CANADA'S AIR QUALITY SINCE 1970

An Environmental Success Story

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APRIL
2017

FRASER
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Contents

Executive Summary

Canadians have long been concerned about the state of our air quality and the belief that air pollution is a major problem seems to be widespread. This publication examines the evolution of air quality in Canada from the 1970s onward and looks at how the current state of air quality compares to the stringent standards established by Canadian government policy. The conclusion is that air quality in Canada has improved substantially and that this significant change over the past four decades occurred at the same time there was considerable growth in Canada's population, economic activity, energy use, and consumption of motor fuel.

Using data from Environment Canada on emissions and ambient concentrations, the study provides accurate and up-to-date information on the status of five major air pollutants in Canada: ground level ozone, fine particulate matter, sulphur dioxide, nitrogen dioxide, and carbon monoxide. Comparing trends for the five air pollutants on three levels—national, city, and monitoring station—against existing national and international air-quality standards shows that air quality is improving for the most part and is now at levels generally deemed safe.

Ground-level ozone

Concentrations of ground-level ozone, a key component of smog, have generally decreased in Canada since 2000. In 2015, the national concentration of ground-level ozone was 27% lower than in 1979 and ozone concentrations have been consistently below the new stringent air-quality standard since 2005. Major Canadian cities have lower ozone concentrations than they had during the late 1970s. In the same period, over 70% of monitoring stations throughout Canada reported ozone concentrations that were above the air-quality standard; that number has fallen to 16% during the most recent interval.

Fine particulate matter

Concentrations of fine particulate matter in Canada have only been measured since 2000 and national ambient levels have consistently remained below the new air-quality standards.

Sulphur dioxide

In the last four decades, concentrations of sulphur dioxide have fallen dramatically across Canada and have met the strictest annual air-quality standard since 1999. In 2015, ambient levels of sulphur dioxide in Canada were 92.3% lower than in 1974. Major Canadian cities also significantly reduced their ambient levels of sulphur dioxide during

the same period. In the mid-to-late 1970s, over 60% of monitoring stations across Canada recorded concentrations out of compliance with the annual air-quality standard, but today only 3% of stations record non-conforming levels.

Nitrogen dioxide

Concentrations of nitrogen dioxide have also been decreasing for decades in Canada. Ambient concentrations of nitrogen dioxide in Canada decreased 74.4% from 1974 to 2015 and ambient levels have been consistently below the strictest air-quality standard since 1985. The decrease in ambient levels was also apparent in all major Canadian cities. Whereas in the mid 1970s, 54% of stations across Canada reported readings out of compliance with the annual air-quality standard for nitrogen dioxide, in 2015 the percentage was zero. All monitoring stations throughout Canada have met the strictest annual air-quality standard for nitrogen dioxide since 2011.

Carbon monoxide

There has also been a substantial reduction in concentrations of carbon monoxide in Canada during the last four decades. Ambient levels fell 90.4% in Canada from 1974 to 2015 and have conformed to the strictest air-quality standard since 1985. Levels of carbon monoxide in major cities have also fallen dramatically over the past four decades. In mid-1970s, 84% of stations had readings for carbon monoxide exceeding the air-quality standards but, since 1999, all stations across Canada—with the exception of one in New Brunswick in 2011—recorded values conforming to the air-quality standard.

Socioeconomic trends

Between 1970 and 2015, real gross domestic product increased by 242% and the Canadian population grew by 68%. From 1980 to 2015, consumption of motor fuel rose by 26% and from 1995 to 2015 energy use increased 21%. At the same time emissions and ambient levels of major air pollutants dropped significantly, indicating the extent to which air pollution has been decoupled from energy use and economic growth in Canada. For this reason, discussions about the need for new policies to tighten emission policies even further should begin with the recognition that air pollution has already substantially declined in Canada and is largely in compliance with some of the strictest standards in the world.

1 Introduction

Canadians have long been concerned about the state of our air quality. Public opinion research conducted by Health Canada in 2004/05 showed Canadians considered air pollution a major environmental problem. A national survey conducted in October 2016 by researchers at the University of Montreal indicated that a large majority of Canadians (73%) want the government to take more action to improve air quality and public health (EcoAnalytics, 2016). The belief that air pollution is a major problem seems to be widespread. The purpose of this study is to investigate whether these perceptions match the available data on levels of air contaminants in Canadian cities.

In this study, we examine the evolution of Canadian air quality from the 1970s onward, and discuss how the current state of air quality compares to the relatively stringent standards established by Canadian government policy. Using long-term monitoring data from Environment Canada's National Air Pollution Surveillance network, we provide accurate and up-to-date information on the status of five major air pollutants in Canada—namely, ground level ozone (O_3), fine particulate matter ($PM_{2.5}$), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO). We explain existing national and international air quality standards and compare the air pollutant trends against these standards to determine whether the state of air quality is improving or worsening, and whether the current state is at levels generally deemed safe. As well, in order to make a systematic assessment, we examine the status of each pollutant on three levels: national level, city level, and station level.

At the national level, two techniques are used to measure air quality over time: ambient concentrations and emission estimates. Ambient concentrations measure the actual amount of pollutant in the air and are usually reported in parts per billions (ppb) or micrograms per cubic metre ($\mu g/m^3$). This measurement reflects both natural and human sources of air pollutants. Emission estimates, however, exclude natural sources and only estimate the amount of particulate pollutants originating in human activity. At the city level, our analysis assesses the trends in five key pollutants in each of four large urban centres: Toronto, Montreal, Vancouver, and Ottawa, over the period from 1974 to 2015, the full interval for which data are available.

To complement our aggregated analysis, we conducted a further analysis of individual stations, examining ambient concentrations of air pollutants at stations over time, across Canada and Canadian provinces, and calculating the number and percentage of stations with readings exceeding the current air quality standards. This analysis helped us understand the state of air quality across various Canadian provinces and localized areas.

In addition to examining data on emissions and ambient concentrations of the five major air pollutants, we looked at the data available on four drivers of air pollution: namely, population, economic activity, energy use, and consumption of motor fuel since the 1970s. Graphs of trends in these drivers show the extent to which Canada has decoupled air pollution from economic growth and energy consumption. Air quality has improved in Canada over the past four decades despite growth in Canada's population and economy.

Ambient concentrations of ground level ozone, a key component of smog, have shown a downward trend since the year 2000, and a reduction of 27% from 1979 to 2015. All major Canadian cities also showed improvement during the same period. Whereas during the late 1970s over 70% of stations throughout Canada reported concentrations that were above the air quality standard, this number fell to 16% during the interval from 2013 to 2015. Ambient concentrations of fine particulate matter, for which the Canadian data covers a shorter period, has consistently remained lower than the new stringent air quality standards since 2000, even though no specific trend was detected. Ambient concentrations of sulphur dioxide, a pollutant largely associated with combustion of oil and coal, have sharply decreased over the last 40 years in Canada. The national ambient levels of SO_2 (annual exposure) in 2015 was 92.3% lower than in 1974. The decrease is also apparent in all major Canadian cities. In the mid-to-late 1970s, over 60% of stations across country recorded concentrations exceeding the annual air quality objectives for SO_2. However, in the most recent year of data, 2015, only 3% of stations recorded non-conforming values. In the last four decades, Canada has also experienced a substantial reduction in its levels of nitrogen dioxide and carbon monoxide: the national ambient level for nitrogen dioxide was 74.4%, and for carbon monoxide, 90.4%, lower than in 1974. All major cities also followed a downward trend in their ambient levels during the same period. In 2015, there was no station in Canada recording values exceeding the strictest air quality standards for these two air pollutants.

Implications for policy

Our analysis suggests that claims of worsening air quality in Canada are not valid. This has implications for policy if the perception that air pollution is not improving leads to calls for new and more stringent policy initiatives that turn out to be unnecessary. For instance, the Canadian Medical Association (2008) predicted massive future costs from air pollution based on the assumption that air quality would remain constant into the future. However, our analysis shows that this assumption is not valid and, as a result, their predictions are overestimated. As air pollution continues to decrease it will be important to keep discussions about energy and air emissions policy rooted in accurate, up-to-date evidence about the actual state of the environment.

This study confirms trends already identified in previous reports from the Fraser Institute on environmental conditions in Canada. The Institute published its first *Environmental Indicators* report in 1997. A number of other studies, such as Brown, Green, Hansen, and Fredricksen (2004), McKitrick (2008) and Wood (2012) measured the state of air quality in Canada. In this study, we incorporate all the available data and extend these previous studies.

2 Air Quality Standards

There are currently two sets of air quality standards enforced in Canada: the National Ambient Air Quality Objectives (NAAQO) and Canadian Ambient Air Quality Standards (CAAQS). Both are benchmarks used to guide decisions on controlling air pollution emissions. The NAAQO were introduced by the federal government in the 1970s. They were the first national air quality goals designed to protect the environment and public health (CCME, 1999). Air quality objectives are usually defined in terms of a concentration measured over a specific period of time. For instance, an annual objective refers to a concentration averaged over a whole year, while a 1-hour objective refers to the concentration averaged over a single hour. Traditional NAAQO pertain to a three-level system that define maximum desirable, maximum acceptable, and maximum tolerable levels of pollution over various periods of time, including 1-hour, 8-hour, 24-hour, and annual.

In 1998, Canadian Environment Ministers signed the Canada-Wide Accord on Environmental Harmonization, which provided new regulatory tools to manage emissions. In 2000, following this framework agreement, a new set of standards, known as Canada-Wide Standards (CWS) for ozone and particulate matter, was established. However, the CWS did not last very long and were replaced by new objectives developed by the Ministry of Environment in 2012. At that time, the federal government and all provinces except Quebec agreed to implement a Canada-wide Air Quality Management System (AQMS) as a new comprehensive approach to managing air pollution across the country. Under this new system, in May 2013 the federal government developed new and more stringent air quality standards for ground-level ozone and fine particulate matter. Titled the Canadian Ambient Air Quality Standards (CAAQS), these new objectives serve as the driving force for AQMS's across Canada. Ozone and fine particulate matter were the first substances to be targeted by the new standards, because of concern about their effects on human health. However, the development of CAAQS for other substances has continued and, in October 2016, CAAQS for sulphur dioxide were announced. Currently, work is in progress to develop CAAQS for nitrogen dioxide. The proposed CAAQS consist of three components: the time-averaging period, a numerical value associated with the time-averaging period, and some specific statistical form described by a metric. **Table 1** presents the existing CAAQS, along with their averaging time and statistical form, as well as the American and international (WHO) air quality standards (CCME, 2012; US-EPA, 2016b; WHO, 2006). The United States has objectives for ozone, fine particulate matter, and sulphur dioxide that are similar to the CAAQS, though less stringent (table 1). These objectives have a statistical form similar to that of

Table 1: Ambient air quality objectives for ozone (O_3), fine particulate matter ($PM_{2.5}$), and sulphur dioxide (SO_2)

Pollutant	Averaging time	CAAQS 2015 Standard	CAAQS 2020 Standard	United States	WHO	Metric (CAAQS and US standards)
O_3 (ppb)	8-hour	63	62	70	50	The three-year average of the annual 4th-highest daily maximum 8-hour average concentrations
$PM_{2.5}$ (μg/m^3)	24-hour	28	27	35	25	The three-year average of the annual 98th percentile of the daily 24-hour average concentrations
	Annual	10	8.8	12	10	The three-year average of the annual average concentrations
SO_2 (ppb)	1-hour	NA	70	75	NA	The three-year average of the annual 99th percentile of the SO_2 daily maximum 1-hour average concentrations
	24-hour	NA	NA	NA	7	NA
	Annual	NA	5	NA	NA	The arithmetic average over a single calendar year of all 1-hour average SO_2 concentrations

Sources: CCME, 2012; US-EPA, 2016b; WHO, 2006.

the CAAQS. International guidelines, the World Health Organization's guidelines, for these air pollutants also exist; however, they are not based on a specific statistical form. Concentrations of ozone, fine particulate matter, and sulphur dioxide in this study were compared against the new CAAQS, which are listed in table 1.

WHO's guidelines and the National Ambient Air Quality Objectives (NAAQO) were used as benchmarks for nitrogen dioxide (NO_2) and carbon monoxide (CO), for which CAAQS have not been developed. **Table 2** displays current existing air quality objectives for nitrogen dioxide and carbon monoxide. The United States has a more stringent objective for a 1-hour average NO_2 (100 ppb) [1] compared to both the NAAQO and WHO, but its annual standard is similar to the NAAQO and is equal to 53 ppb. To date, WHO does not have guidelines for carbon monoxide (WHO, 2006).

[1] The United States' standard for 1-hour NO_2 is 100 ppb and is defined as a 3-year moving average for the annual 98th percentile of the daily 1-hour maximum concentrations.

Table 2: Ambient air quality objectives for nitrogen dioxide (NO_2) and carbon monoxide (CO)

Pollutant	Averaging time	NAAQO		United States	WHO
		Desirable	Acceptable		
NO_2 (ppb)	1-hour	NA	213	100	106
	Annual	32	53	53	21
CO (ppb)	1-hour	13	31	35	NA
	8-hour	5	13	9	NA

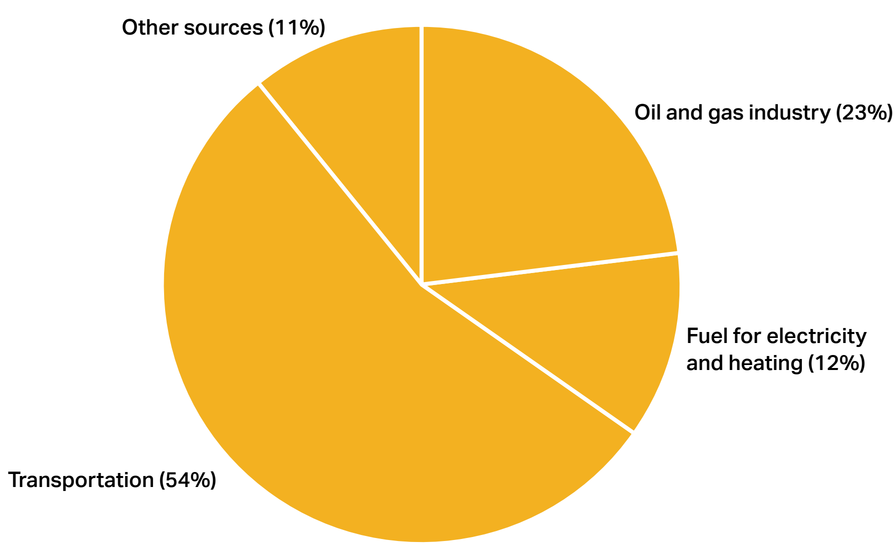
Note: WHO set no guidelines for carbon monoxide.
Source: US-EPA, 2016b; WHO, 2006; Wood, 2012.

