A Comparative Analysis of Particulate Matter ≤ 2.5μm Emissions Across Canadian Universities from 2012-2022

Avery Markle, Alliyah Borrowman, Ben Davies, and Olivia Fox

ENVS 3502

Professor Caroline Franklin

April 8, 2024

Table of Contents

Keywords: particulate matter, PM2.5, Canadian university, emissions, human health, environmental impacts, air quality standards

Abstract

Particulate matter <= 2.5 micrometers (PM2.5) has been linked to cause harm to human health (Health Canada, 2021) and the environment (CARB, 2024). Exposure to PM2.5 leads to various adverse health outcomes, including respiratory symptoms, decreased lung function, and premature mortality (Xing et al., 2016). Accumulation of PM2.5 in ecosystems effects water quality, visibility, and threatens plant growth (CARB, 2024). The purpose of this study is to analyze and compare PM2.5 emissions from select Canadian universities from 2012-2022. The question we aim to answer through our research is how Canadian universities release of particulate matter <= 2.5 micrometers change over the span of 10 years (2012-2022). Using data from the National Pollutant Release Inventory (NPRI), the research team performed statistical analyses using Excel and R Studio. Several universities, including Dalhousie University, Memorial University of Newfoundland, University of Saskatchewan, McGill University, and University of British Columbia, maintained relatively low emission levels from 2012-2022. Queen's University, Western University, and University of Calgary had stable but higher emission levels. Notably, the University of New Brunswick had PM2.5 emissions approximately 34 times higher than the other universities averaged over the study period. Statistical analysis showed significant differences in PM2.5 emissions between 2012 and 2022 for the University of New Brunswick, Laval University, University of Alberta, University of Toronto, and the University of Manitoba, with all five showing significant decreases. Rankings based on PM2.5 estimated marginal means placed the University of British Columbia with the lowest emissions and the University of New Brunswick with the highest emissions in both 2012 and 2022. Understanding PM2.5 emission sources and levels can aid in national air quality management standards and initiatives. Addressing PM2.5 emissions is crucial, given projected exacerbation due to climate change. Implementing mitigation strategies and establishing enforceable federal air quality standards are essential steps. Cleaner energy sources and increased awareness of the health and environmental impacts of PM2.5 can drive efforts to reduce emissions and improve air quality nationwide.

Introduction

Particulate matter is a mixture of solid particles and liquid droplets in the air and is classified based on size. Fine particulate matter is particulate matter that is 2.5 micrometers (PM2.5) or less. The average hair is about 70 micrometers in diameter, which is 30 times larger than PM2.5 (EPA, 2023). Major sources of PM2.5 include motor vehicles, power plants, industrial facilities, residential fireplaces, and wildfires.

PM2.5 has a high potential to cause harm to humans (Health Canada, 2021). Annually, air pollution contributes to over 15,000 deaths in Canada (Health Canada, 2021) and PM2.5 attributes 4 to 9 million deaths worldwide (Meng et al., 2019). There is a strong correlation between fine particle pollutants and respiratory morbidity and mortality (Xing et al., 2016). Studies conducted in Canada and the United States reveal that prolonged exposure to PM2.5 significantly escalates the risk of both cardiopulmonary issues and lung cancer mortality (Xing et al., 2016). Particularly vulnerable to particulate matter pollution are older adults, children, and individuals with existing heart or lung conditions (Kim et al., 2016). The adverse health effects of exposure to particulate matter include increased hospital admissions, emergency room visits, respiratory symptoms, exacerbation of chronic diseases, decreased lung function, and premature mortality, with potential additional outcomes such as low birth weight, pre-term deliveries, and fetal or infant deaths (Kim et al., 2016). Furthermore, particles can deeply infiltrate the lungs and settle on the alveoli, leading to many detrimental effects (Nelin et al., 2016). Moreover, these particles can permeate into both pulmonary and systemic circulations, directly impacting the heart and blood vessels, further compounding the health risks associated with fine particle pollution (Nelin et al., 2016).

In addition to human health effects, PM2.5 also impacts the environment (CARB, 2024). PM2.5 significantly affects ecosystems through its accumulation and uptake by soils, water, and plants (CARB, 2024). PM2.5 can impact water quality and clarity as well as decrease visibility in the air through its alteration of light interactions in the atmosphere (CARB, 2024). Additionally, the metal and organic compounds contained in PM2.5 pose a large threat to plant growth and yield. (CARB, 2024).

Numerous studies have been conducted on particulate matter and air pollution levels in cities across Canada. In 2013, the three top sectoral contributors to PM2.5 in Canada were wildfires, transportation, and residential combustion, such as residential fuel and wood combustion emissions (Meng et al, 2019). The contribution of different sectoral emissions varies across Canada, as well as seasonally. Annual concentrations have been shown to be significantly higher in Canada's larger cities, including Toronto, Vancouver, Hamilton, and Quebec City, compared to more rural areas (The University of British Columbia, 2022). Particulate matter concentrations in larger cities have ranged from 8 to 16 µg/m3 and 2 to 6 µg/m3 in rural areas (The University of British Columbia, 2022). In 2012, the Canadian Ambient Air Quality Standards (CAAQS) adopted new concentration targets for 2015, 2020, and 2025 to reduce various air pollutants. Currently, the 2020 standards suggest the average fine particulate matter concentrations fall below 8.8 µg/m3 (The University of British Columbia, 2022).

In Western Canada, wildfires and agriculture are the largest contributors to PM2.5 levels (Meng et al., 2019). The smoke generated from wildfires can significantly degrade air quality, even in urban areas far away from fires. Residential wood burning is a contributing factor of PM2.5 concentrations in British Columbia, as 30% of homes outside of Vancouver burn wood in a fireplace or other wood burning appliance (Mustel Group Market Research, 2012). In Alberta, the primary contributor to PM2.5 pollution is secondary aerosols, which stem from the province's large oil and gas extractions (Bari & Kindzierski, 2018). Similarly, wildfires are the leading contributor of PM2.5 in Northern Canada (Meng et al., 2019).

In Atlantic Canada, wildfires and secondary organic aerosol are top contributors of PM2.5 concentrations (Meng et al, 2019). The University of New Brunswick (UNB) and its subsequent Fredericton Campus, generate energy in a unique manner. The Central Heating Plant (CHP) at UNB possesses a distinctive fuel combination, allowing for the combustion of three different fuels: Biomass, Natural Gas, and #6 fuel oil (UNB, 2024). Currently, their Central Heating Plant burns 35-60% biomass (UNB, 2024).

In Central Canada, residential combustion and transportation are the leading contributors (Meng et al., 2019). In Southern Ontario, previous studies have identified particulate matter originating from the United States due to southerly and southwesterly winds (Liu & Cui, 2014). Canada's seasonal changes are influential in PM2.5 concentrations. In 2006, PM2.5 concentrations in

Southern Ontario were 30 to 40% higher in the summer than in the winter, due to the airflow trajectories and transport of pollutants from the United States (Liu & Cui, 2014). The sources of PM2.5 concentrations also differ seasonally across Canada. In winter, residential combustion is a predominant contributor due to home heating, while in summer, wildfires are a leading contributor (Meng et al., 2019). Understanding the specific sources of PM2.5 can aid in national air quality management and the connection to health outcomes.

Air pollution from emissions have decreased significantly over the past decades (Government of Canada, 2023a). Data from 1990 to 2021 demonstrate a general decline in pollutant emissions, such as sulfur oxides, nitrogen oxides, and volatile organic compounds, but an increase in fine particulate matter (Government of Canada, 2023a). While significant progress has been made in reducing air pollution, PM2.5 concentrations and air quality remains an issue in areas across Canada.

Analyzing past studies on particulate matter can help stakeholders identify different emission sources and explore air quality management initiatives to help reduce emissions. Despite the immense research on particulate matter in major cities, there is a gap in the literature on particulate matter concentrations among university campuses. Many Canadian universities house a large population of students, faculty, and staff, which highlights the importance of air quality management on campuses. Understanding the health and environmental effects of PM2.5 emphasizes the need for air quality standards. Identifying emission sources and analyzing data on PM2.5 emissions can help governments, policy makers, and institutions explore mitigation strategies to reduce their PM2.5 emissions and foster healthier environments for residents across Canada. By examining the amount of PM2.5 released from select universities over a 10-year period this study will help fill a gap in the literature regarding PM2.5 emissions across Canadian universities.

The high potential for PM2.5 to cause harm to humans and the environment highlights the importance of this study. The question we aim to answer through our research is how Canadian universities release of particulate matter <= 2.5 micrometers change over the span of 10 years (2012-2022).

