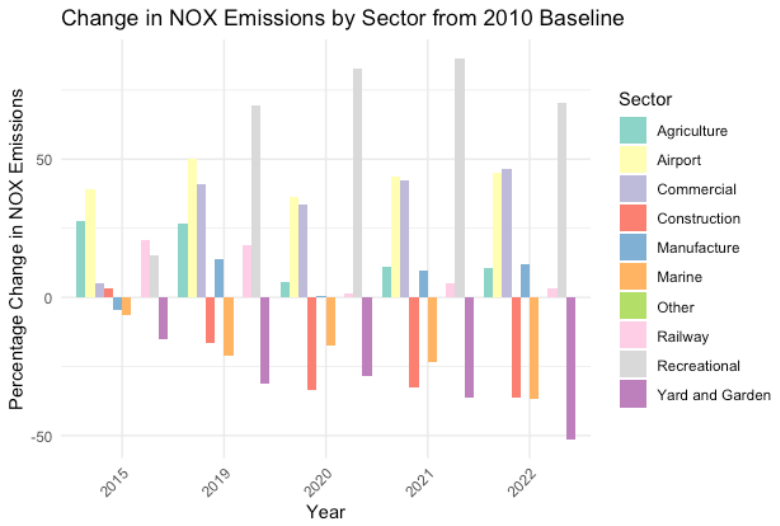

Figure 3 (c) Change in NOX emissions for each sector compared to 2010 baseline

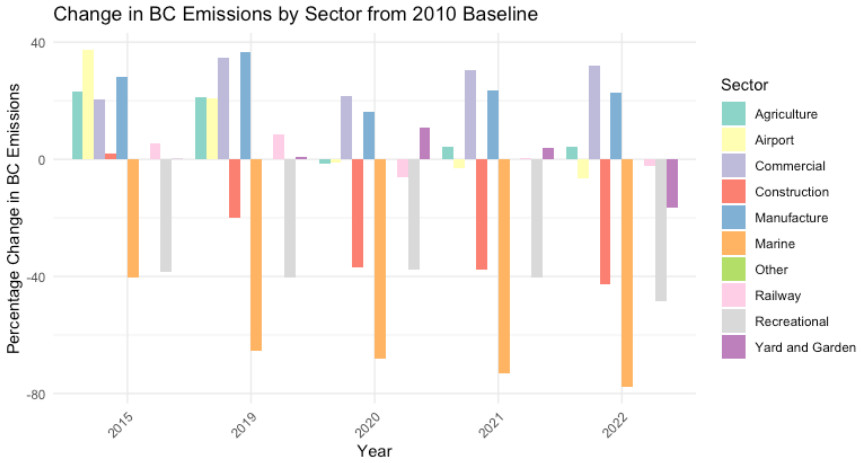

Figure 3 (d) Change in BC emissions for each sector compared to 2010 baseline

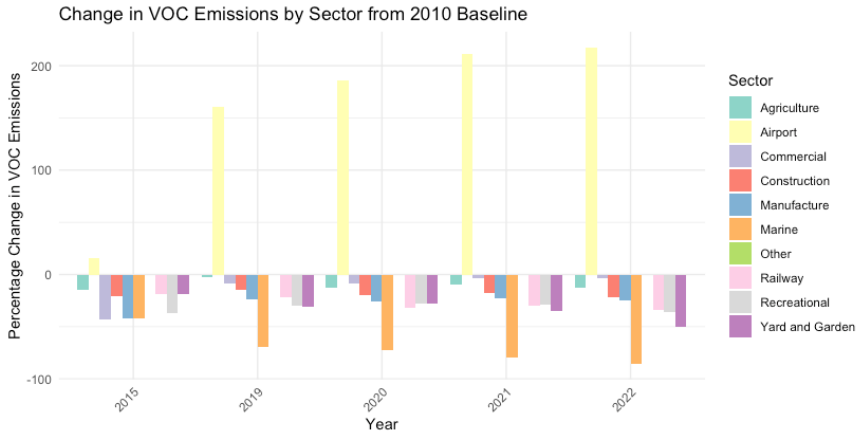

Figure 3 (e) Change in VOC emissions for each sector compared to 2010 baseline

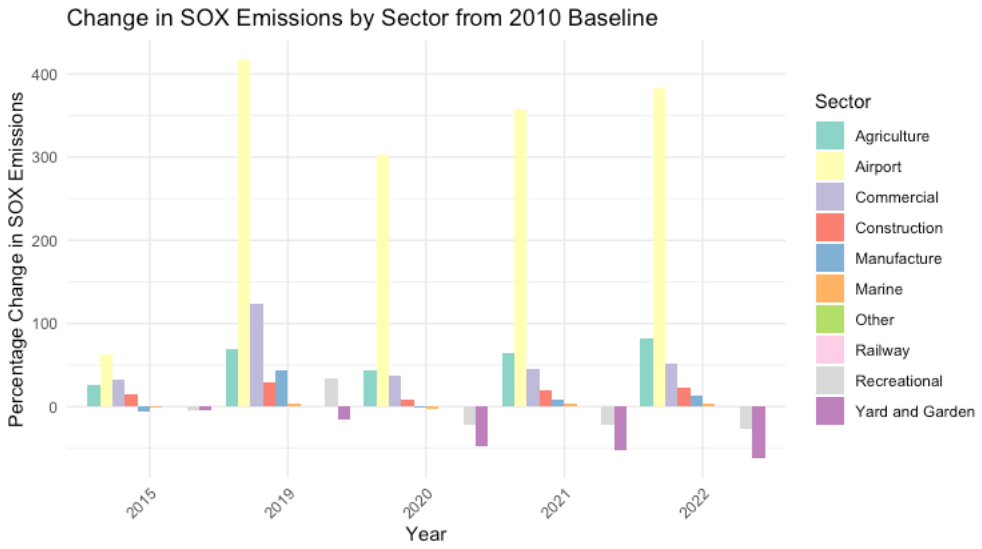

Figure 3 (f) Change in SOX emissions for each sector compared to 2010 baseline

4. Limitations of this methodology

There are two major limitations of this disaggregation methodology. Firstly, using surrogate ratios as shown in Table 1 to disaggregate data from national to provincial, and then further from provincial to regional scale can be oversimplistic. The equations in Table 1 do not account for a regions effort to adopt zero emission equipment or take measures to reduce GHG emissions in specific sectors. To do this, local economic, environmental policy, and political variables will need to be added to the surrogate ratios. Secondly, the top-down data used to generate this emissions inventory is susceptible to many errors caused by approximation and assumptions. The provincial emissions inventory provided by ECCC was disaggregated from the national NRE emissions inventory. The national emissions inventory was in turn compiled from a PSR database EnginLink^{TM}, that compiles worldwide engine production data through inquiry with engine manufacturers, suppliers, and industry reference sources. While this dataset is very comprehensive, the disaggregation methodology can provide a best estimate of the regional emissions. Coupling it with bottom-up data can help record more accurate population and emissions data on NREs in the Metro Vancouver region.

5. Recommendations for policymakers

- NREs are a heterogeneous class of engines. Regional governments and businesses need to tailor emission reduction strategies to the specific pollutant and sector concerned, as no one size fits all in the case of NREs.
- NREs used in construction are the highest emitting sector for all measured pollutants. Thus, efforts to reduce emissions from construction engines can have a significant positive impact on

regional emissions. This is followed by emissions from engines used in manufacture and commercial sectors.

- There is increasing need for good quality and reliable bottom-up data to support evidence-based policymaking. This emissions inventory is entirely top-down and thus prone to errors. Metro Vancouver's nonroad diesel engine regulatory program aims at mandating the registration of diesel nonroad engines operating in the region in a phased approach. Policymakers can similarly work with individuals and authorities, such as the port authority, landscaping businesses, construction companies, etc. to maintain a record and register the population of engines being used.