3 Ground-Level Ozone (O_3)

Ozone (O_3) is a colorless gas that is present both at the ground level and in the stratosphere. In the higher level of the atmosphere, it shields the earth from harmful ultraviolet rays. However, in the lower atmosphere at ground level, it becomes a major contributor to smog and thus poses risks to human health depending on the concentration. High levels of ozone exposure can cause respiratory problems, lung damage, asthma attacks, premature deaths, and increased hospital admissions (US-EPA,2016a; Bell, McDermott, Zeger, Samet, and Dominici, 2004). Ground-level ozone can also damage sensitive vegetation and ecosystems.

Ground-level ozone is not directly emitted and is instead formed through a chemical reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in sunlight. Since ozone is a major ingredient of urban smog, emissions of both NO_x and VOC are targeted by regulators to control ozone concentrations. Nitrogen oxides (NO_x) are the generic term for nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. According to data from Environment Canada (ECCC, 2016a), major sources of NO_x in 2014 were transportation (54%), the oil and gas industry (23%), and fuel for electricity and heating (12%) (**figure 1**). Additional sources, which include home firewood burning,

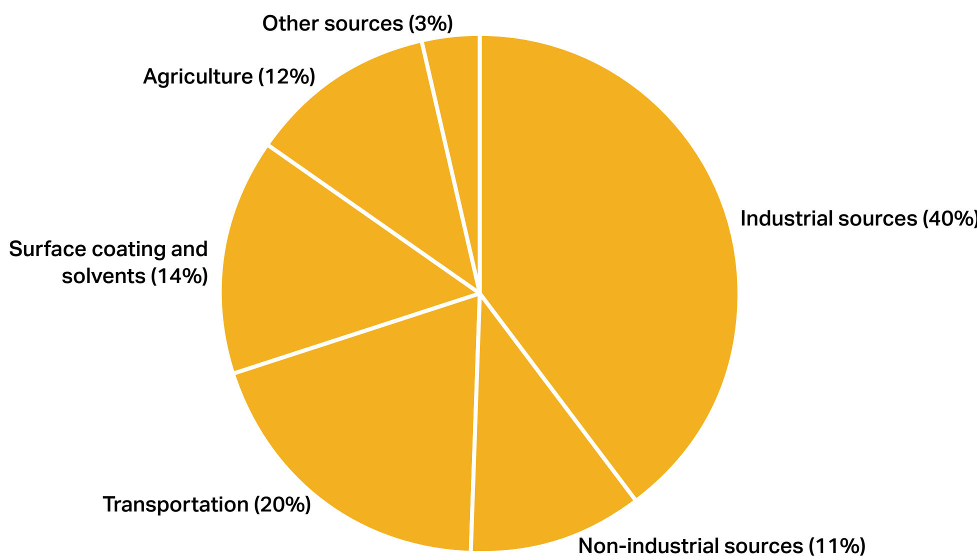
Figure 1: Sources of emissions of nitrogen oxides in Canada, 2014



Note: Other sources include other industries, home firewood burning, incinerations and miscellaneous, and open sources.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

incineration and miscellaneous, and open sources, accounted for 11%. Volatile organic compounds are carbon-containing vapours and gases—for example, solvents and gasoline fumes—released into the air through natural sources and human activity. Although natural sources, such as vegetation, forest fires, and soil, are responsible for releasing VOCs into the atmosphere, human activity is the primary source of VOCs in urban areas (ECCC, 2017b). In 2014, major sources resulting from human activity included industry (40%), transportation (20%), and paints and solvents (14%). Emissions from the oil and gas industry constitute a large fraction of industrial sources, accounting for 34% of the total VOC emissions in 2014 (**figure 2**).

Figure 2: Sources of emissions of volatile organic compounds in Canada, 2014



Note: Non-industrial sources include commerical and residential fuel combustion, power generation, and home firewood burning. Other sources include open sources (minus agriculture) and incineration and miscellaneous.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

Over time, concern about persistently high levels of ozone led regulators to develop more stringent standards for ambient levels. Accordingly, in May 2013, through a collaborative process among federal, provincial, and territorial governments, two new CAAQS (standards) were developed for ozone, one taking effect in 2015 and another in 2020. The standards only cover short-term (8-hour) exposure (table 1) and no standard was set for the annual period. This takes into account that adverse health effects are associated with brief exposure to high levels of ozone rather than low levels over a long time. The proposed CAAQS for ozone for the year 2015 is 63 ppb and for 2020, 62 ppb; they are defined as a 3-year moving average of the annual peak (4^{th}-highest) daily maximum 8-hour average concentrations.

Assessing concentrations of ground-level ozone

In order to make a meaningful assessment of ozone concentrations over time, ambient concentrations of ozone should be expressed in a form that permits comparison against the ozone CAAQS. We did this as follows. First, hourly ozone concentration data for all stations across Canada, within the period from 1977 to 2015, were obtained through the National Air Pollution Surveillance (NAPS) archive. [2] Using hourly data for a given station, 24 consecutive 8-hour average concentrations were calculated for each day. Second, daily maximum 8-hour average concentrations, which are the highest value of the 24 calculated average concentrations, were found. All the calculated daily maximum 8-hour concentrations were ordered in an array from highest to lowest, and the 4th-highest ranking value was identified as the annual peak (4th-highest) 8-hour concentration for that station. Subsequently, following the statistical form of the proposed standard, we ignored the first three highest values of daily maximum (8-hour average) concentrations, as these high values might have occurred due to external factors (for example, heat waves). Then, the 3-year moving average of the annual peak (4th-highest) 8-hour concentrations for each station was calculated. Finally, in order to obtain the national ambient levels of ozone, all the station-level 3-year moving averages of annual peak values were averaged over the stations throughout Canada. Figure 3 displays the 3-year moving average of the national ambient ozone levels from 1979 to 2015 against the 2015 CAAQS. In other words, this figure represents average of the 3-year moving average of annual 4th-highest daily maximum 8-hour concentrations for ozone at monitoring stations across Canada. [3]

Ambient levels of (peak) ground-level ozone in Canada decreased 27% between 1979 and 2015 (figure 3). From 1979 to 1987, ambient levels of peak ozone decreased by 17%; however, from 1987 to 2003 it increased by almost 6.5%. From 2000, a decreasing annual trend of −0.65 ppb for ozone has been detected. Ambient levels of ozone frequently exceeded the CAAQS standard between 1979 and 2005. However, in 2005, ozone concentrations fell below CAAQS and have remained there.

Montreal, Ottawa, Toronto, and Vancouver

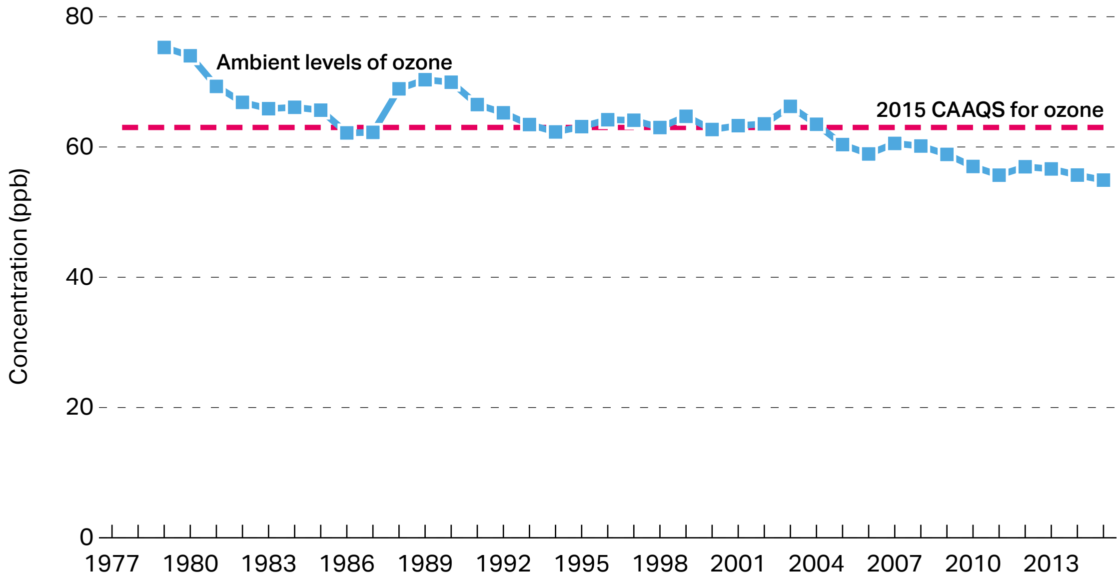
Ambient levels of ozone in four large Canadian cities—Montreal, Ottawa, Toronto, and Vancouver—were also calculated, using the same procedure previously outlined. [4] Figure 4

[2] Although the NAPS archive has provided data on ozone concentration levels since 1974, no hourly data is available for the year 1976. Therefore, ambient levels of ozone in Canada and various cities were calculated based on data from 1977 to 2015.

[3] The air quality standard shown in figure 3 is the current one, which differs from that applied in previous decades. Throughout this publication, even though the figures show data back to the 1970s, the air quality standards used as benchmarks are those that are now in force.

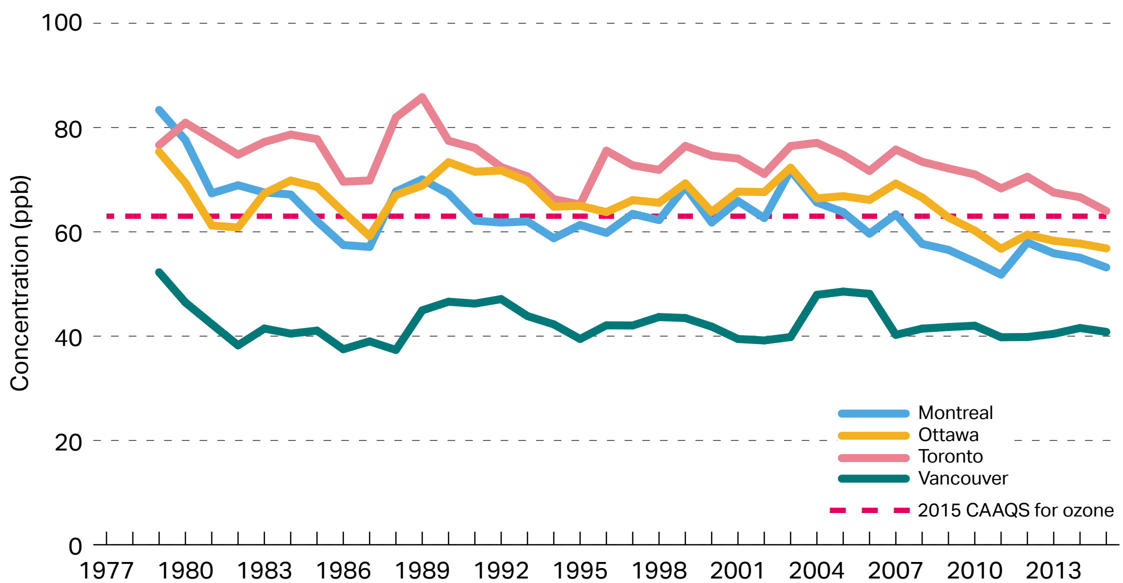
[4] We have used multiple stations to calculate ambient levels of ozone for all cities except Ottawa, where, because of insufficient data, we have used only one station, 60104, located in downtown Ottawa.

Figure 3: Ambient levels of ozone in Canada, 1977–2015



Note: Ambient levels are an average of the 3-year moving average of the annual 4th-highest daily maximum 8-hour average (1977–2015) for ozone at monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 4: Ambient levels of ozone in Montreal, Ottawa, Toronto, and Vancouver, 1977–2015



Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

shows the ambient levels of ozone in those cities over the period from 1979 to 2015. In 2015, as shown in figure 4, Toronto had the highest ambient levels of peak ozone among the four large cities. Since 1985, peak ozone concentrations in Toronto consistently exceeded the 2015 CAAQS. However, since 2003, a downward trend has been observed and in 2015 the peak was 16.4% lower than in 1979. Vancouver had the lowest ambient levels of ozone among the four large cities, consistently below CAAQS from 1979 to 2015. Peak ozone concentrations in 2015 were almost 22% lower than in 1979.

Ottawa has the second highest levels of peak ozone concentration among the four large cities. However, they were about 25% lower in 2015 than in 1979. Although the peak ozone concentration in Ottawa was frequently above the 2015 CAAQS before 2009, its concentrations have been consistently below the standard since 2009. Similar to Toronto, a downward trend has been detected for Ottawa since 2003. Montreal has the third highest levels of peak ozone concentration among the four large cities. The ozone concentration in 2015 was about 36.2% lower than in 1979. In fact, among the four cities, Montreal has shown the greatest decrease in its peak ozone concentration during the period. Although ozone levels in Montreal were frequently above the CAQQS before 2006, the concentrations fell below the standard in 2006 and have remained there.

Station-level analysis

In order to better examine the recent changes in ambient levels of ground level ozone, and also to verify the results obtained from national and regional analysis, a similar station-level analysis was conducted. Using the same procedure as before, the annual peak (4^{th}-highest) 8-hour concentrations for stations across Canada over the period from 1977 to 2015 were calculated, and then a 3-year moving average of these readings was obtained. The resulting measure was then compared with the 2015 CAAQS of 63 ppb.

Table 3 shows the numbers of stations, by province, that had readings exceeding, or equal to, the ozone standard, as well as the total number of stations in that province during the interval. Figure 5 shows the national percentage of stations out of compliance with the current CAAQS for ozone over the period from 1979 to 2015. As shown, the percentage of stations with noncompliant readings across Canada fell significantly over time. Over the 1977-to-1979 interval, 73% of stations throughout Canada reported concentrations equal to, or exceeding, the ozone CAAQS (63 ppb); this fell to 16% during the 2013–2015 interval.