Methods

Data Collection

For this study, we used secondary data from the National Pollutant Release Inventory (NPRI). The NPRI is a public inventory of releases, disposals, and transfers of pollutants in over 7,000 facilities across Canada (Government of Canada, 2023). The data are reported yearly, mandated by the Canadian Environmental Protection Act (Government of Canada 2023b). According to Darrell Boutilier the Director of Operations at Dalhousie University's Studley campus facility, a third-party consultant that specializes in plant air emissions is hired to calculate the emissions to be reported to the NPRI database. These calculations are derived from the fuel type and yearly consumption at each facility, with the consultant considering any emission control measures implemented at the facility. Numerous universities across Canada have reporting facilities and are mandated to report because they fall under these criteria: (1) a minimum of 10 full-time employees that work over 20,000 hours per year, (2) specified activities take place at the facility (e.g., wastewater treatment, fuel combustion, etc.), and (3) they are above the reporting limit for NPRI substances.

We strived to include all Canadian U15 universities with at least one campus representing each province and territory in Canada. We included 12 of the U15 universities and incorporated schools from Newfoundland and New Brunswick. Despite being members of the U15, the University of Montreal, University of Ottawa, and University of Waterloo are not included in our analysis as they do not have a facility or data in the NPRI database. Additionally, Prince Edward Island, the Northwest Territories, Nunavut, and Yukon did not have a university campus with NPRI data on PM2.5 emissions, therefore they were not included in our study. In total, we analyzed 14 universities across Canada: Dalhousie University, University of British Columbia (UBC), University of Alberta, University of Calgary, University of Manitoba, University of Saskatchewan, Western University, University of Toronto, Queen's University, McMaster University, McGill University, Laval University, Memorial University of Newfoundland, and University of New Brunswick (UNB) in our analysis. Our objective is to analyze and compare PM2.5 emissions from universities across Canada from 2012-2022.

Data Analysis

The data was downloaded from the NPRI database and opened in Excel (Appendix A1). Using Excel, initial graphs were created to display the trends in the PM2.5 emissions for each university from 2012-2022. In the initial graphs we discovered that UNB was an outlier and therefore the statistical tests were done a second time with UNB removed to improve the results. Excel was also used to calculate the mean and median releases of each university over the time frame.

A csv file was created containing university identifiers, year, and PM2.5 emissions (tonnes) and exported to R Studio. R Studio was used to perform a variety of statistical tests. A Two-Way ANOVA test was run and showed that assumptions of normality and homoscedasticity were not met. Therefore, we logged the PM2.5 emissions to improve normality and performed the Two-Way ANOVA tests, one with and one without UNB. We then conducted a post-hoc analysis using the 'emmeans' package in R studio. This package allowed us to perform pairwise comparisons of the estimated marginal means (EMM) of the PM2.5 emissions for 2012 and 2022 for each school based on the Two-Way ANOVA performed using a linear regression model. Using the results from the post-hocs we created various graphs in Excel and maps in ArcGIS to display the changes from 2012-2022 for the universities. We then established a ranking system based on the EMM of the total amount of PM2.5 emissions released from each university from 2012 and 2022, in which #1 released the lowest amount of PM2.5 emissions and #14 released the highest amount of PM2.5 emissions. This allowed us to see if there was a change in the highest or lowest PM2.5 emitters in the time span. The differences between the EMMs (Estimated Marginal Means) in 2012 and in 2022 were calculated and graphed in Excel, with significant changes indicated.

Limitations

The NPRI presented a few limitations in providing concrete conclusions for this study. Missing data was the largest limitation. Data was not reported for the Western University or the University of British Columbia from 2012 to 2014. It was also not specified why that data was missing. It also limited the schools we were able to include as they had to have data on PM2.5 emissions in the NPRI database. We were also limited by our previous knowledge. Conducted over a four-month period at Dalhousie University, this report lacked in-depth understanding of the various statistical tests available for analysis, as we did not have adequate time to explore and learn the intricacies of every potential test.

Results

There was variation in the trends of the PM2.5 emissions, in which some universities remained relatively stable from 2012-2022 and some fluctuated throughout. Notably, the University of New Brunswick (UNB) had PM2.5 emissions approximately 34 times higher than the other universities averaged over the study period (Figure 1). At their highest, UNB experienced a slight decline from 2012 to 2014, then began to increase again until 2017, and hit a steep decline from 2019 to 2022. However, even with the decline, UNB's PM2.5 emissions levels at their lowest in 2022 (7.08 tonnes) were still roughly 3 times higher than the next highest school for that year (Laval University at 2.3 tonnes). UNB's emissions accounted for roughly 42% of emissions released in 2022 from all universities (17.01 tonnes total).

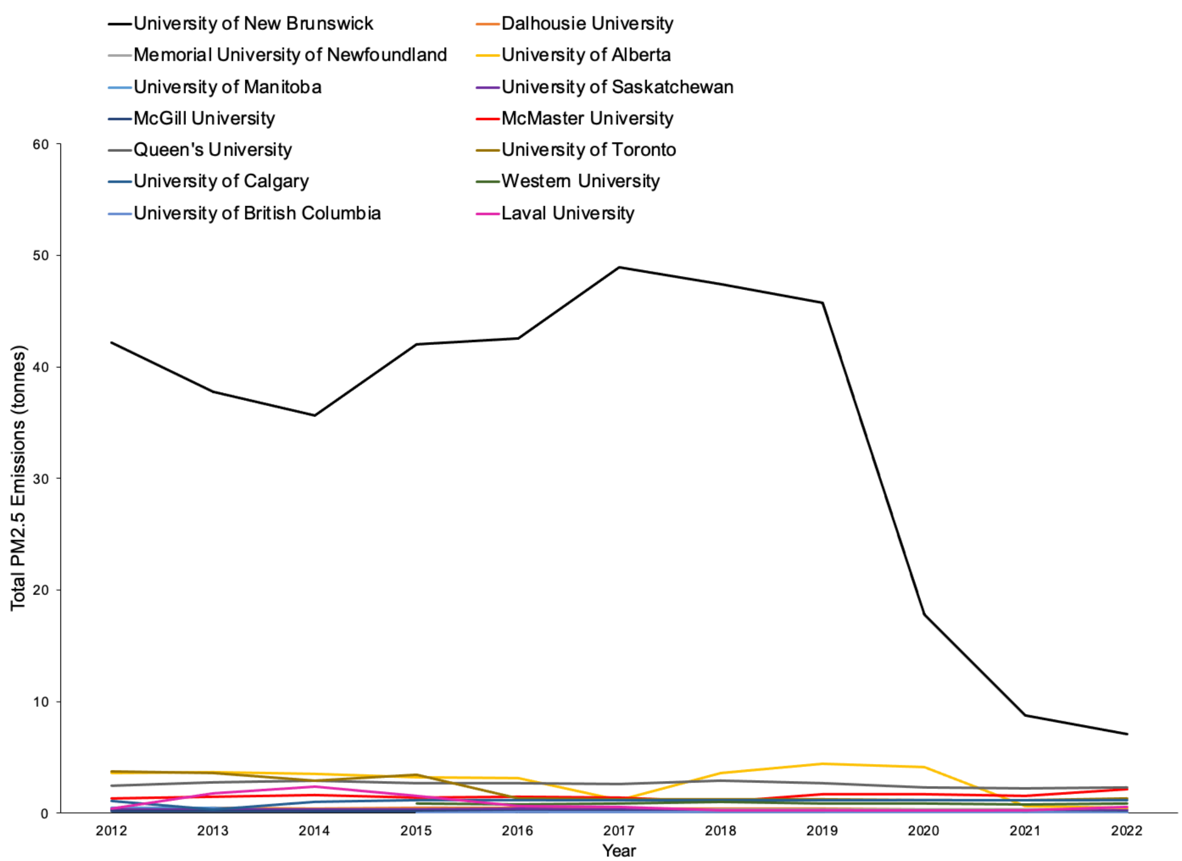

Figure 1 Total contributions of PM2.5 (tonnes) for each of the selected universities from 2012 to 2022.

Observing the trends of the PM2.5 emissions from 2012 to 2022 for all universities except UNB showed that Dalhousie University, the Memorial University of Newfoundland, the University of Saskatchewan, McGill University, and UBC all had relatively steady and low emission releases (Figure 2). Queen's University, Western University, and the University of Calgary remained stable however, they had a higher level of emissions. The University of Alberta had a lot of variation over the time period, with a sharp decrease from 2020 to 2021 (Figure 2). McMaster University saw a slight increase in 2022 from the relatively steady level it sustained from 2019 to 2021. The University of Toronto had variation from 2012 to 2015, however it declined in 2016 and remained stable until 2022.

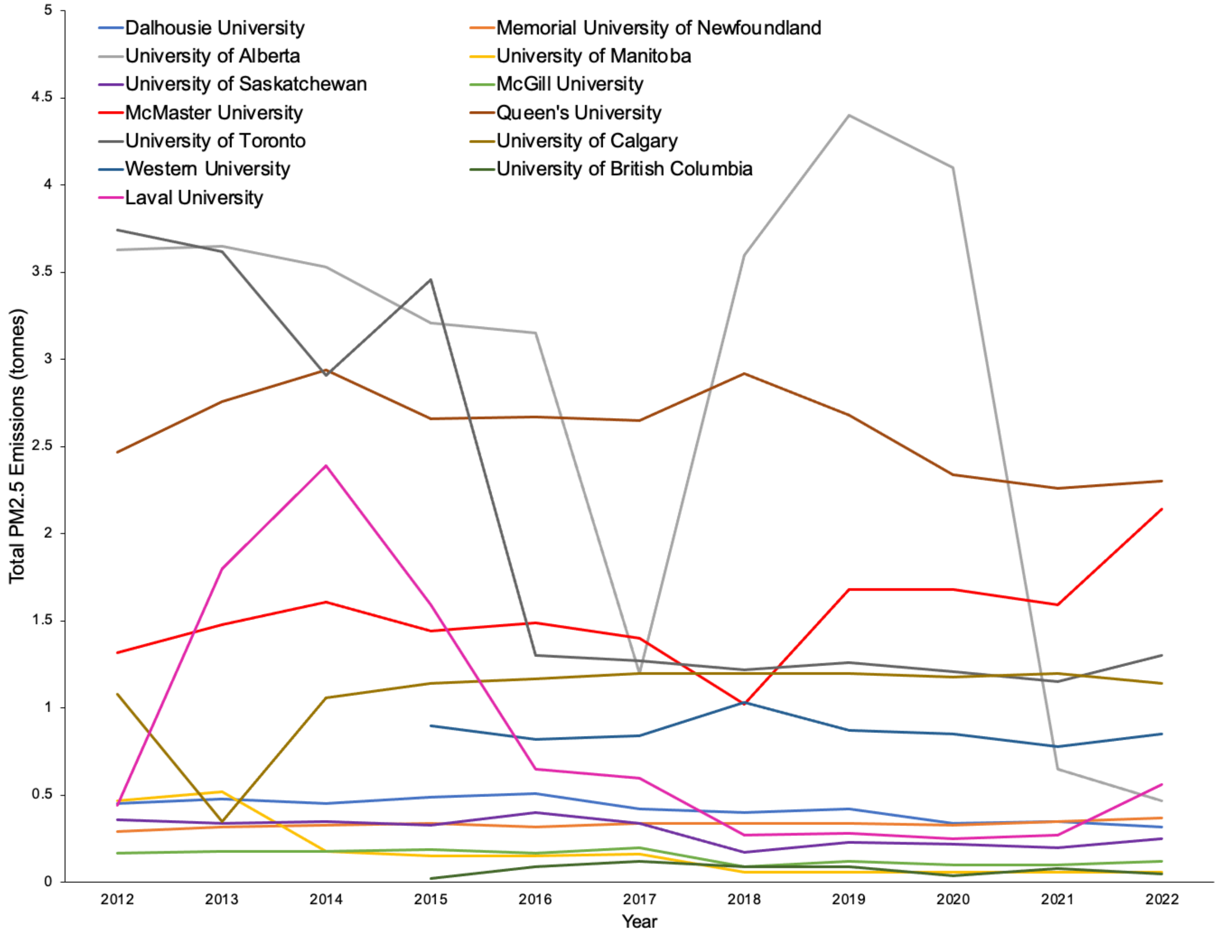

Figure 2 Total contributions of PM2.5 (tonnes) for each of the selected universities, excluding the University of New Brunswick, from 2012 to 2022.

To determine how much each university was emitting more generally, we calculated the mean and median for each of the selected universities from 2012 to 2022, or 2015 to 2022 for UBC and Western University (Table 1). UNB had the highest mean (34.2 tonnes) and UBC had the lowest mean (0.07 tonnes). Similarly, UNB has the highest median (42.0 tonnes) and UBC has the lowest median (0.085 tonnes).

Table 1 The mean and median PM2.5 emissions (tonnes) of the selected universities averaged over 2012 (or 2015) to 2022.

University	Mean	Median
Dalhousie University	0.42	0.42
Memorial University of Newfoundland	0.33	0.34
University of New Brunswick	34.17	42.03
University of Manitoba	0.18	0.15
University of Saskatchewan	0.29	0.33
McGill University	0.15	0.17
University of Toronto	2.04	1.30
University of British Columbia	0.07	0.09
University of Calgary	1.08	1.17
Western University	0.87	0.85
Queens University	2.60	2.66
McMaster University	1.53	1.49
University of Alberta	2.87	3.53
Laval University	0.83	0.56

We logged the PM2.5 emissions to have a more normal distribution and then ran a Two-Way ANOVA on all universities and found that there was a significant difference between the PM2.5 emissions depending on the year, a significant difference between the PM2.5 emissions depending on the university, and an interaction between the year and the university (Table 2). We then ran another Two-Way ANOVA without UNB which yielded the same significance results (Table 3).

Table 2 Results from Two-Way ANOVA test performed in R.

	Degree of Freedom	Sum of Squares	Mean Square	F-value	P-value	Significant at alpha=0.001
Year	1	11.27	11.2678	80.1863	<0.0001	Yes
University	13	325.14	25.0106	177.9853	<0.0001	Yes
Interaction	13	9.76	0.7510	5.3442	<0.0001	Yes
Residuals	120	16.86	0.1405	-	-	-

Table 3 Results from the logged Two-Way ANOVA test performed in R without the University of New Brunswick.

	Degree of Freedom	Sum of Squares	Mean Square	F-value	P-value	Significant at alpha=0.001
Year	1	8.096	8.0964	62.2545	<0.0001	Yes
University	12	169.143	14.0952	108.3808	<0.0001	Yes
Interaction	12	8.994	0.7495	5.7631	<0.0001	Yes
Residuals	111	14.436	0.1301	-	-	-

Since the results of the Two-Way ANOVA's indicated that there was a significant interaction between year and university, we decided to compare the PM2.5 emissions for the first year we examine (2012 or 2015) to those of 2022 for each university using a post-hoc test. The University of British Columbia and Western University only contain data from 2015 to 2022 so their comparison was done using 2015 instead of 2012. The post-hoc comparison allowed us to perform pairwise comparisons of the estimated marginal means (EMM) of the PM2.5 emissions for each school based on the Two-Way ANOVA performed using a linear regression model. The pairwise comparisons for UNB were done using the Two-Way ANOVA performed with all data. The Two-Way ANOVA without UNB included was used for all other universities to improve the accuracy of the results for the other schools. The results of the pairwise comparisons between the EMM for 2012 (or 2015) and 2022 for each university show which universities had a significant change (table 4). The tests were performed on the log scale. The results show that at an alpha=0.05 there was a significant difference between the total PM2.5 emissions from 2012 (or 2015) to 2022 for UNB, University of Toronto, University of Manitoba, University of Alberta, and Laval University.

Table 4 The output of the pairwise comparison between the EMM for 2012 (or 2015) and 2022 for each university (alpha=0.05). The tests were performed on the log scale.

University	Ratio	SE	df	P-value	Significant at alpha=0.05
The University of New Brunswick	4.52	1.61	120	<0.0001	Yes
Dalhousie University	1.49	0.511	111	0.2515	No
Queen's University	1.17	0.403	111	0.6471	No
University of British Columbia	0.81	0.315	111	0.5895	No
University of Saskachewan	1.88	0.645	111	0.0701	No
Western University	1.07	0.416	111	0.8672	No
University of Toronto	3.77	1.3	111	0.0002	Yes
University of Manitoba	9.68	3.33	111	<0.0001	Yes
University of Calgary	0.598	0.206	111	0.1392	No
University of Alberta	4.25	1.46	111	0.0001	Yes
Memorial University of Newfoundland	0.862	0.296	111	0.666	No
McMaster University	0.778	0.268	111	0.4672	No
McGill University	1.96	0.674	111	0.0526	No
Laval University	4.91	1.69	111	<0.0001	Yes

Using the back-transformed data from the post-hoc (Appendix B3), we graphed the EMM (+SE) of the PM2.5 emissions for the first year and last year of each university in the database except UNB (Figure 3). UNB was not included in the graph as it would make it more difficult to examine the trends of the universities. The University of Toronto and the University of Alberta both started off with the highest EMMs in 2012 and then decline significantly to no longer be the highest emitters. Queen's University was the third highest emitter in 2012 and was the highest in 2022 as it did not decline significantly.