All provinces except Saskatchewan decreased the percentage of their nonconforming stations from 1979 to 2015. Concentrations in Saskatchewan were consistently lower than the CAAQS until the most recent interval, when one station (out of 6), located in Bratt's lake, recorded exceeding values. Concentrations in the provinces of Newfoundland & Labrador and Prince Edward Island almost never exceeded the CAAQS from 1979 to 2015. Nova Scotia showed the greatest decrease in its fraction

Table 3: Number of stations out of compliance with the CAAQS ozone standard, by province, 1977–2015

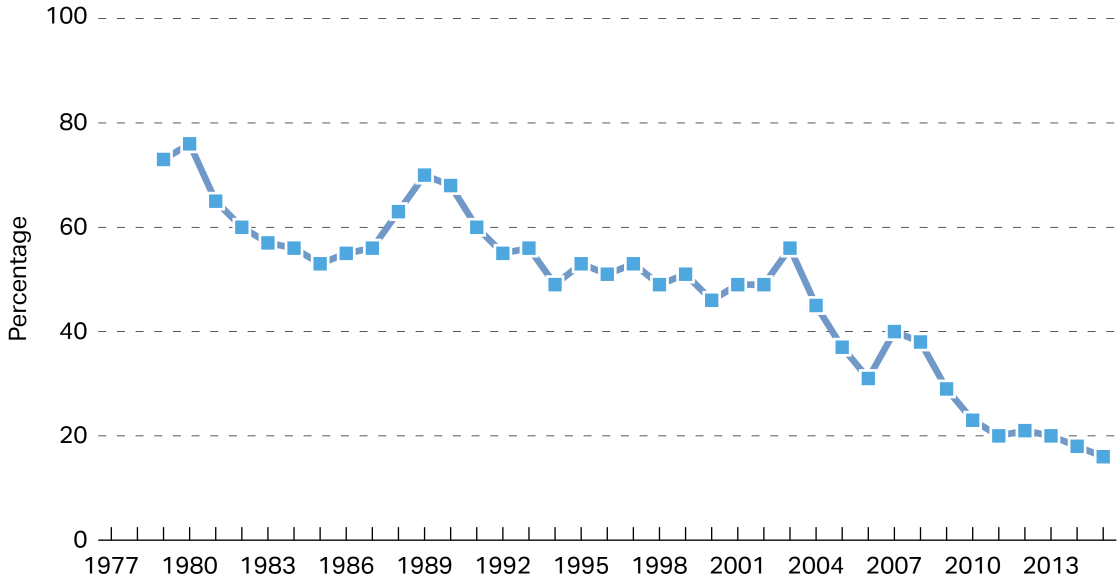
	BC	AB	SK	MB	ON	QC	NB	NS	PE	NF
1977–1979	2	2	0	1	19	9	0	2	0	0
Total	6	5	1	3	20	10	1	2	0	0
1978–1980	2	2	0	0	30	10	2	1	0	0
Total	7	5	1	2	30	12	3	2	0	0
1979–1981	1	2	0	0	30	8	2	0	0	0
Total	7	5	1	2	34	12	3	2	0	0
1980–1982	3	2	0	0	28	9	2	0	0	0
Total	14	4	1	2	34	13	3	2	0	0
1981–1983	2	2	0	0	30	9	1	0	0	0
Total	15	4	1	2	36	14	3	2	0	0
1982–1984	2	2	0	0	29	10	2	0	0	0
Total	18	4	2	2	35	15	3	2	0	0
1983–1985	4	0	1	0	32	9	2	1	0	0
Total	19	4	2	2	39	15	3	3	0	0
1984–1986	7	0	1	0	31	8	2	2	0	0
Total	22	5	3	2	40	10	3	4	0	0
1985–1987	7	1	1	1	32	10	3	2	0	0
Total	24	5	3	3	42	16	4	5	0	0
1986–1988	8	1	1	1	47	13	3	2	0	0
Total	24	5	3	3	57	20	4	4	0	0
1987–1989	8	1	0	2	48	22	5	2	0	1
Total	23	5	2	3	55	28	6	4	0	1
1988–1990	10	1	0	1	49	19	6	1	0	0
Total	21	5	2	3	55	30	6	5	0	1
1989–1991	2	2	0	0	48	24	6	3	0	0
Total	24	8	3	3	53	36	7	6	0	1
1990–1992	1	0	0	0	48	25	6	2	0	0
Total	26	8	5	3	53	40	7	5	1	1
1991–1993	0	0	0	0	46	30	6	2	0	0
Total	26	9	5	3	57	39	7	4	1	1
1992–1994	1	0	0	0	42	27	3	3	0	0
Total	26	10	5	3	53	42	7	5	1	1
1993–1995	1	2	0	0	49	25	4	2	0	0
Total	28	10	3	3	55	43	8	5	1	1
1994–1996	1	1	0	0	47	23	5	2	0	0
Total	27	10	2	3	52	44	8	5	2	1
1995–1997	0	4	0	1	44	28	4	3	0	0
Total	27	13	2	3	51	45	10	5	2	1

Table 3, cont'd: Number of stations out of compliance with the CAAQS ozone standard, by province, 1977–2015

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NF
1996–1998	2	4	1	1	40	31	4	3	0	0
Total	34	16	3	3	50	49	11	5	2	1
1997–1999	0	5	0	1	41	36	3	4	0	0
Total	35	19	3	3	45	49	11	5	2	1
1998–2000	0	4	0	0	41	29	2	3	0	0
Total	35	20	3	3	46	45	14	5	0	1
1999–2001	0	5	0	0	45	33	2	3	0	0
Total	37	20	3	3	50	43	14	6	0	2
200–2002	0	7	0	0	45	31	3	3	0	0
Total	34	20	3	3	52	42	14	7	0	3
2001–2003	1	10	0	0	46	37	4	2	0	0
Total	34	20	3	3	50	43	14	8	0	3
2002–2004	3	6	0	0	44	30	1	2	0	0
Total	36	26	3	3	50	43	14	8	0	4
2003–2005	2	1	0	0	48	28	1	2	0	0
Total	40	38	4	3	53	50	14	10	0	6
2004–2006	3	3	0	0	44	19	0	2	0	0
Total	42	38	4	3	53	51	15	9	0	6
2005–2007	2	5	0	0	47	32	1	2	0	0
Total	40	38	4	3	53	51	12	9	0	6
2006–2008	2	8	0	0	48	21	1	2	0	0
Total	40	32	4	3	52	51	14	10	0	5
2007–2009	0	7	0	0	46	12	0	0	0	0
Total	43	30	5	3	52	51	14	10	1	5
2008–2010	0	6	0	0	43	4	0	0	0	0
Total	45	31	5	3	52	51	14	12	1	7
2009–2011	0	6	0	0	38	2	0	1	0	0
Total	49	29	5	3	49	51	14	13	1	8
2010–2012	0	3	0	0	39	4	0	1	0	0
Total	41	31	5	4	48	50	14	12	2	7
2011–2013	0	3	0	0	41	1	0	0	0	0
Total	40	33	5	5	49	51	14	8	0	6
2012–2014	0	2	0	0	37	1	0	0	0	0
Total	43	33	6	5	49	49	14	8	0	7
2013–2015	0	5	1	0	31	0	0	0	0	0
Total	44	38	6	5	48	49	14	8	3	8

Note: Rows headed by intervals (e.g., 1977–1979) give the number of stations, by province, that had readings exceeding, or equal to, the CAAQS ozone standard. Rows headed by "Total" give the total number of stations, by province, during the interval.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 5: National percentage of stations out of compliance with the current CAAQS for ozone, 1977–2015



Note: Percentages are calculated using the 3-year moving average of the annual 4th-highest daily maximum 8-hour average (1977–2015) for ozone at monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

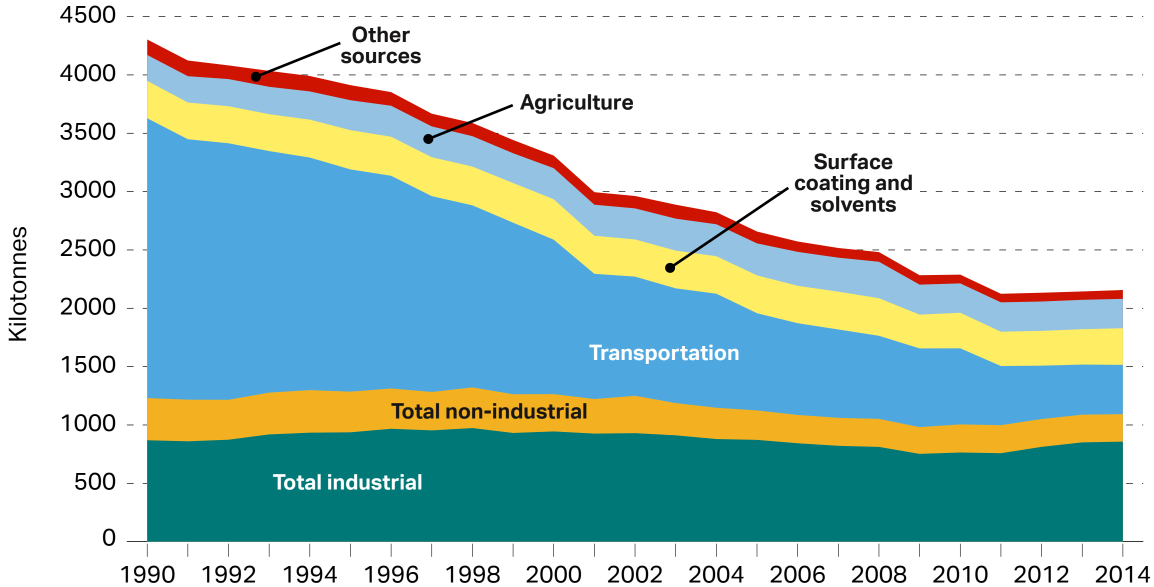
of nonconforming stations, since the percentage declined from 100% between 1977 and 1979 to 0% between 2013 to 2015. Quebec also showed a significant reduction in the percentage of nonconforming stations, dropping from 90% to 0% in recent years. All stations in British Columbia and New Brunswick have conformed to CAAQS since 2009. From 2000 onward, concentrations in Manitoba have remained lower than the CAAQS.

Over the latest 3-year interval (2013–2015), only Saskatchewan, Ontario, and Alberta had stations reporting noncompliant ozone levels. The data suggest that Ontario has the largest problem with ozone as 65% of its stations from 2013 to 2015 showed concentrations that peaked above the CAAQS. Out of 48 stations across Ontario, only 17 recorded values consistently in line with the current CAAQS. These were in Ottawa (two stations), Kingston, Toronto (only one station in Etobicoke), Hamilton, Sudbury, Sault Ste. Marie, Thunder Bay, Cornwall, Oshawa, North Bay, Dorset, Experimental Lakes area, Barrie, Morrisburg, Moonbeam and Petawawa. Alberta, over the latest 2013–2015 interval, had five stations (out of 38) with exceeding values, located in Edmonton (two stations), Red Deer, Esther, and Steeper.

Precursor gases—VOCs and NO_x

In addition to examining the ambient concentrations of ozone, we examined emissions of precursor gases (VOCs and NO_x) over time. **Figure 6** displays the sources of

Figure 6: Emissions of VOCs by source, 1990–2014

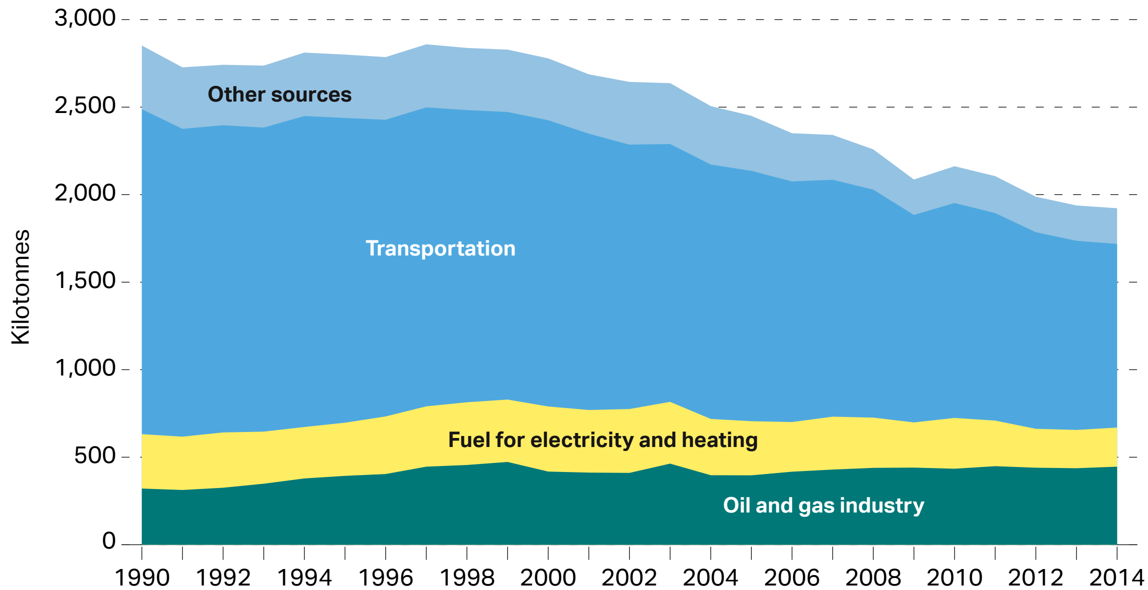


Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

VOC emissions in Canada from 1990 to 2014. As shown, total VOC emissions declined by almost 50% between 1990 and 2014. The largest reduction (82.3%) is attributed to transportation. Detailed inventory data (not shown) shows that reductions in emissions from off-road vehicles played an especially large role. Emissions from industrial sources, non-industrial sources (residential and commercial fuel combustion, power generation, and home firewood burning), paints, and solvents also decreased over the same period. Agriculture is the only source that increased emissions within the examined period.

Emissions of nitrogen oxide (NO_x) by source from 1990 to 2014 are shown in figure 7. Emissions decreased 32.6% during that period. The largest reduction (43%) was in transportation, which came as a result of the introduction of cleaner technology. Emissions from fuel combustion and power generation fell by 28%. While emissions from industry decreased as a whole, emissions from the oil and gas sector rose over the same period.

Figure 7: Emissions of nitrogen oxides by source, 1990–2014



Note: Other sources include other industries, home firewood burning, incinerations and miscellaneous, and open sources.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

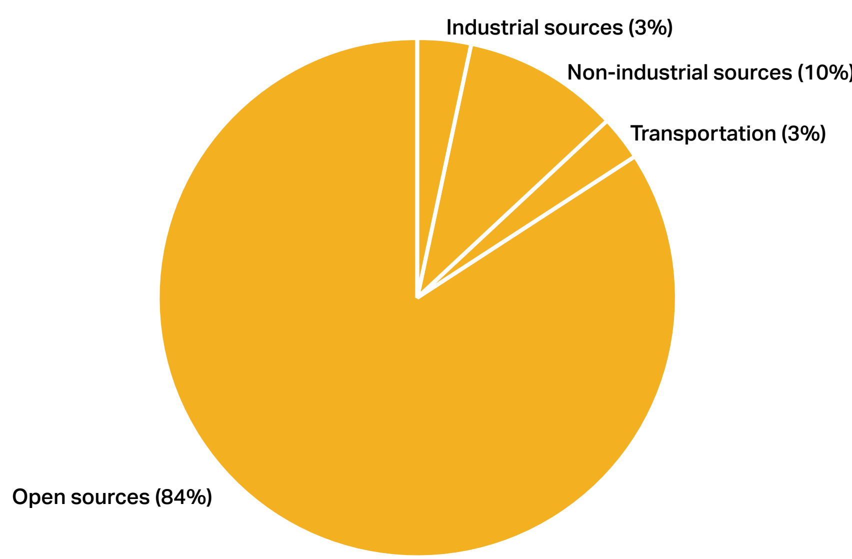
4 Fine Particulate Matter ($PM_{2.5}$)

Particulate matter (PM) is a term used to describe the composition of liquid droplets and solid particles suspended in the earth's atmosphere. Particulate matter that is 2.5 micrometers or less in diameter ($PM_{2.5}$) is emitted into the air from both natural sources and human activity. It can also form in the atmosphere through reactions of nitrate oxides, sulphur oxides, volatile organic matter, and ammonia (ECCC, 2017a). Along with ozone, fine particulate matter is a major ingredient of smog and is considered harmful to human health at sufficiently high levels. Elevated levels of $PM_{2.5}$ also causes environmental hazards like damage to vegetation, soiling, and corrosion, and reduces visibility (Ontario Ministry of Environment, 2008).