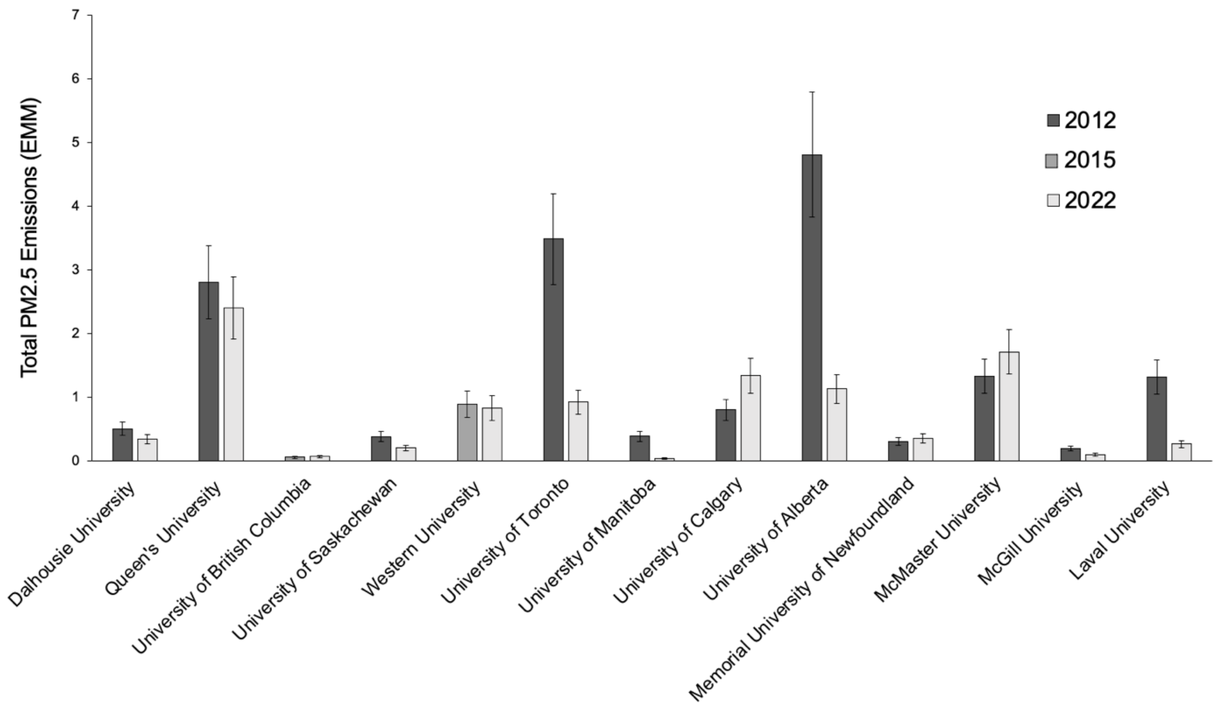

Figure 3 The EMMs (+SE) of the total PM2.5 emissions for 2012 (or 2015) and 2022 for all universities except the University of New Brunswick.

Using the data from the post-hoc (Appendix B3), we graphed the EMM (+SE) of the PM2.5 emissions for the first year and last year of UNB separately (Figure 4). UNB had a significant decline.

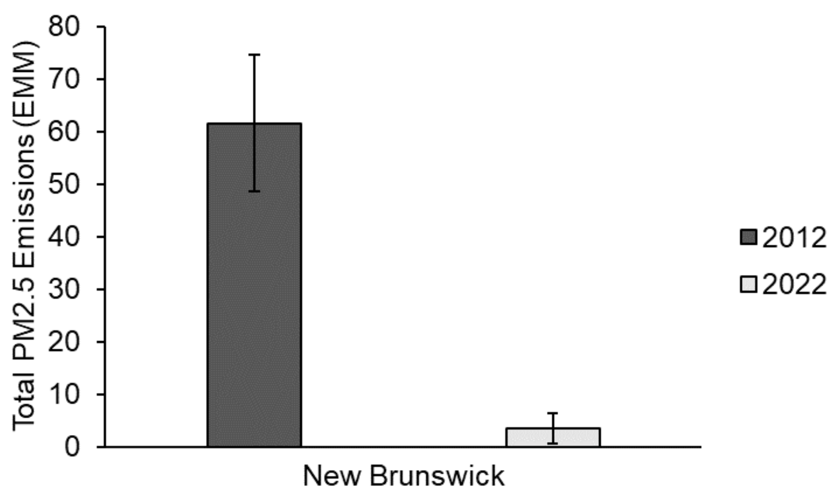

Figure 4 The EMMs (+SE) of the total PM2.5 emissions for 2012 and 2022 for the University of New Brunswick.

Using ArcGIS, we mapped all the universities represented by points increasing in size to indicate the EMM of PM2.5 emissions for both 2012 and 2022 (Appendix B3) (Figure 5). This map shows the University of New Brunswick's significant decline that brings it to a closer level to the other universities by 2022.

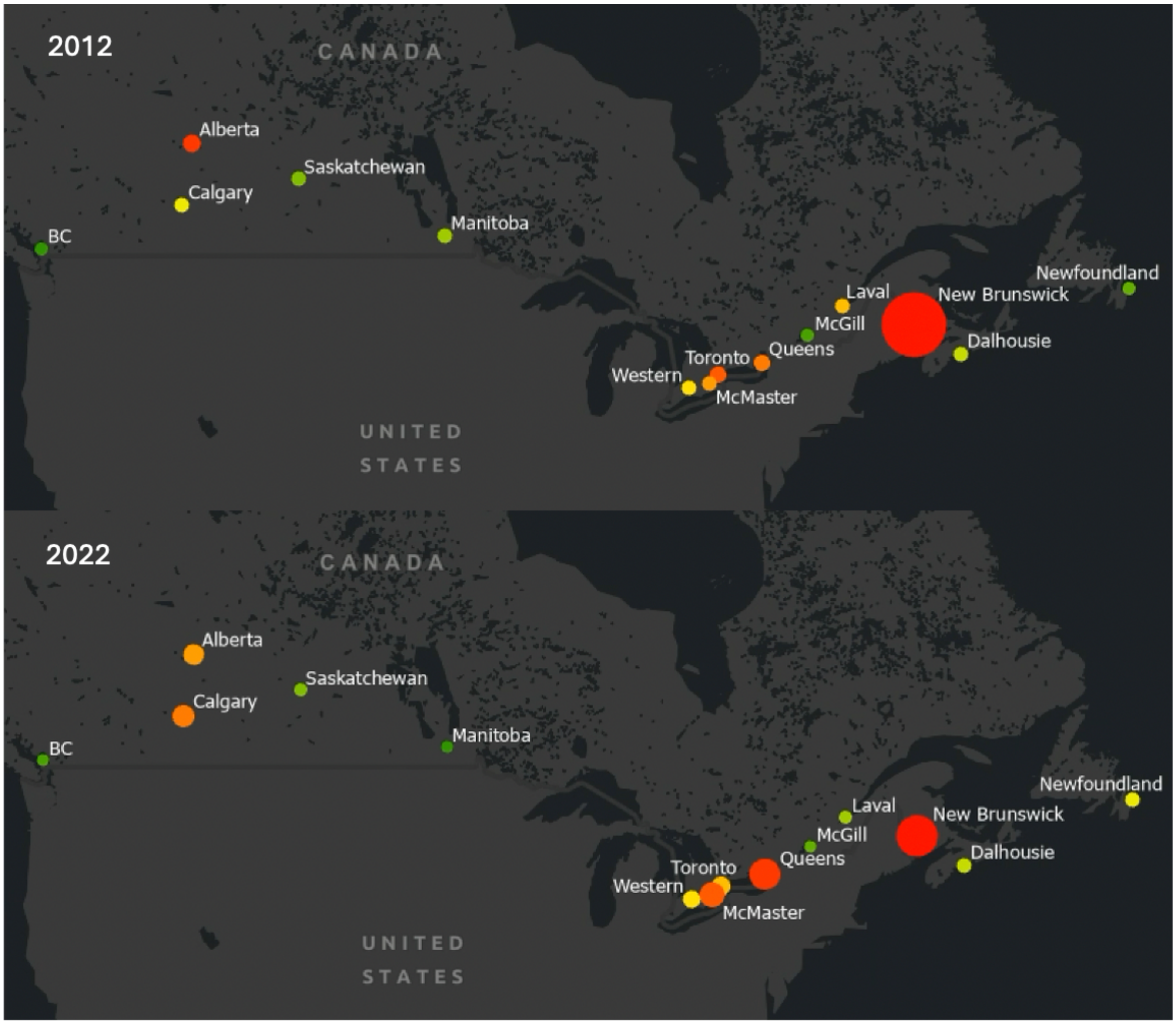

Figure 5 Map created using ArcGIS Pro showing the locations of the universities being studied, with increasing size relating to the EMMs for 2012 and 2022.

We created a ranking system in which the EMMs of each university in 2012 (or 2015) and in 2022 was compared and the lowest value was ranked #1 and the highest value was ranked #14 (Table 5). UBC ranked number 1 in lowest average of PM2.5 emissions, with an EMM value of 0.06 tonnes in 2015, and 0.07 tonnes in 2022. UNB ranked last as it had the highest EMMs in both 2012 (61.5 tonnes) and 2022 (3.6 tonnes).

Table 5 Ranking the total PM2.5 emissions based on the EMMeans in 2012 (2015 for UBC and Western University) and comparing it to the total PM2.5 emissions based on the EMMeans in 2022.

	2012 / 2015		2022	
University	EMMeans	Rank	EMMeans	Rank
University of British Columbia	0.0576	1	0.0711	2
McGill University	0.198	2	0.101	3
Memorial University of Newfoundland	0.309	3	0.359	7
University of Saskatchewan	0.383	4	0.204	4
University of Manitoba	0.391	5	0.0404	1
Dalhousie University	0.508	6	0.342	6
University of Calgary	0.802	7	1.341	11
Western University	0.894	8	0.837	8
Laval University	1.32	9	0.269	5
McMaster University	1.33	10	1.71	12
Queen's University	2.81	11	2.4	13
University of Toronto	3.485	12	0.925	9
University of Alberta	4.81	13	1.13	10
University of New Brunswick	61.5	14	3.6	14

We then graphed the difference between the EMMs of the total PM2.5 emissions between 2012 (or 2015) and 2022 for all universities except UNB (Figure 6). The stars indicate the significance in the change for University of Toronto, University of Manitoba, University of Alberta, and Laval University. The PM2.5 emissions decreased for most of the universities, however there was an increase for UBC, the University of Calgary, the Memorial University of Newfoundland, and McMaster University. The increase for UBC was small, but the University of Calgary had a more notable increase. None of the universities increased significantly.

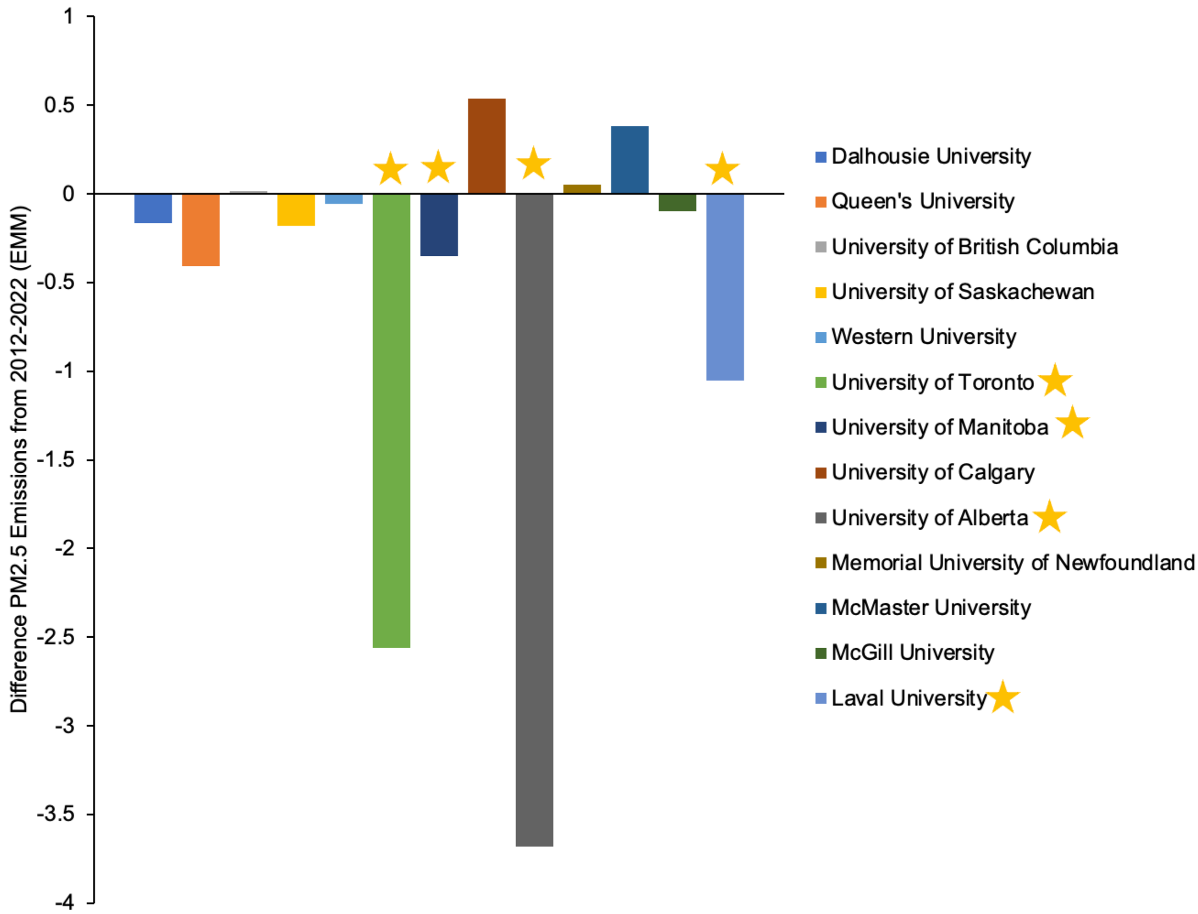

Figure 6 The difference between the EMMs of the total PM2.5 emissions for 2012 (or 2015) and 2022 for all universities except the University of New Brunswick. The stars indicate significance.

Discussion

This study examined PM2.5 emissions from chosen universities, comparing emissions within each institution from 2012 to 2022. UNB consistently exhibited substantially higher PM2.5 emissions compared to other universities throughout the study period, with its emissions remaining considerably elevated even at their lowest point in 2022. Several universities, such as Dalhousie University, Memorial University of Newfoundland, University of Saskatchewan, McGill University, and UBC, maintained relatively steady and low emission levels throughout the study period. Queen's University, Western University, and University of Calgary had stable but higher emission levels. Statistical analysis, including Two-way ANOVA tests and post-hoc comparisons, revealed significant declines in PM2.5 emissions between 2012 and 2022 for the UNB, Laval University, the University of Alberta, the University of Toronto, and the University of Manitoba. We then ranked the universities based on their estimated marginal means of PM2.5 emissions in 2012 and 2022, with UBC (beginning in 2015) having the lowest emissions and UNB having the highest total emissions in both 2012 and 2022. Overall, highlighting the differences in PM2.5 emissions among Canadian universities as well as year.

PM2.5 emissions at UNB were 34 times higher than the combined average of all other schools over the 10-year period (table 1). A possible explanation for the significant difference of New Brunswick is the province's source of energy generation. The Central Heating Plant (CHP) at the University of New Brunswick utilizes a distinctive fuel combination, allowing the institution to utilize three types of fuel: biomass, natural gas, and #6 fuel oil (Bunker C) (UNB, 2024). Presently, the CHP primarily relies on biomass, constituting 35-60% of its fuel mix, thereby leveraging a sustainable and renewable energy source (UNB, 2024). It is important to note that biomass' status as a renewable resource is highly controversial and may be overturned in the coming years. Beyond the burning of biomass, which significantly increases PM2.5 emissions, the burning of Bunker C; a very dirty fuel used by marine vessels, has been banned in Antarctica, and Canada supported the ban of its use in 2024 (Weber, 2020).