Agriculture, construction, and dust from paved and unpaved roads, which are known collectively as "open sources", accounted for 84% of $PM_{2.5}$ emissions in 2014. Of these, road dust accounted for 41%, construction 33%, and agriculture 31%. Other sources like industrial activity, home firewood burning, and transportation made up 16% of total $PM_{2.5}$ emissions. **Figure 8** shows Canadian $PM_{2.5}$ emissions by source for 2014. Home firewood burning is the major component (95%) of non-industrial sources.

As was the case for ozone, in 2013, under the adapted Air Quality Management System, new standards for $PM_{2.5}$ were proposed for 2015 and 2020. Two standards were

Figure 8: Sources of emissions of fine particulate matter in Canada, 2014



Note: Non-industrial sources include fuel combustion, power generation, and home firewood burning.
Source: Environment and Climate Change Canada, 2016c.

set, one for a 24-hour exposure and another averaged annually. The 24-hour standard was set as the 3-year moving average for the annual 98th percentile of the daily 24-hour average concentration. The annual standard was set by taking a 3-year average of the annual average concentrations. For 2015, the proposed 24-hour CAAQS for $PM_{2.5}$ is 28 micrograms per cubic meter ($\mu g/m^3$); the annual CAAQS is 10 $\mu g/m^3$.

Assessing concentrations of fine particulate matter

As before, we measured national ambient levels of fine particulate matter in the same statistical form as the corresponding standards. There is a limitation, however, in the interpretation of $PM_{2.5}$ concentrations that should be kept in mind. In mid-2000, new $PM_{2.5}$ monitoring instruments were introduced in Canada and gradually deployed to replace older monitoring instruments. [5] The new equipment measures a portion of $PM_{2.5}$ mass that was not measured by older equipment and, as a result, newer instruments report higher levels of $PM_{2.5}$ concentrations (ECCC, 2016b). As a result of the differences in the new and old monitoring instruments, some of the year-to-year variations in $PM_{2.5}$ concentrations might be attributable to the deployment of the new monitors rather than an actual change in $PM_{2.5}$ concentration.

In our analysis, we have selected only stations [6] that are operating with new technology to capture the most accurate $PM_{2.5}$ measurements. Hourly data on $PM_{2.5}$ concentrations for 71 stations across Canada, between 2000 and 2015, were obtained from the National Air Pollution Surveillance (NAPS) archive. The national ambient levels of $PM_{2.5}$ were then constructed in two ways to reflect the 24-hour and annual standards.

For a given station, all valid daily (24-hour) averages were calculated from January 1 to December 31. The summation of these daily averages and divisions by the number of valid days resulted in the station-level annual average concentration. Next, a 3-year moving average of the calculated annual averages was obtained for each station. Finally, the calculated readings were averaged for the selected stations throughout Canada, in order to calculate the national ambient levels of $PM_{2.5}$ concentrations. Figure 9 displays an average for the 3-year moving average of the annual 24-hour average $PM_{2.5}$ concentrations from 2002 to 2015, obtained from the selected monitoring stations across Canada and examined against the annual CAAQS for $PM_{2.5}$ (10 $\mu g/m^3$).

The national ambient level of $PM_{2.5}$ was consistently below the annual CAAQS for $PM_{2.5}$, over the period from 2000 to 2015 (figure 9). No significant trend was detected.

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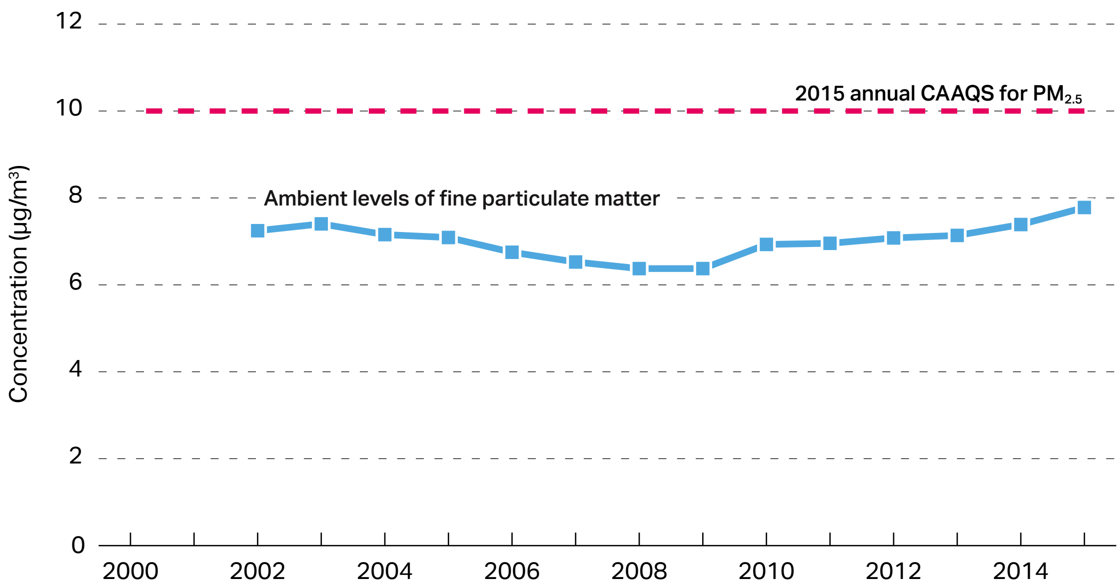
[5] For information about the new technology and a table listing the stations where the new technologies are in use and the year of installation, see Annex C. Fine Particulate Matter Measurement Technological Transition in ECCC, 2016b.

[6] With the exception of Prince Edward Island, stations from all Canadian provinces are represented in this analysis.

Figure 9: Ambient levels of fine particulate matter, annual exposure, in Canada, 2000–2015



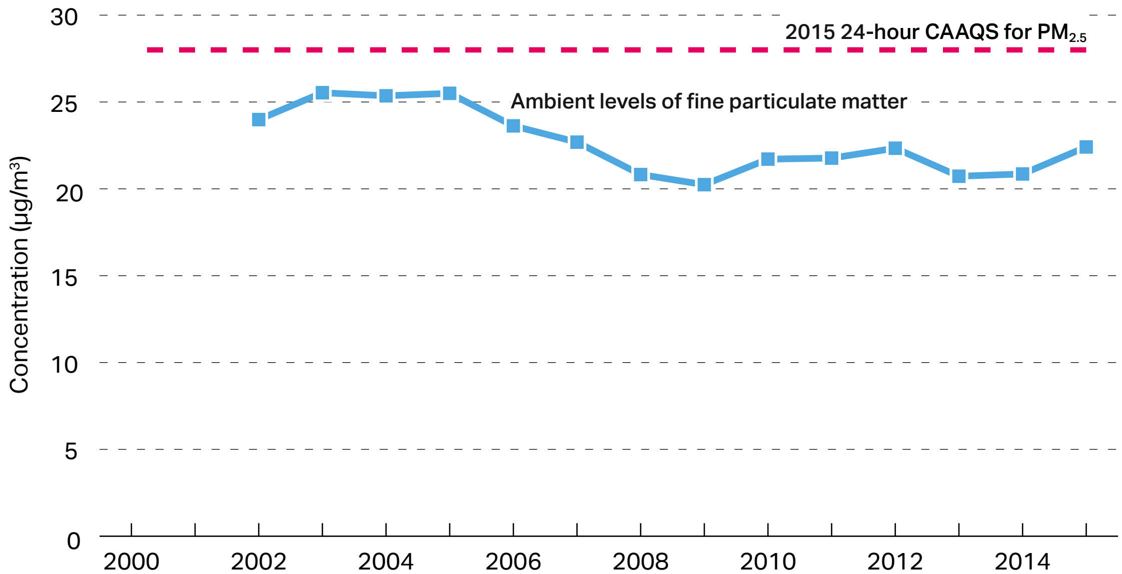
Note: Ambient levels are an average of the 3-year moving average of the annual 24-hour average concentrations (2000–2015) of $PM_{2.5}$ at selected monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Some of the factors that might have contributed to changes in $PM_{2.5}$ concentrations were variations in weather conditions, regional transport and variation in transboundary pollution from the United States, dispersion, and deployment of newer monitoring equipment (ECCC, 2017a).

The second national ambient level was constructed based on a 3-year moving average for the annual 98th percentile of the daily 24-hour average concentration to compare to the short-term standard. First, all daily averages were calculated for a given station and year. Next, the 98th percentile value of all the daily averages were calculated; this value corresponded to the station-level annual peak concentration. The 98th percentile was the value below which 98% of the daily averages fell. Subsequently, a 3-year moving average of the calculated annual peak averages was obtained for each station. The calculated readings were averaged for the selected stations throughout Canada, which resulted in the national peak ambient levels of $PM_{2.5}$ concentrations. **Figure 10** shows an average for the 3-year moving average of the annual 98th-percentile 24-hour average $PM_{2.5}$ concentrations, obtained from the selected monitoring stations across Canada and compared to the 24-hour CAAQS for $PM_{2.5}$ (28 µg/m^3).

Peak ambient levels of $PM_{2.5}$ were consistently below the 24-hour CAAQS for $PM_{2.5}$ over the period from 2000 to 2015 (figure 10). No significant trend was detected. However, the 3-year moving average for the national peak ambient levels of $PM_{2.5}$ in 2015 was 6.54% lower than in 2002.

Figure 10: Ambient levels of fine particulate matter, 24-hour exposure, in Canada, 2000–2015



Note: Ambient levels are an average of the 3-year moving average of the annual 98th-percentile 24-hour average for concentrations (2000–2015) of $PM_{2.5}$ at selected monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

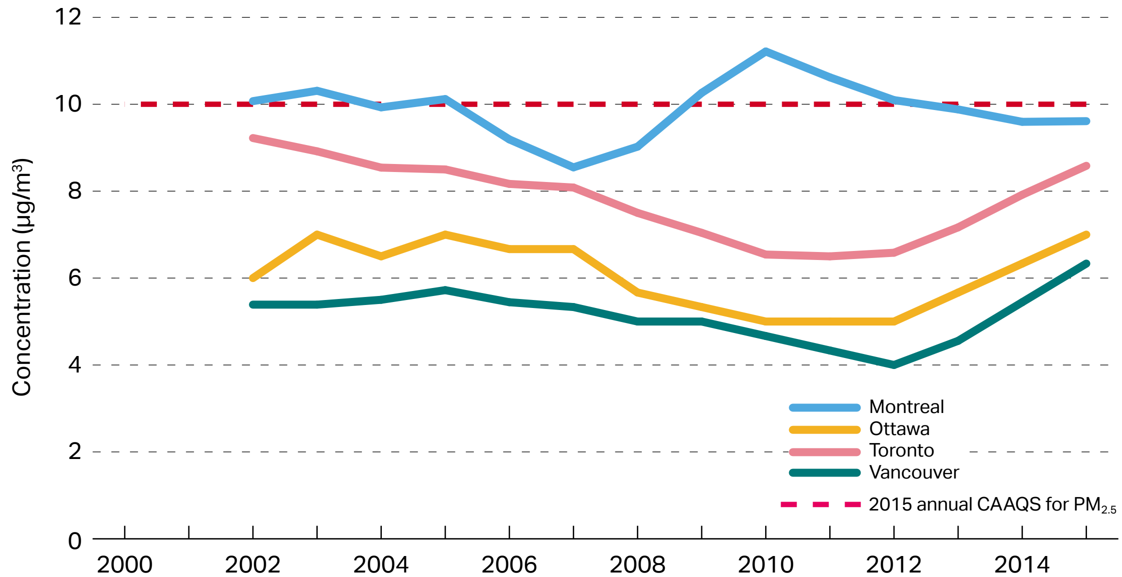
Montreal, Ottawa, Toronto, and Vancouver

Figure 11 represents ambient levels of fine particulate matter (annual metric) for four large Canadian cities [7] over the same period from 2000 to 2015, compared to the annual CAAQS. Of these cities, Montreal had the highest levels of $PM_{2.5}$ over the period but levels have decreased since 2010 and fell below the annual CAAQS in 2013. Concentrations of $PM_{2.5}$ in the other three cities were consistently below the annual CAAQS from 2000 to 2015. Unlike Montreal, concentrations have increased in Toronto, Ottawa, and Vancouver over the last five years. However, as mentioned before, these increases, at least to some extent, might be attributable to the deployment of new instruments in these cities and not necessarily to an actual increase in $PM_{2.5}$ levels.

Figure 12 shows ambient levels of peak fine particulate matter (24-hour exposure) for large Canadian cities over the period from 2000 to 2015, against the 24-hour CAAQS. For Montreal, a downward trend for peak ambient levels of $PM_{2.5}$ has been observed since 2010. Although concentrations in Montreal were mostly above the 24-hour CAAQS over the examined period, they fell below the standard in 2013. Ambient peak levels of $PM_{2.5}$ for Toronto were initially above the standard; however, they fell below the 24-hour standard in 2008 and never surpassed it again. Ambient peak levels of $PM_{2.5}$

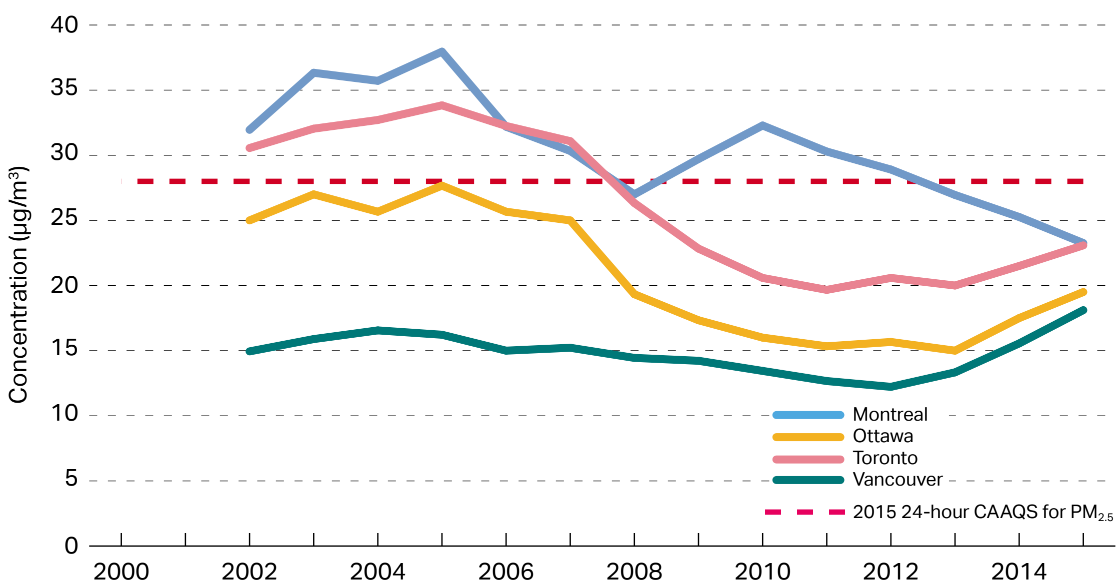
[7] Ambient levels of $PM_{2.5}$ for Vancouver are calculated based on stations in Greater Vancouver, since stations in Vancouver city were not among those selected (stations operating with new technology).

Figure 11: Ambient levels of fine particulate matter, annual exposure, in Montreal, Ottawa, Toronto, and Vancouver, 2000–2015



Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 12: Ambient levels of fine particulate matter, 24-hour exposure, in Montreal, Ottawa, Toronto, and Vancouver, 2000–2015



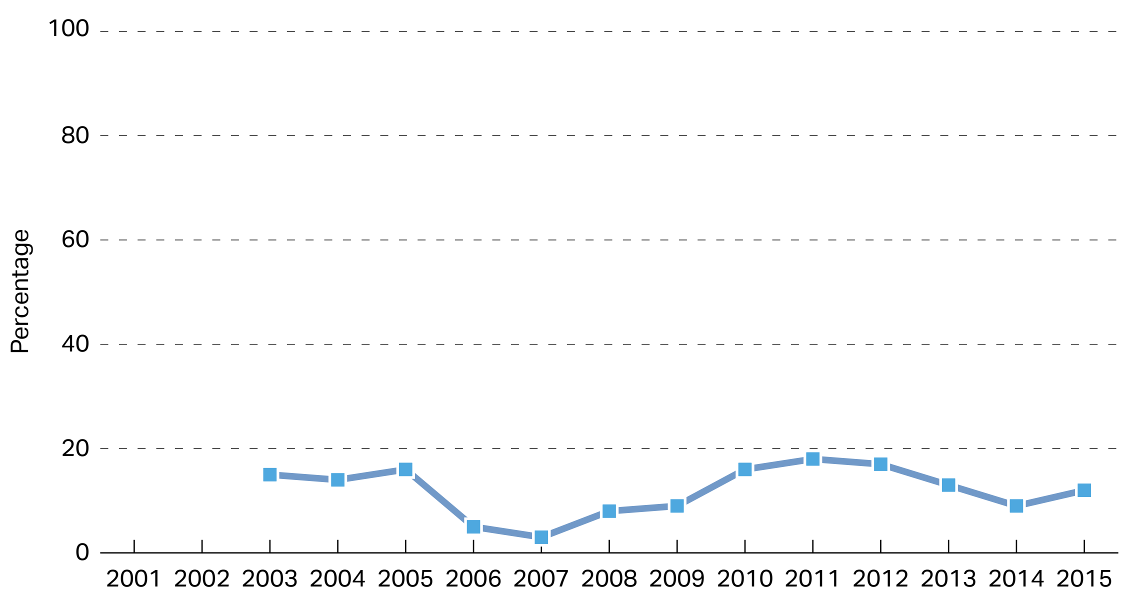
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

for Vancouver and Ottawa have been consistently below the 24-hour standard over the past 16 years. Of the four large cities examined, Vancouver had the lowest levels of peak ambient $PM_{2.5}$ concentrations.

Station-level analysis

Table 4 displays the number of stations by province with readings exceeding the annual CAAQS for $PM_{2.5}$ as well as the total number of stations. **Figure 13** shows the national percentage of stations out of compliance with the annual CAAQS for $PM_{2.5}$. No trend is apparent. The percentage of stations with readings at or above 10 μg/m³ fell from 15% between 2001 and 2003, to 12% between 2013 and 2015. Over the period from 2001 to 2003, Quebec and Ontario were the only provinces to have stations recording readings at or above the standards. Over time, while there was a reduction in the number of stations with such readings in Ontario, the number of nonconforming stations in Quebec remained relatively constant: 45% of stations in Quebec showed noncompliant readings (3 in Montreal and 2 in Quebec City out of 11). No stations in Alberta were out of compliance between 2003 and 2009; since 2010, however, some stations have had concentrations greater than, or equal to, the annual standard. All stations in Newfoundland & Labrador, Nova Scotia, New Brunswick, Manitoba, and Saskatchewan met the annual standard throughout the examined period, as did all stations in British Columbia since 2006.

Figure 13: National percentage of stations out of compliance with the current annual CAAQS for fine particulate matter, 2001–2015



Note: Percentages are calculated using the 3-year moving average of annual 24-hour average concentrations (2001-2015) for fine particulate matter at selected monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Table 4: Number of stations out of compliance with annual CAAQS $PM_{2.5}$ standard, by province, 2001–2015

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NF
2001–2003	0	0	0	0	4	5	0	0		0
Total	11	8	1	3	21	12	4	1		1
2002–2004	1	0	0	0	4	4	0	0		0
Total	11	8	1	3	22	12	4	1		1
2003–2005	1	0	0	0	4	5	0	0		0
Total	11	8	1	3	22	12	4	1		1
2004–2006	0	0	0	0	1	2	0	0		0
Total	11	8	1	3	23	12	4	1		1
2005–2007	0	0	0	0	1	1	0	0		0
Total	11	8	1	3	23	12	4	1		1
2006–2008	0	0	0	0	1	4	0	0		0
Total	11	8	1	3	24	12	4	1		1
2007–2009	0	0	0	0	1	5	0	0		0
Total	11	8	1	3	24	12	4	1		1
2008–2010	0	3	0	0	1	7	0	0		0
Total	11	9	1	3	25	12	4	1		1
2009–2011	0	4	0	0	1	7	0	0		0
Total	12	9	1	3	25	12	4	1		1
2010–2012	0	4	0	0	1	7	0	0		0
Total	12	9	1	3	25	13	4	1		1
2011–2013	0	3	0	0	0	6	0	0		0
Total	12	9	1	3	26	12	4	1		1
2012–2014	0	1	0	0	0	5	0	0		0
Total	12	9	2	3	26	12	4	1		1
2013–2015	0	1	0	0	2	5	0	0		0
Total	12	9	2	3	26	11	4	1		1

Note: Rows headed by intervals (e.g., 2001–2003) give the number of stations, by province, that had readings exceeding, or equal to the annual CAAQS $PM_{2.5}$ standard. Rows headed by "Total" give the total number of stations, by province, during the interval.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products.*

Table 5 presents the number of stations by province with readings exceeding the 24-hour CAAQS for $PM_{2.5}$, as well as the total number of stations, over the 2001-to-2015 interval. **Figure 14** displays the national percentage of stations with readings exceeding the 24-hour CAAQS for $PM_{2.5}$. It falls from 42% between 2001 and 2003 to 10% between 2013 and 2015. In recent years, from 2013 to 2015, Alberta, Saskatchewan, and British Columbia were the only provinces with stations recording readings out of compliance

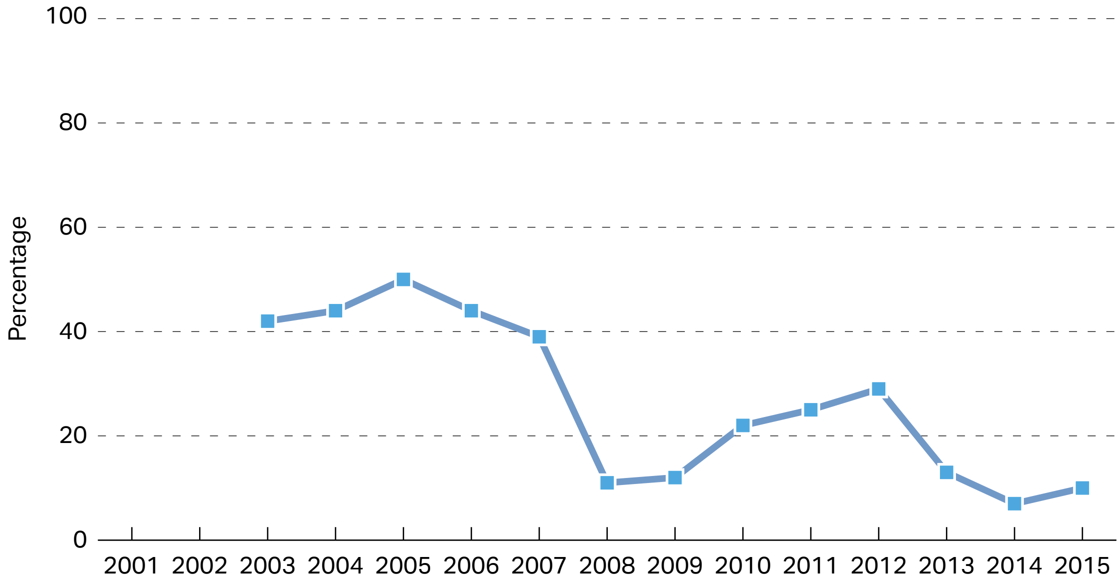
Table 5: Number of stations out of compliance with 24-hour CAAQS $PM_{2.5}$ standard, by province, 2001–2015

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NF
2001–2003	1	0	0	0	16	9	0	0		0
Total	11	8	1	3	21	12	4	1		1
2002–2004	1	0	0	0	18	9	0	0		0
Total	11	8	1	3	22	12	4	1		1
2003–2005	1	0	0	0	19	12	0	0		0
Total	11	8	1	3	23	12	4	1		1
2004–2006	1	0	0	0	18	9	0	0		0
Total	11	8	1	3	23	12	4	1		1
2005–2007	0	0	0	0	18	7	0	0		0
Total	11	7	1	3	23	12	4	1		1
2006–2008	0	1	0	0	2	4	0	0		0
Total	11	9	1	3	24	12	4	1		1
2007–2009	0	1	0	0	1	6	0	0		0
Total	11	9	1	3	24	12	4	1		1
2008–2010	4	3	0	0	0	8	0	0		0
Total	12	9	1	3	25	12	4	1		1
2009–2011	4	5	0	0	0	8	0	0		0
Total	12	9	1	3	25	13	4	1		1
2010–2012	4	6	0	0	0	10	0	0		0
Total	12	9	1	3	25	13	4	1		1
2011–2013	0	4	0	0	0	5	0	0		0
Total	12	9	1	3	26	13	4	1		1
2012–2014	2	2	0	0	0	1	0	0		0
Total	12	9	2	3	26	12	4	1		1
2013–2015	1	4	1	0	0	0	0	0		0
Total	12	9	2	3	26	12	4	1		1

Note: Rows headed by intervals (e.g., 2001–2003) give the number of stations, by province, that had readings exceeding, or equal to, the 24-hour CAAQS $PM_{2.5}$ standard. Rows headed by "Total" give the total number of stations, by province, during the interval.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

with the standard. Specifically, four stations in Alberta, located in East Edmonton, Fort McMurray, Fort McKay, and Fort Chipewyan, one station in Prince George out of 12 in British Columbia, and one station in Regina out of two in Saskatchewan reported exceeding values. Locations in Ontario have not reported exceeding values since 2010. All stations in Newfoundland & Labrador, Nova Scotia, New Brunswick, Manitoba, and Saskatchewan met the short-term standard during the examined period.

Figure 14: National percentage of stations out of compliance with the current 24-hour CAAQS for fine particulate matter, 2001–2015



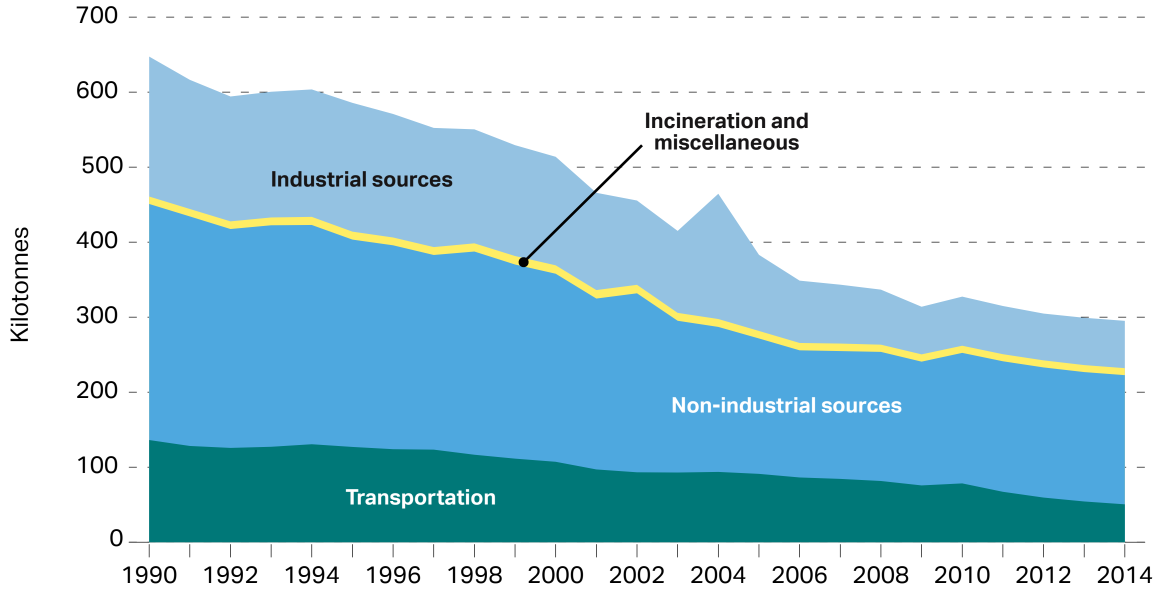
Note:Percentages are calculated using the 3-year moving average of annual 98th-percentile 24-hour average (2001-2015) for fine particulate matter at selected monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Emissions and sources

In addition to ambient levels of $PM_{2.5}$, we also examined emissions of fine particulate matter and their sources over the period from 1990 to 2014. $PM_{2.5}$ emissions in Canada (excluding open sources) decreased by 54.4% from 1990 to 2014 (**figure 15**). [8] The largest reduction in emissions (66.2%) came from industrial sources. Transportation had the second largest reduction (63%) while non-industrial sources fell by 45.2%.