Dalhousie University ranked sixth in comparison to the other selected universities in both 2012 and 2022 (table 5). Dalhousie had a consistently low mean over the 10-year timespan (figure 2). Dalhousie University has a history of using "dirty" energy sources, which makes its higher ranking unexpected. Prior to 2012, Dalhousie's Studley campus was heated by Bunker C fuel, then the university made a switch to Bunker A fuel in 2012 and 2013, then subsequently changed to Bunker B in 2014 up until 2021, where furnace oil was then instituted (Dalhousie University, 2023). Interestingly, Dalhousie University did not experience significant emissions increases or reductions from 2012 through 2022 even though they were using various bunker fuels that UNB also utilized. This leads us to assume that New Brunswick's extremely high emissions are not fully due to Bunker C, but instead due to their incessant biomass burning.

With exceptions of the Memorial University of Newfoundland, McMaster University, University of Calgary, and UBC, PM2.5 emissions decreased over the 10-year period, from 2012 to 2022. The greatest decreases in PM2.5 emissions were seen by the University of Alberta, University of Toronto, and University of Manitoba. The University of Alberta's emissions decreased in 2017, then began to increase in 2018 and continued until 2021. Possible explanation for the PM2.5

decrease in 2017, and the subsequent increase in 2018 are because of the wildfires in Alberta (Government of Alberta, 2024), in which we see a significant decrease in PM2.5 in 2016, then a slight increase – still below the annual average in 2017, and then a sharp increase in 2018. However, the NPRI data showed a decrease in PM2.5 emissions in 2019 that is not seen in the University of Alberta GHG emissions data (University of Alberta, 2022). We believe this is because GHG emissions are not wholly representative of PM2.5 emissions, and therefore, we cannot confidently predict the cause of this decrease and increase in the University of Alberta's PM2.5 data.

The University of Toronto exhibits the most successful transition regarding their ability to reduce PM2.5 emissions. In which, we see a significant drop in their PM2.5 emissions in 2016, that is maintained until 2022. We did not see evidence of the other universities achieving comparable success. Therefore, we suggest that Canadian universities facing challenges in reducing emissions, specifically Queens University, McMaster University, and UNB, adopt similar approaches and strategies as the University of Toronto. The University of Toronto has implemented numerous sustainable features, such as customizable heating and cooling systems for each floor, highly efficient lighting, low-flow bathroom fixtures, and a rainwater collection system to eliminate the need for potable water in landscaping (UToronto, 2016). Additionally, the University of Toronto's decrease in emissions can be presumably attributed to a variety of other factors, such as reduced smog advisories and vehicle emissions. Over 50 percent of Toronto's pollution is sourced from within the city's boundaries, predominantly from the by-products of burning fossil fuels, traffic-related emissions, industrial emissions, and residential sources (City of Toronto, 2024a). Additionally, Toronto has not experienced a smog advisory since 2016, despite them being a once frequent occurrence (City of Toronto, 2024a). Toronto has set targets to reduce their greenhouse gas emissions, such as the TransformTO Net Zero Strategy and DriveON (Government of Ontario, 2022), which has helped to implement new initiatives and regulations, and improve air quality (City of Toronto, 2024b). Additionally, coal-fired electricity generation has been phased out in Ontario, which has helped to reduce particulate matter emissions and improve air quality (Government of Ontario, 2017). Through new standards and regulations, the City of Toronto has been able to reduce their greenhouse gas emissions, which is a possible explanation for the reduced levels of particulate matter at the University of Toronto.

There were a few limitations to our discussion. The PM2.5 emissions were reported in tonnes when many other sources use the unit of ug/m3, making it difficult to make comparisons or relate it to other studies. Our study also relied on secondary data from external sources for understanding the impacts of particulate matter, rationalizing trends, and drawing conclusions. Another limitation was the surrounding buildings or large roads near the selected facility were not considered.

With a changing climate, levels of PM2.5 are projected to rise (Climate Atlas of Canada, 2023). Climate change is increasing the risk of wildfires and heat, which are strongly correlated with increases in air pollution and PM2.5 emissions (Climate Atlas of Canada, 2023). Increases in PM2.5 concentrations are associated with increases in human morbidity and premature mortality (Fang et al., 2013). Climate change mitigation strategies are valuable in reducing PM2.5 emissions, for the health of humans and the environment.

Conclusion

The study examined PM2.5 emissions from a range of Canadian universities between 2012 and 2022, highlighting disparities both between institutions and within each university over the timeframe. While Dalhousie University, Memorial University of Newfoundland, University of Saskatchewan, McGill University, and UBC, maintained low emission levels through the study period, Queen's University, Western University, and the University of Calgary had stable but higher levels. Statistical analyses highlighted differences in emissions over time, with significant reductions observed in the University of Toronto, Laval University, the University of Alberta, the University of Manitoba, and UNB. UNB consistently had much higher emissions compared to others, remaining elevated even at their lowest point in 2022. The high levels of PM2.5 at UNB highlights the need for cleaner practices within the province of New Brunswick.

With climate change projected to exacerbate PM2.5 levels, implementing mitigation strategies becomes imperative for human health and environmental well-being. Establishing federal air quality standards that are applicable across Canada can play a key role in helping to ensure all provinces and territories are mitigating their emissions. Canadian Ambient Air Quality Standards (CAAQS) are non-binding goals under the Canadian Environmental Protection Act that set targets for outdoor air quality. The current standard for PM2.5 24 hours stands at $10ug/m^3$. To see the full effect from the CAAQS, the standards should be enforceable under federal law to encourage provinces to place more effort into monitoring their air pollution levels. These standards should also be updated consistently to match the current research surrounding PM2.5. Governments can implement regulations for cleaner energy sources, such as solar and wind, which would be beneficial in reducing PM2.5 emissions.

Additionally, increasing awareness and education of the health and environmental impacts of PM2.5 could help push for better regulations and practices. Many Canadians are unaware of the amount of particulate matter polluting the air of their province. Therefore, further outreach explaining the risks associated with PM2.5 could encourage communities to set their own personal goals for reducing emissions and advocate for more guidance from higher levels of government. Reducing PM2.5 emissions is valuable in improving air quality and quality of life for residents.

Acknowledgements

Special acknowledgements to Tristan Lecompte for his guidance with the NPRI. The NPRI was a vital source of information for this project. The research team would also like to acknowledge the NPRI Academic Challenge for the opportunity to conduct research using real life pollution data while connecting with Environment and Climate Change Canada. The research team would also like to thank Derrell Boutilier, the Director of Operations at Dalhousie’s reporting facility. Finally, the team would like to thank our Professor and Teaching Assistant, Caroline Franklin and Madeline Healy for their suggestions, guidance, and support throughout the process of our research.

References

Bari MdA, Kindzierski WB. 2018. Characterization of air quality and sources of fine particulate matter (PM2.5) in the city of Calgary, Canada. Atmos. Pollut. Res. ;9(3):534–543. https://doi.org/10.1016/j.apr.2017.11.014

California Air Resources Board (CARB). 2024. Inhalable particulate matter and health (PM2.5 and PM10). California Air Resources Board. https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health#:~:text=PM%20can%20adversely%20affect%20ecosystems,alter%20plant%20growth%20and%20yield.

City of Toronto. 2024a. Air Pollution. City of Toronto. https://www.toronto.ca/community-people/health-wellness-care/health-programs-advice/air-quality/air-pollution-and-health/

City of Toronto. 2024b. TransformTO net zero strategy. City of Toronto. https://www.toronto.ca/services-payments/water-environment/environmentally-friendly-city-initiatives/transformto/#:~:text=Toronto%20City%20Council%20has%20adopted,most%20ambitious%20in%20North%20America

Climate change, air quality, and public health. 2023. Climate Atlas of Canada. https://climateatlas.ca/climate-change-air-quality-and-public-health

EPA. 2023 Jul 11. Particulate Matter (PM) Pollution. United States Environmental Protection Agency. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

Fang Y, Mauzerall DL, Liu J, Fiore AM, Horowitz LW. Impacts of 21st century climate change on global air pollution-related premature mortality. Climatic Change. 2013;121(2):239–253. doi:10.1007/s10584-013-0847-8

Government of Canada. 2023a. Air pollutant emissions. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/air-pollutant-emissions.html

Government of Canada. 2023b. National pollutant release inventory. Canada.ca. https://www.canada.ca/en/services/environment/pollution-waste-management/national-pollutant-release-inventory.html

Government of Ontario. 2022 Mar 21. Driveon: Emissions and safety inspection program. Ontario.ca. https://www.ontario.ca/page/driveon-emissions-and-safety-inspection-program

Health Canada. 2021. Heath Impacts of Air Pollution in Canada: Estimates of morbidity and premature mortality outcomes. Canada.ca. Report. https://www.canada.ca/en/health-canada/services/publications/healthy-living/health-impacts-air-pollution-2021.html

Kim K, Kabir E, Kabir S. 2016. A review on the human health impact of airborne particulate matter. Environ Int.74:136-143. https://doi.org/10.1016/j.envint.2014.10.005.