[8] Open sources are diffused and often occur in areas outside urban centers. Therefore, emissions from open sources were excluded from figure 15.

Figure 15: Emissions of fine particulate matter by source, 1990–2014



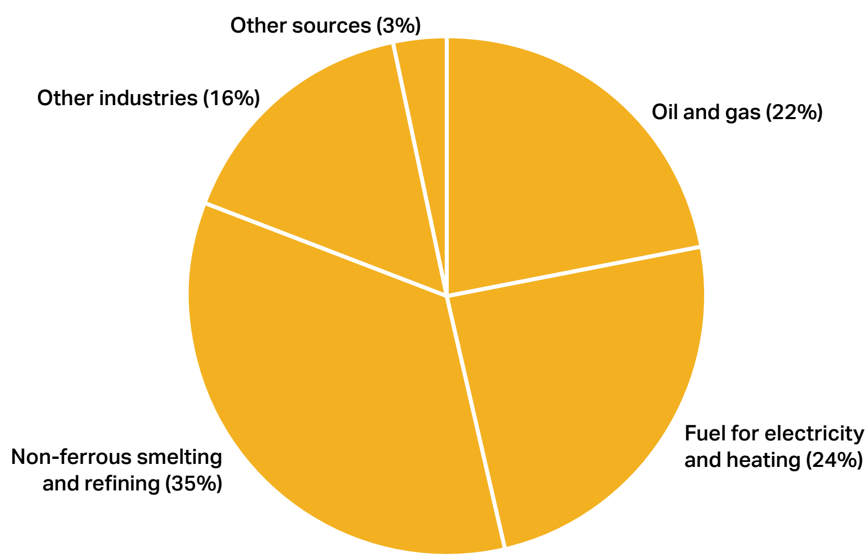
Note: Emissions from open sources are excluded.

Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

5 Sulphur Dioxide (SO_2)

Sulphur dioxide (SO_2) is a colourless and toxic gas with an irritating and pungent smell. High concentrations of SO_2 can be detrimental to human health, contributing to heightened respiratory and cardiovascular disease, respiratory difficulty and illness, and a mortality increase in infants and the elderly. Sulphur dioxide is generated by both natural resources and human activity, but human activity is the primary cause for its release. SO_2 is also known as a contributor to acid deposition. [9] According to data from Environment Canada (ECCC, 2016a), the major contributing sources of atmospheric SO_2 in Canada in 2015 were smelting and refining non-ferrous metals (35%), fuel for electricity and heating (24%), and the oil and gas industry (22%) (**figure 16**). In the same year, the aluminum industry contributed 5.4%; the pulp and paper industry, 2.3%; and the cement and concrete industry, 2.2% of emissions of atmospheric SO_2 in Canada.

Figure 16: Sources of emissions of sulphur oxides in Canada, 2015



Note: Other sources include transportation, incineration and miscellaneous, home firewood burning, and open sources.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory.*

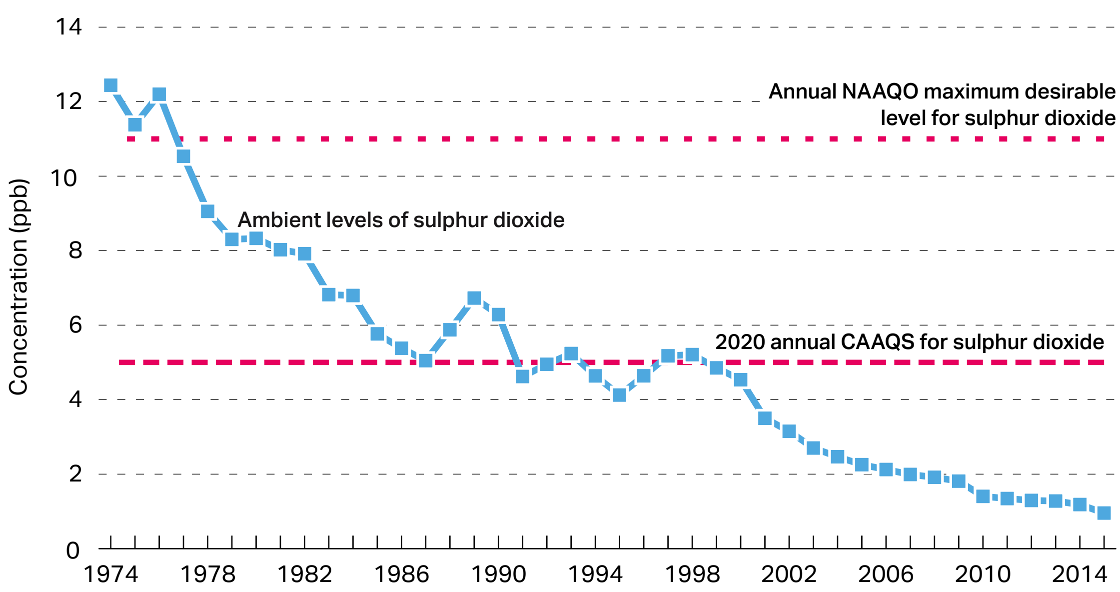
[9] "Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulfuric or nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can include rain, snow, fog, hail or even dust that is acidic" (US-EPA, 2017).

Under the NAAQO, the federal annual average Maximum Acceptable Level is 21 ppb, and the Maximum Desirable Level is 11 ppb. In October 2016, under the national Air Quality Management System, new and more stringent CAAQS for SO_2 were announced, with enforcement pending for 2020 and 2025. The new CAAQS include 1-hour standards and annual standards. The 1-hour 2020 CAAQS for SO_2 is 70 ppb, which is the 3-year average for the annual 99th percentile of the daily maximum 1-hour average concentration. The annual 2020 CAAQS for SO_2 is 5 ppb, which is the arithmetic average of all 1-hour SO_2 concentrations in a single year. As above, national ambient levels of SO_2 are measured in the statistical form aligned with the proposed CAAQS for SO_2. Therefore, two national ambient levels of SO_2 were constructed to capture both annual exposure and 1-hour exposure.

Assessing concentrations of sulphur dioxide

Figure 17 shows the average for the annual average of hourly SO_2 concentrations from monitoring stations across Canada over the period from 1974 to 2015, compared against the annual CAAQS (effective 2020) and annual maximum desirable level of NAAQS. Ambient SO_2 levels in Canada have dramatically improved since the 1970s. The ambient levels of SO_2 fell below the annual CAAQS in 1999 and have remained there. The national SO_2 concentration in 2015 is 92.3% lower than in 1974. These improvements are likely due to technological upgrades for non-ferrous metal smelters, improved emissions controls for the petroleum refining sector, and the implementation of lower-sulphur fuels (ECCC, 2016d)

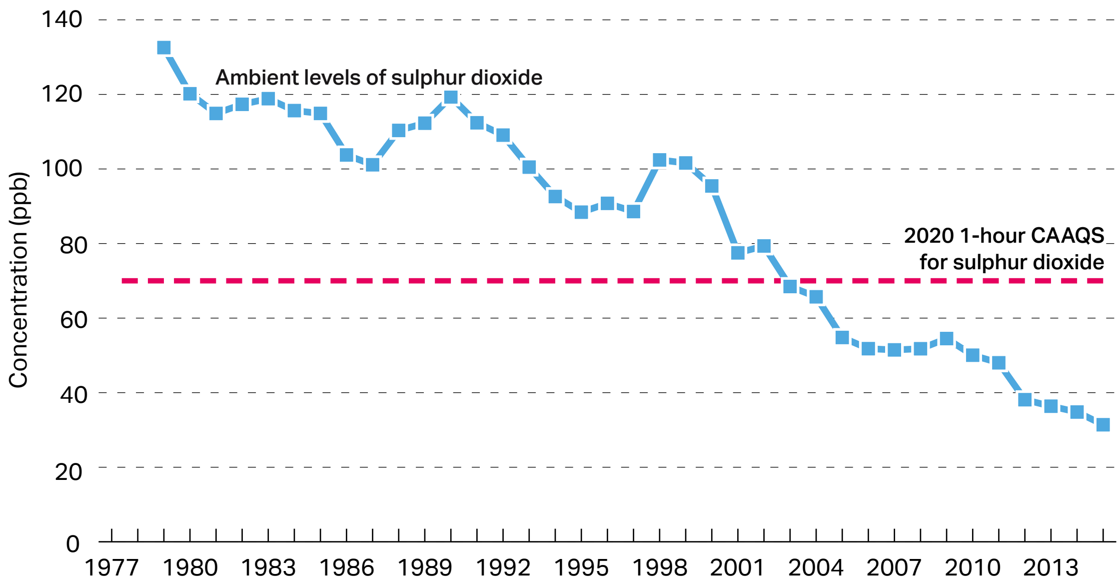
Figure 17: Ambient levels of sulphur dioxide, annual exposure, in Canada, 1974–2015



Note: Ambient levels are an average of the annual average concentrations (1974–2015) of SO_2 at monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 18 displays national 1-hour peak ambient levels of SO_2 over the period from 1977 to 2015 [10] in Canada, against the 1-hour CAAQS for SO_2 (70 ppb). This national peak ambient level of SO_2 is the average for the 3-year moving average of the annual 99th percentile daily maximum 1-hour SO_2 average at all monitoring stations across Canada. This measure also exhibits a clear downward trend. It fell below the 1-hour CAAQS in 2003 and has remained there ever since.

Figure 18: Ambient level of sulphur dioxide, 1-hour exposure, in Canada, 1977–2015



Note: Ambient levels are an average of the 3-year moving average annual 99th-percentile daily maximum 1-hour average concentrations (1977–2015) of SO2 at monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Montreal, Ottawa, Toronto, and Vancouver

Ambient levels of SO_2 (both annual and 1-hour exposure) were also calculated for four large Canadian cities over the same period from 1974 to 2015. These cities significantly reduced their SO_2 concentrations during that time (**figure 19**). Ottawa (98%) [11] and Montreal (96%) had the greatest reductions, while Toronto (92%) and Vancouver (90%) also show respectable reductions. All four cities have successfully met the annual NAAQO's strictest standard (maximum desirable) since 1983 and they have met the CAAQS standard since 2005.

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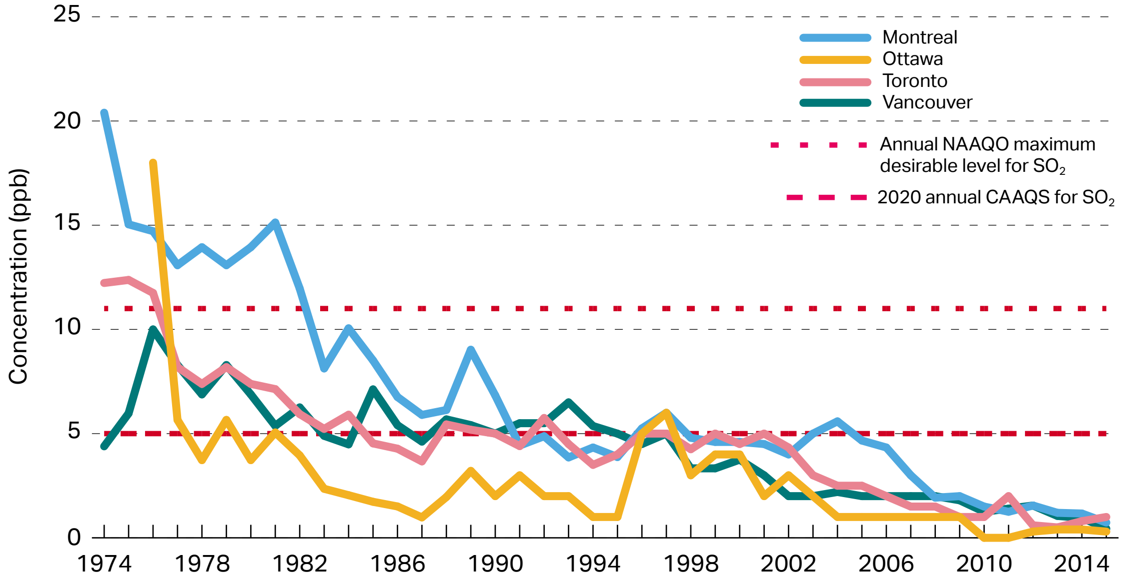
[10] Although NAPS archive provides data on SO_2 ambient levels since 1974, no hourly data is available for the year 1976. As a result, 1-hour peak ambient levels of SO_2 were calculated based on hourly data for the period from 1977 to 2015.

[11] Data for Ottawa is based on one station, 60104, which is located downtown. Data for this station is available since 1976.

Figure 19: Ambient levels of suphur dioxide, annual exposure, in Montreal, Ottawa, Toronto, and Vancouver, 1974–2015



Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

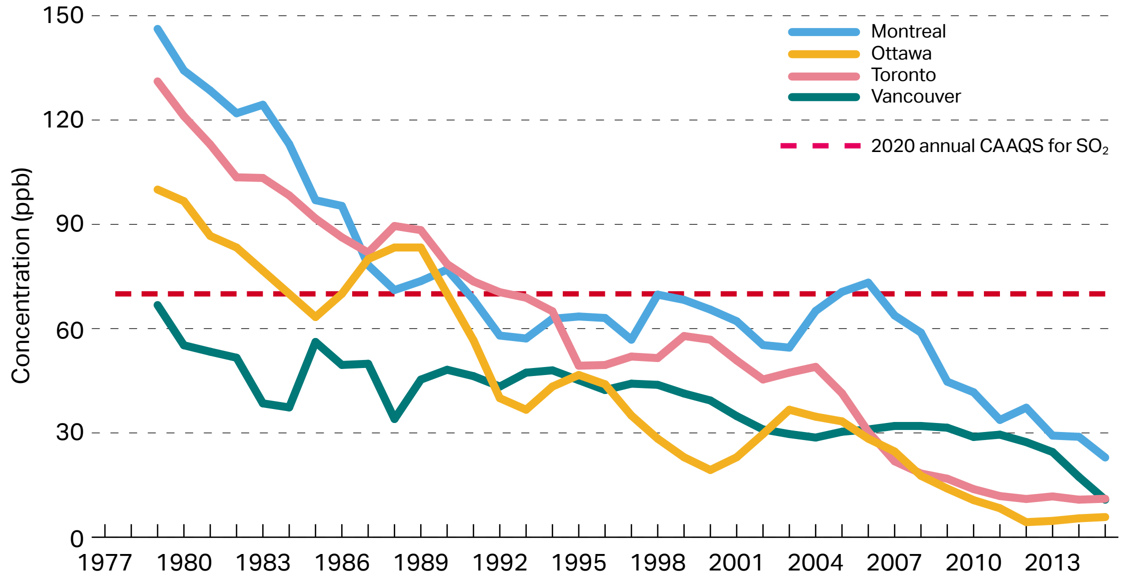
Ambient 1-hour peak levels of SO_2 were also significantly reduced in the four cities over this period (**figure 20**). Ottawa (94.2%) and Toronto (91.5%) had the greatest reductions. Toronto's ambient 1-hour peak level of SO_2 moved below the standard in 1993 and never rose above it again. Peak SO_2 concentrations for Ottawa fell below the standard in 1991 and have remained there ever since.

Since the late 1990s, Montreal had the highest peak ambient levels among these four cities. However its levels fell by 84.3% over the sample period and were regularly below the standard between 2007 and 2015. Vancouver achieved an 83.8% reduction in its peak SO_2 levels over the same period and its peak SO_2 levels were consistently below the standard.

Station-level analysis

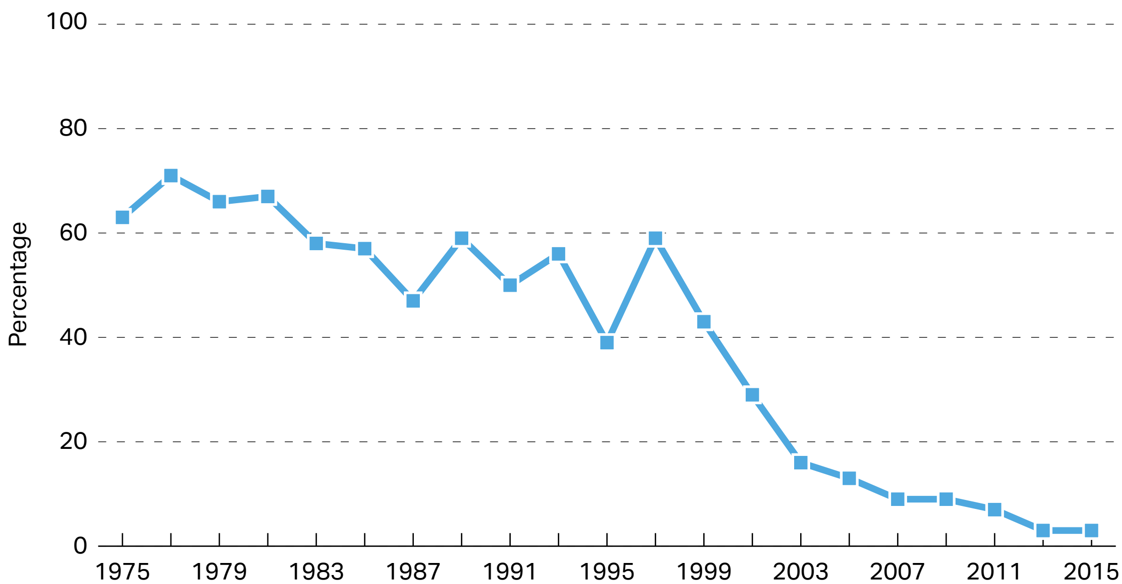
Station-level analysis also reaffirmed the downward trend observed over the period of 1975 to 2015 for SO_2 concentrations in Canada. The percentage of stations with readings exceeding the SO_2 annual CAAQS objective (5 ppb) fell from 63% in 1975 to 3% in 2015 (**figure 21**). As shown in **table 6**, all provinces, except Alberta, decreased their number of stations with exceeding readings over the period. From 2013 to 2015, Quebec, Alberta, and British Columbia were the only provinces to continue having stations with readings above the objective, though there were only four in total. Newfoundland & Labrador, Prince Edward Island, and New Brunswick showed the greatest improvement in reducing the number of nonconforming stations. During the examined period, stations in Saskatchewan consistently reported values below the standard.

Figure 20: Ambient levels of suphur dioxide, 1-hour exposure, in Montreal, Ottawa, Toronto, and Vancouver, 1977–2015



Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 21: National percentage of stations out of compliance with the 2020 annual CAAQS for sulphur dioxide, 1975–2015



Note: Percentages are calculated using the annual average SO_2 concentrations from stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

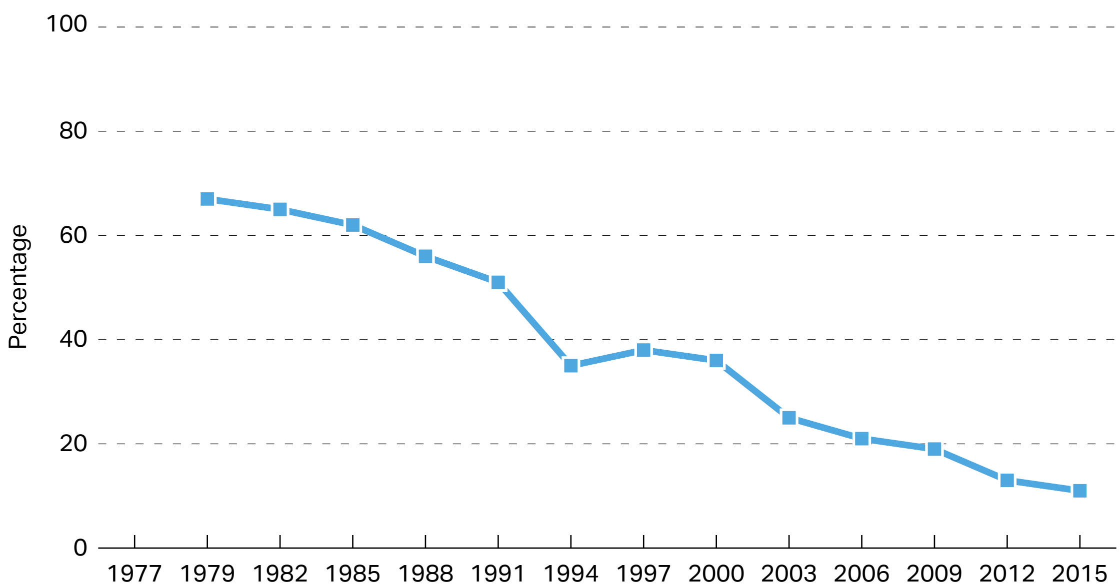
Table 6: Number of stations out of compliance with annual CAAQS SO_2 standard, by province, 1975–2015

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NF
1975	4	0	0	0	14	16	1	4	1	1
Total	8	6	4	5	15	19	1	5	1	1
1977	5	0	0	2	27	21	1	3	1	1
Total	8	6	4	5	29	24	1	5	1	1
1979	4	0	0	0	26	21	1	5	1	1
Total	7	7	5	5	30	25	1	6	1	1
1981	4	0	0	0	22	21	1	4	1	1
Total	6	6	4	2	31	23	1	6	1	1
1983	2	0	0	0	16	20	1	5	1	1
Total	7	2	4	2	31	24	1	6	1	1
1985	4	0	0	0	17	14	1	3	1	1
Total	6	2	4	2	29	20	1	6	1	1
1987	3	0	0	0	16	10	2	2	0	1
Total	6	2	4	2	29	21	2	4	1	1
1989	2	0	0	0	19	17	2	2	0	1
Total	6	2	2	2	30	23	2	4	1	1
1991	2	0	0	0	17	5	1	1	0	1
Total	6	5	2	2	29	18	1	1	1	1
1993	3	0	0	0	15	8	2	4	0	1
Total	5	5	2	0	26	14	2	4	0	1
1995	1	0	0	0	12	1	1	4	0	0
Total	6	5	2	0	22	8	1	4	1	0
1997	1	0	0	0	17	10	2	0	0	0
Total	5	5	2	0	23	13	2	0	0	0
1999	3	0	0	0	14	9	2	0	0	0
Total	16	4	2	0	23	18	2	1	0	1
2001	2	0	0	0	12	10	1	1	0	0
Total	21	19	2	0	23	19	2	2	0	1
2003	1	0	0	1	4	6	1	1	0	0
Total	25	18	2	1	18	16	2	2	0	2
2005	1	0	0	1	4	6	1	1	0	0
Total	32	30	3	1	19	17	2	1	0	2
2007	1	0	0	1	3	4	1	0	0	0
Total	36	32	3	1	17	17	2	2	0	1
2009	4	0	0	1	1	3	0	0	1	0
Total	34	34	3	2	16	17	2	1	1	2
2011	4	1	0	0	2	1	0	0	0	0
Total	40	31	4	3	10	13	3	4	0	3
2013	3	0	0	0	0	1	0	0	0	0
Total	38	40	4	3	11	9	4	3	0	5
2015	2	1	0	0	0	1	0	0	0	0
Total	38	45	4	3	11	10	4	4	1	6

Note: Rows headed by dates (e.g.,1975) give the number of stations, by province, that had readings exceeding, or equal to, the annual CAAQS SO_2 standard. Rows headed by "Total" give the total number of stations, by province, during the interval.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products.*

Figure 22 displays the national percentage of stations out of compliance with the 1-hour CAAQS for SO_2. The number of stations with exceeding readings has clearly declined over time, from 67% during the 1977-to-1979 interval to 11% during the 2013-to-2015 interval. The provincial patterns are very similar to those in table 6 and are not shown. In all provinces, the number of nonconforming stations decreased. Two stations out of 13 in Quebec, three out of 11 in Ontario, one out of 4 in Manitoba, two out of 51 in Alberta, and eight out of 54 in British Columbia recorded readings out of compliance during the 2013-to-2015 interval. As before, Newfoundland & Labrador, Prince Edward Island, and New Brunswick showed the greatest improvements, reducing the number of their nonconforming stations from 100% to 0% over the examined period. Throughout the same time frame, stations in Saskatchewan consistently reported values below the standard.

Figure 22: National percentage of stations out of compliance with the 1-hour CAAQS for sulphur dioxide, 1977–2015

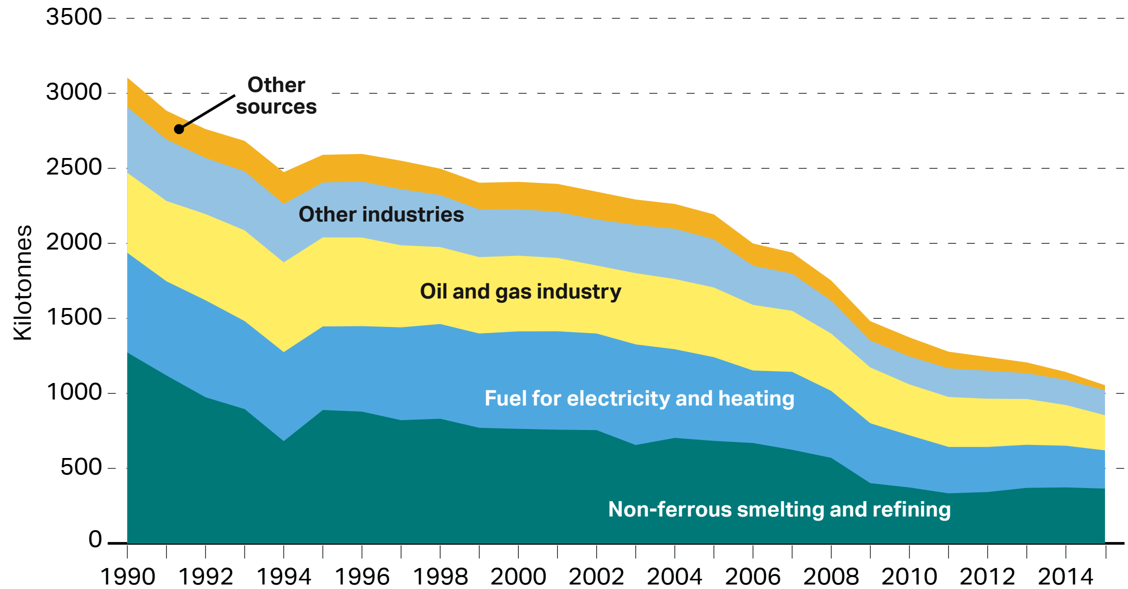


Note: Percentages are calculated using the 3-year moving average of annual 99th-percentile daily maximum 1-hour average concentrations (1977–2015) for sulphur dioxide at monitoring stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Emissions and sources

Figure 23 displays emissions of sulphur oxide (SO_x) in Canada, by source, over the period from 1990 to 2014. They fell 66.1% from 1990 to 2015. The largest reductions (71.3%) were in non-ferrous smelting and refining. Emissions from power generation and fuel combustion fell by 61.6%, those from the oil and gas industry by 56.1%.

Figure 23: Emissions of sulphur oxides, by source, 1990–2015



Note: Other sources include transportation, incineration and miscellaneous, home firewood burning, and open sources.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

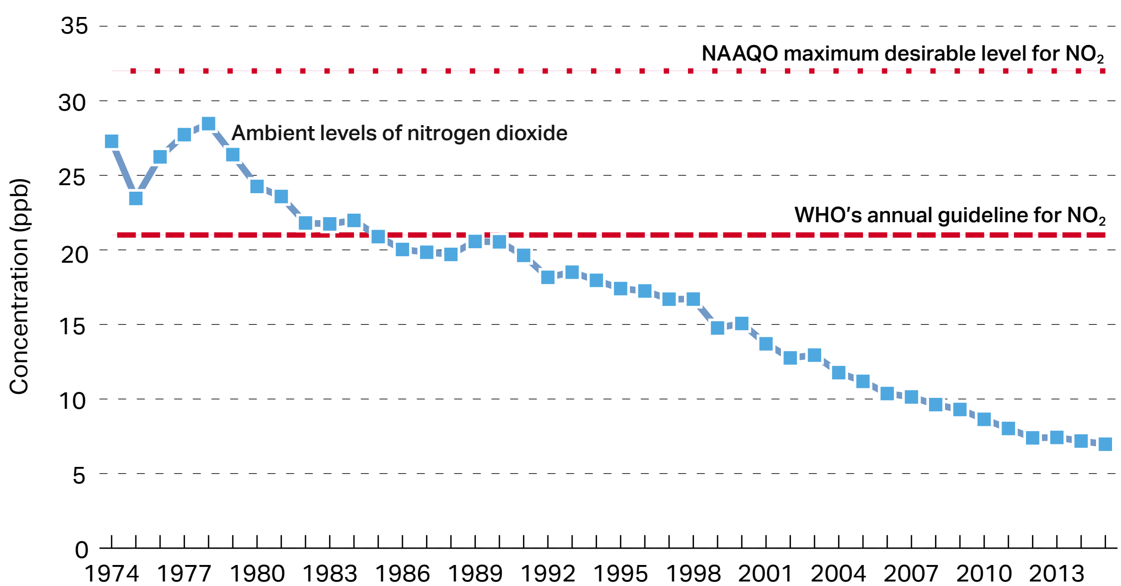
6 Nitrogen Dioxide (NO_2)

Nitrogen dioxide (NO_2) is a reddish-brown toxic gas with an irritating smell. Nitrogen dioxide contributes to the formation of ozone, a major component of smog. It is also a precursor to nitrates and fine particulate matter. Emissions from NO_2 contribute to lake eutrophication and acid depositions (ECCC, 2017c). Exposure to high levels of NO_2 is linked to respiratory problems, reduced lung function, and increased mortality. As discussed and shown previously in figure 1, major sources of NO_2 emissions in Canada in 2014 were transportation (54%), the oil and gas industry (23%), and fuel for electricity and heating (12%). Additional sources, which include home firewood burning, incineration and miscellaneous, and open sources, accounted for 11%.