Liu J, Cui S. 2014. Meteorological influences on seasonal variation of fine particulate matter in cities over southern Ontario, Canada. Adv. Meteorol. 2014:1–15.

Meng J, Martin RV, Li C, van Donkelaar A, Tzompa-Sosa ZA, Yue X, Xu J-W, Weagle CL, Burnett RT. 2019. Source contributions to ambient fine particulate matter for Canada. Environ. Sci. Technol. 53(17):10269–10278. https://doi.org/10.1021/acs.est.9b02461

Mustel Group. 2012. Inventory of wood-burning appliance use in British Columbia. British Columbia Ministry of the Environment. Report. https://www.canada.ca/en/health-canada/services/publications/healthy-living/health-impacts-air-pollution-2021.html https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/wood_burning_appliances_report.pdf

Nelin TD, Joseph AM, Gorr MW, Wold LE. 2012. Direct and indirect effects of particulate matter on the cardiovascular system. Toxicol Lett. 208(3):293-299. https://doi.org/10.1016/j.toxlet.2011.11.008

Office of Sustainability.2024. Natural environment. Dalhousie University; [accessed 2024 Feb 13]. https://www.dal.ca/dept/sustainability/campus-initiatives/Natural_Environment.html

The University of Alberta. 2024. Greenhouse Gas Emissions Dashboard. [accessed 2024 March 5]. https://analytics.figbytes.biz/open-view/1924756000007525912

The University of British Columbia. 2022. Even low levels of air pollution contribute to increased health risk. UBC Faculty of Medicine; [accessed 2024 Feb 13]. https://www.med.ubc.ca/news/even-low-levels-of-air-pollution-contribute-to-increased-health-risk/

The University of New Brunswick (UNB). 2024. Central heating plant | Facilities Management. Energy Management; [accessed 2024 Feb 13]. https://www.unb.ca/capitalplanning/energy/central-heating.html

Xing YF, Xu YH, Shi MH, Lian YX. 2016. The impact of PM2.5 on the human respiratory system. J Thorac. 8(1):69-74. https://doi.org/10.3978/j.issn.2072-1439.2016.01.19

Young L. 2021. 86% of Canadians live in areas where air pollution exceeds WHO guidelines: researchers. Global News. [accessed 2024 Feb 16]. https://globalnews.ca/news/8250831/canada-air-pollution-guidelines/

Appendices

Appendix A: Methods

Table A1: Raw data from the NPRI website displaying the total PM2.5 emissions (tonnes) produced for each university from 2012 (or 2015) to 2022.

NPRI ID	Year	Company	Latitude	Longitude	Facility	City	Province	Air (tonnes)
6008	2012	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.45
6008	2013	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.48
6008	2014	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.45
6008	2015	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.49
6008	2016	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.51
6008	2017	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.42
6008	2018	Dalhousie University	44.6367	-63.5878	Dalhousie University	HALIFAX	Nova Scotia	0.4
6008	2019	Dalhousie University	44.6367	-63.5878	Main Campus	HALIFAX	Nova Scotia	0.42
6008	2020	Dalhousie University	44.6367	-63.5878	Main Campus	HALIFAX	Nova Scotia	0.34
6008	2021	Dalhousie University	44.6367	-63.5878	Main Campus	Halifax	Nova Scotia	0.35
6008	2022	Dalhousie University	44.6367	-63.5878	Main Campus	Halifax	Nova Scotia	0.32
6050	2012	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.29
6050	2013	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.32
6050	2014	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.33
6050	2015	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.34
6050	2016	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.32
6050	2017	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.34

6050	2018	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.34
6050	2019	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.34
6050	2020	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	ST. JOHN'S	Newfoundland and Labrador	0.33
6050	2021	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	St. John's	Newfoundland and Labrador	0.35
6050	2022	Memorial University of Newfoundland	47.5737	-52.7387	MAIN CAMPUS SITE, ST. JOHN'S	St. John's	Newfoundland and Labrador	0.37
6069	2012	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	42.15
6069	2013	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	37.78
6069	2014	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	35.68
6069	2015	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	42.03
6069	2016	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	42.56
6069	2017	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	48.9
6069	2018	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	47.43
6069	2019	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	45.75
6069	2020	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	FREDERICTON	New Brunswick	17.8
6069	2021	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	Fredericton	New Brunswick	8.73
6069	2022	University of New Brunswick	45.9463	-66.6427	DEPARTMENT OF Facilities Management	Fredericton	New Brunswick	7.08
6836	2012	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.47

6836	2013	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.52
6836	2014	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.18
6836	2015	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.15
6836	2016	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.15
6836	2017	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.16
6836	2018	University of Manitoba	49.8071	-97.1324	Central Energy Plant (Powerhouse)	WINNIPEG	Manitoba	0.06
6836	2019	University of Manitoba	49.8071	-97.1324	Powerhouse	WINNIPEG	Manitoba	0.06
6836	2020	University of Manitoba	49.8071	-97.1324	Powerhouse	Winnipeg	Manitoba	0.06
6836	2021	University of Manitoba	49.8071	-97.1324	Powerhouse	Winnipeg	Manitoba	0.06
6836	2022	University of Manitoba	49.8071	-97.1324	Powerhouse	Winnipeg	Manitoba	0.06
6937	2012	University of Saskatchewan	52.1299	-106.6313	UNIVERSITY OF SASKATCHEWAN - SASKATOON	SASKATOON	Saskatchewan	0.36
6937	2013	University of Saskatchewan	52.1299	-106.6313	UNIVERSITY OF SASKATCHEWAN - SASKATOON	SASKATOON	Saskatchewan	0.34
6937	2014	University of Saskatchewan	52.1299	-106.6313	UNIVERSITY OF SASKATCHEWAN - SASKATOON	SASKATOON	Saskatchewan	0.35
6937	2015	University of Saskatchewan	52.1299	-106.6313	UNIVERSITY OF SASKATCHEWAN - SASKATOON	SASKATOON	Saskatchewan	0.33
6937	2016	University of Saskatchewan	52.1299	-106.6313	UNIVERSITY OF SASKATCHEWAN - SASKATOON	SASKATOON	Saskatchewan	0.4
6937	2017	University of Saskatchewan	52.1299	-106.6313	University of Saskatchewan	SASKATOON	Saskatchewan	0.34
6937	2018	University of Saskatchewan	52.1299	-106.6313	University of Saskatchewan	SASKATOON	Saskatchewan	0.17
6937	2019	University of Saskatchewan	52.1299	-106.6313	University of Saskatchewan	SASKATOON	Saskatchewan	0.23
6937	2020	University of Saskatchewan	52.1299	-106.6313	University of Saskatchewan	Saskatoon	Saskatchewan	0.22
6937	2021	University of Saskatchewan	52.1299	-106.6313	University of Saskatchewan	Saskatoon	Saskatchewan	0.2

6937	2022	University of Saskatchewan	52.1299	-106.6313	University of Saskatchewan	Saskatoon	Saskatchewan	0.25
8510	2012	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.17
8510	2013	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.18
8510	2014	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.18
8510	2015	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.19
8510	2016	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.17
8510	2017	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.2
8510	2018	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.09
8510	2019	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.12
8510	2020	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	MONTREAL	Quebec	0.1
8510	2021	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	Montreal	Quebec	0.1
8510	2022	Institution royale pour l'avancement des sciences	45.50555	-73.57834	Université McGill - Campus Centre-Ville	Montreal	Quebec	0.12
11865	2012	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	3.74
11865	2013	The Governing Council of the	43.66579	-79.39917	St George Campus	TORONTO	Ontario	3.62

		University of Toronto						
11865	2014	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	2.91
11865	2015	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	3.46
11865	2016	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	1.3
11865	2017	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	1.27
11865	2018	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	1.22
11865	2019	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	1.26
11865	2020	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	TORONTO	Ontario	1.21
11865	2021	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	Toronto	Ontario	1.15
11865	2022	The Governing Council of the University of Toronto	43.66579	-79.39917	St George Campus	Toronto	Ontario	1.3
29129	2015	University of British Columbia	49.261962	-123.253171	Campus Energy Center	VANCOUVER	British Columbia	0.02
29129	2016	University of British Columbia	49.261962	-123.253171	Campus Energy Center	VANCOUVER	British Columbia	0.09
29129	2017	University of British Columbia	49.261962	-123.253171	Campus Energy Center	VANCOUVER	British Columbia	0.12
29129	2018	University of British Columbia	49.261962	-123.253171	Campus Energy Center	VANCOUVER	British Columbia	0.09

29129	2019	University of British Columbia	49.261962	-123.253171	Campus Energy Center	VANCOUVER	British Columbia	0.09
29129	2020	University of British Columbia	49.261962	-123.253171	Campus Energy Centre	VANCOUVER	British Columbia	0.04
29129	2021	University of British Columbia	49.261962	-123.253171	Campus Energy Centre	Vancouver	British Columbia	0.08
29129	2022	University of British Columbia	49.261962	-123.253171	Campus Energy Centre	Vancouver	British Columbia	0.05
23257	2012	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.08
23257	2013	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	0.35
23257	2014	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.06
23257	2015	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.14
23257	2016	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.17
23257	2017	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.2
23257	2018	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.2
23257	2019	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.2
23257	2020	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	CALGARY	Alberta	1.18
23257	2021	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	Calgary	Alberta	1.2
23257	2022	University of Calgary	51.0749	-114.1387	Central Heating and Cooling Plant	Calgary	Alberta	1.14
27020	2015	The University of Western Ontario	43.013	-81.274	Main Campus	LONDON	Ontario	0.9
27020	2016	The University of Western Ontario	43.013	-81.274	Main Campus	LONDON	Ontario	0.82
27020	2017	The University of Western Ontario	43.013	-81.274	Main Campus	LONDON	Ontario	0.84
27020	2018	The University of Western Ontario	43.013	-81.274	Main Campus	LONDON	Ontario	1.03
27020	2019	The University of Western Ontario	43.013	-81.274	Main Campus	LONDON	Ontario	0.87
27020	2020	The University of Western Ontario	43.013	-81.274	Main Campus	LONDON	Ontario	0.85

27020	2021	The University of Western Ontario	43.013	-81.274	Main Campus	London	Ontario	0.78
27020	2022	The University of Western Ontario	43.013	-81.274	Main Campus	London	Ontario	0.85
10730	2012	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.47
10730	2013	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.76
10730	2014	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.94
10730	2015	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.66
10730	2016	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.67
10730	2017	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.65
10730	2018	Queen's University at Kingston	44.22526	-76.49526	Main Campus	KINGSTON	Ontario	2.92
10730	2019	Queen's University at Kingston	44.22526	-76.49526	Queen's University - Kingston Main Campus	KINGSTON	Ontario	2.68
10730	2020	Queen's University	44.22526	-76.49526	Queen's University - Kingston Main Campus	KINGSTON	Ontario	2.34
10730	2021	Queen's University	44.22526	-76.49526	Queen's University - Kingston Main Campus	Kingston	Ontario	2.26
10730	2022	Queen's University	44.22526	-76.49526	Queen's University - Kingston Main Campus	Kingston	Ontario	2.3
10600	2012	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.32
10600	2013	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.48
10600	2014	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.61
10600	2015	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.44
10600	2016	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.49
10600	2017	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.4

10600	2018	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.02
10600	2019	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.68
10600	2020	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	HAMILTON	Ontario	1.68
10600	2021	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	Hamilton	Ontario	1.59
10600	2022	McMaster University	43.2609	-79.9194	MCMASTER UNIVERSITY	Hamilton	Ontario	2.14
6678	2012	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	3.63
6678	2013	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	3.65
6678	2014	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	3.53
6678	2015	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	3.21
6678	2016	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	3.15
6678	2017	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	1.2
6678	2018	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	3.6
6678	2019	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	4.4
6678	2020	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	EDMONTON	Alberta	4.1
6678	2021	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	Edmonton	Alberta	0.65
6678	2022	University of Alberta Heating Plant	53.5196	-113.529	Heating Plant	Edmonton	Alberta	0.47
6454	2012	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	0.44
6454	2013	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	1.8
6454	2014	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	2.39

6454	2015	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	1.59
6454	2016	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	0.65
6454	2017	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	0.6
6454	2018	Université Laval	46.783	-71.2654	Centrale thermique, Service des immeubles	QUÉBEC	Quebec	0.27
6454	2019	Université Laval	46.783	-71.2654	Centrales thermiques et tours d'eau, Service des immeubles	QUÉBEC	Quebec	0.28
6454	2020	Université Laval	46.783	-71.2654	Centrales thermiques, Service des immeubles	QUÉBEC	Quebec	0.25
6454	2021	Université Laval	46.783	-71.2654	Centrales thermiques, Service des immeubles	Québec	Quebec	0.27
6454	2022	Université Laval	46.783	-71.2654	Centrales thermiques, Service des immeubles	Québec	Quebec	0.56

Appendix B: Results

Table B1: R script for performing the Two-Way ANOVAs for the dataset with and without the University of New Brunswick.

```
#all_universities
all.lm <- lm(log(PM) ~ year * ID, data = mydata)
anova(all.lm)
#no_newbrunswick
nonewbr.lm <- lm(log(mydata.PM)~mydata.year*mydata.ID, data=no_newbr)
anova(nonewbr.lm)
```

Table B2: R script for post hoc comparisons performed in R studio on all universities.

```
all.lm <- lm(log(PM) ~ year * ID, data = mydata)
#no newbrunswick dataset
nonewbr.lm <- lm(log(mydata.PM)~mydata.year*mydata.ID, data=no_newbr)
emmeans_newbr <- emmeans(all.lm, pairwise ~ year | ID, at = list(ID = "newbr", year = c(2012,2022)), type='response')
print(emmeans_newbr)
emmeans_dal <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "dal", mydata.year =
c(2012,2022)), type='response')
print(emmeans_dal)
emmeans_queens <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "queens", mydata.year
= c(2012,2022)), type='response')
print(emmeans_queens)
emmeans_ubc <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "ubc", mydata.year =
c(2015,2022)), type='response')
print(emmeans_ubc)
emmeans_sask <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "sask", mydata.year =
c(2012,2022)), type='response')
print(emmeans_sask)
emmeans_western <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "western",
mydata.year = c(2015,2022)), type='response')
print(emmeans_western)
emmeans_uoft <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "uoft", mydata.year =
c(2012,2022)), type='response')
print(emmeans_uoft)
emmeans_uofman <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "uofman",
mydata.year = c(2012,2022)), type='response')
print(emmeans_uofman)
emmeans_uofcal <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "uofcal", mydata.year =
c(2012,2022)), type='response')
print(emmeans_uofcal)
emmeans_uofa <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "uofa", mydata.year =
c(2012,2022)), type='response')
print(emmeans_uofa)
emmeans_newf <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "newf", mydata.year =
c(2012,2022)), type='response')
print(emmeans_newf)
emmeans_mac <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "mac", mydata.year =
c(2012,2022)), type='response')
print(emmeans_mac)
emmeans_mcgill <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "mcgill", mydata.year =
c(2012,2022)), type='response')
print(emmeans_mcgill)
emmeans_laval <-emmeans(nonewbr.lm, pairwise ~ mydata.year | mydata.ID, at = list(mydata.ID = "laval", mydata.year =
c(2012,2022)), type='response')
print(emmeans_laval)
```

Table B3: The first output of the post hoc done in R studio showing the estimated marginal means (EMMeans), SE, and df for each University for their first year in the database (2012 or 2015) and 2022 (alpha=0.05). This output was back-transformed from the log scale.

University	Year	EMMeans	SE	df
The University of New Brunswick	2012	61.5	13	120
	2022	3.6	2.88	120
Dalhousie University	2012	0.508	0.1033	111
	2022	0.342	0.0695	111
Queen's University	2012	2.81	0.571	111
	2022	2.4	0.488	111
University of British Columbia	2015	0.0576	0.0134	111
	2022	0.0711	0.0165	111
University of Saskachewan	2012	0.383	0.078	111
	2022	0.204	0.0416	111
Western University	2015	0.894	0.208	111
	2022	0.837	0.195	111
University of Toronto	2012	3.485	0.709	111
	2022	0.925	0.188	111
University of Manitoba	2012	0.391	0.07953	111
	2022	0.0404	0.00821	111
University of Calgary	2012	0.802	0.163	111
	2022	1.341	0.273	111
University of Alberta	2012	4.81	0.979	111
	2022	1.13	0.23	111
Memorial University of Newfoundland	2012	0.309	0.0629	111
	2022	0.359	0.073	111
McMaster University	2012	1.33	0.271	111
	2022	1.71	0.348	111
McGill University	2012	0.198	0.0404	111
	2022	0.101	0.0206	111
Laval University	2012	1.32	0.2686	111
	2022	0.269	0.0547	111