Assessing concentrations of nitrogen dioxide

Figure 24 displays ambient concentrations in Canada over the period from 1974 to 2015. Since no new CAAQS for NO_2 have been proposed, we used the currently existing National Ambient Air Quality Objectives (NAAQO) and the guidelines of the World Health Organization (WHO) for NO_2 as benchmarks. The 1-hour Maximum Acceptable

Figure 24: Ambient levels of nitrogen dioxide in Canada, 1974–2015



Note: Ambient levels are an average of the annual average concentrations (1974–2015) of NO_2 at monitoring stations across Canada

Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

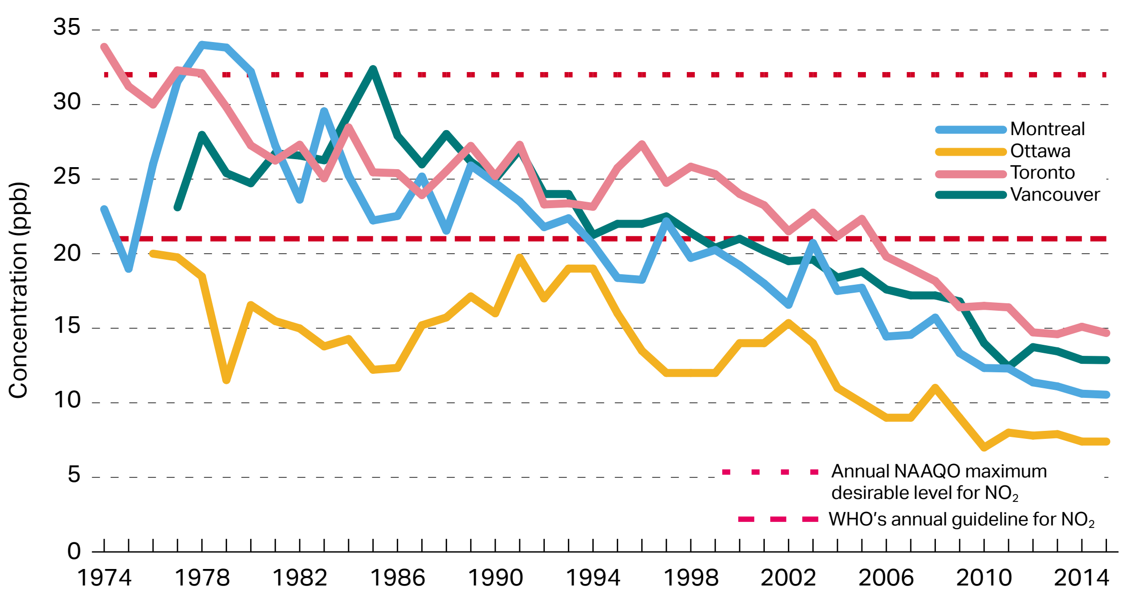
Level NAAQO for NO_2 is 213 parts per billion (ppb). The annual Maximum Desirable level for NO_2 is 32 ppb and the Maximum Acceptable level is 53 ppb. However, the World Health Organization's guidelines proposed in 2005 are more stringent than the NAAQO: the WHO's guidelines for 1-hour NO_2 concentration is 106 ppb and, for annual concentrations, 21 ppb.

The national ambient level of NO_2 was based on the average for the annual average of hourly NO_2 concentrations from stations across Canada. From 1974 to 2015 ambient levels of NO_2 in Canada decreased by 74.4% (figure 24) and, in addition, Canadian ambient levels of NO_2 were consistently well below the strictest level of NAAQO and have been below the standard set by the WHO's guideline since 1985.

Montreal, Ottawa, Toronto, and Vancouver

City trends show similar results. **Figure 25** displays ambient levels of NO_2 in four large Canadian cities from 1974 to 2015. During this time, all four cities reported decreasing levels of NO_2. The largest improvements were in Ottawa, where ambient levels of NO_2 declined by 63%, and Toronto, where levels declined by 56.6%. In addition, NO_2 ambient levels in all these cities have been well below the annual strictest level for NAAQO since 1986. With respect to the WHO'S annual guideline, all cities have performed to this standard since 2006.

Figure 25: Ambient levels of nitrogen dioxide, annual exposure, in Montreal, Ottawa, Toronto, and Vancouver, 1974–2015



Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Station-level analysis

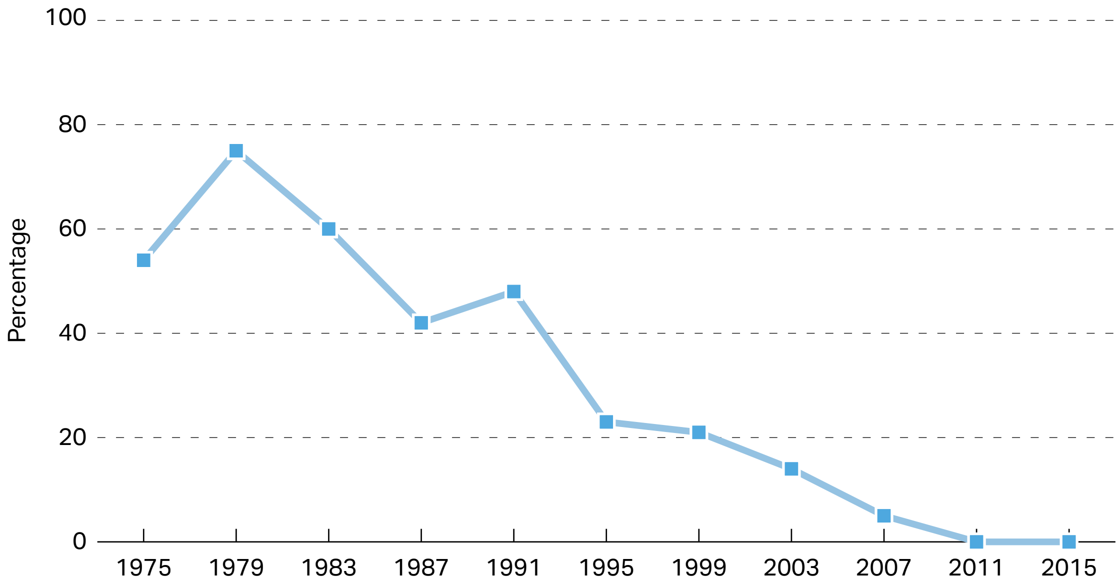
Station-level analysis shows similar results. First, we examined stations focusing on readings at, or in excess of, the annual NAAQO. Under the annual NAAQO, since 1995, no stations have reported readings that were equal to, or greater than, 32 ppb. Since the WHO's guidelines for NO_2 (21 ppb) are more stringent than the NAAQO, we retabulated the data against this standard (**table 7** and **figure 26**). The national percentage of stations exceeding the WHO's annual guideline decreased from 54% in 1975 to 0% in 2015. Since 2011, all stations throughout Canada have conformed to WHO's annual guideline.

Table 7: Number of stations out of compliance with the WHO's NO_2 annual guideline, by province, 1975–2015

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NF
1975	0	4	0	0	9	1	0	0	0	0
Total	0	4	0	1	13	6	0	2	0	0
1979	4	5	1	0	16	9	0	1	0	0
Total	6	5	1	2	21	11	0	2	0	0
1983	5	3	0	0	15	11	0	0	0	0
Total	6	4	1	2	28	13	1	2	0	0
1987	8	2	1	0	14	6	0	0	0	0
Total	15	5	2	2	31	12	2	2	0	0
1991	8	5	0	0	13	3	0	1	0	0
Total	13	8	1	2	30	7	0	1	0	1
1995	4	3	0	0	6	2	0	0	0	0
Total	19	9	2	2	22	8	1	1	0	0
1999	2	4	0	0	8	3	0	0	0	0
Total	26	13	2	2	19	17	1	0	0	1
2003	2	4	0	0	4	3	0	0	0	0
Total	28	18	2	3	18	15	3	0	0	3
2007	1	2	0	0	2	2	0	0	0	0
Total	33	30	2	3	35	18	3	2	0	1
2011	0	0	0	0	0	0	0	0	0	0
Total	34	34	4	2	37	19	4	6	0	4
2015	0	0	0	0	0	0	0	0	0	0
Total	36	39	3	3	38	14	5	5	3	5

Note: Rows headed by dates (e.g.,1975) give the number of stations, by province, that had readings exceeding, or equal to, the WHO's annual guidelines for nitrogen dioxide. Rows headed by "Total" give the total number of stations, by province, during the interval.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products.*

Figure 26: National percentage of stations out of compliance with the WHO's annual guideline for nitrogen dioxide, 1975–2015



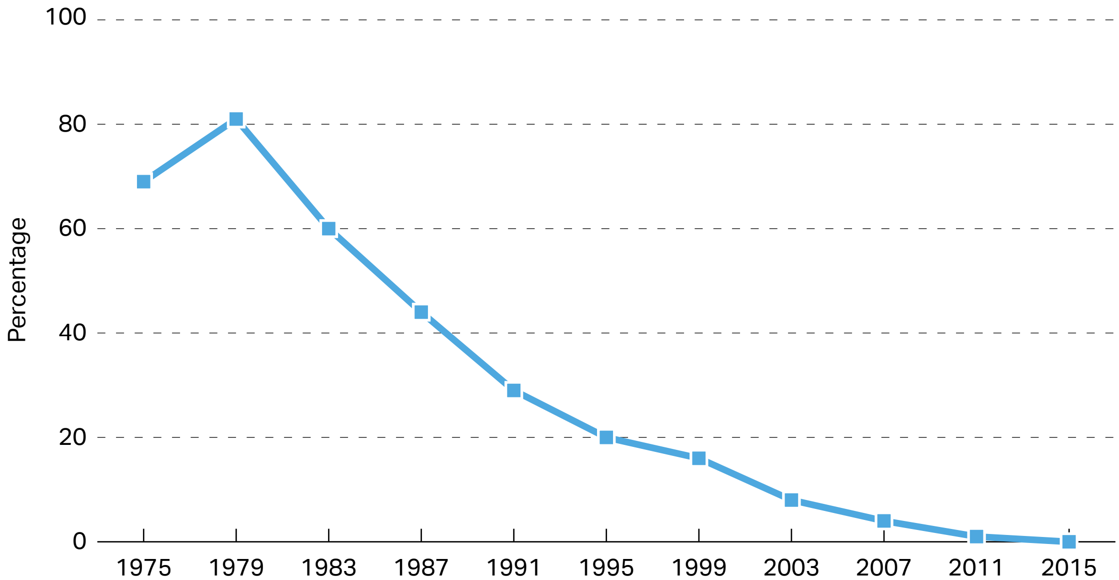
Note: Percentages are calculated using the annual average NO_2 concentrations (1975–2015) from stations across Canada.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

A similar trend was found when examining stations against the WHO's 1-hour objective. Measured by the 1-hour NAAQO for NO_2, no stations have had non-conforming values since 2002. Under the WHO's 1-hour guideline, the percentage of stations with readings at, or in excess of, the 1-hour guideline fell from 69% in 1975 to 0% in 2015 (**figure 27**).

Emissions and sources

Nitrogen oxide (NO_x) emissions, along with their Canadian sources, were shown in figure 7 (p. 16) and the discussion of ground-level ozone (O_3): emissions of nitrogen oxide decreased by 32.6% during the period from 1990 to 2014. The largest source of reduction in emissions was attributed to transportation, where they fell by 43% over this period. Reduction in emissions from fuel combustion and power generation by 28.12% likewise contributed to the decline in NO_x emissions.

Figure 27: National percentage of stations out of compliance with the WHO's 1-hour guideline for nitrogen dioxide, 1975–2015



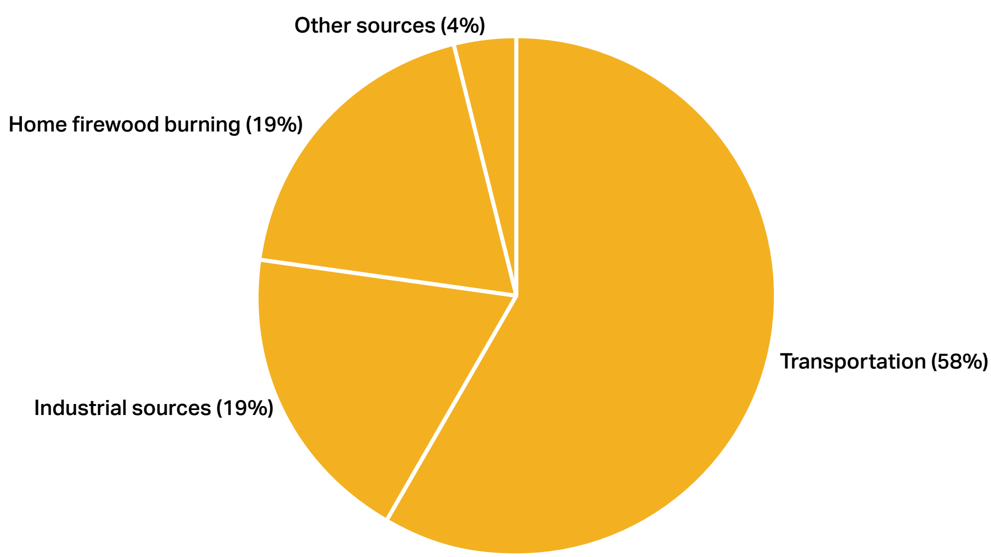
Note: Percentages are calculated considering stations with at least one 1-hour average concentration equal to, or greater than, the WHO's 1-hour guideline for nitrogen dioxide.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

7 Carbon Monoxide (CO)

Carbon monoxide (CO) is a highly toxic, colourless, odourless, and tasteless gas that is produced from incomplete combustion of hydrocarbon-based fuels (ECCC, 2016e). Levels of carbon monoxide are of particular concern, because they can have a significant adverse impact on human health. When carbon monoxide is inhaled, it reduces the blood's capacity to transport oxygen to organ and tissues. High levels of CO can cause dizziness, unconsciousness, brain damage, and death. According to data from Environment Canada, in 2014, major sources of carbon monoxide emissions in Canada were transportation (58%), home firewood burning (19%), and industry (19%) (**figure 28**). Other sources, including incineration and miscellaneous, fuel for electricity and heating, and open sources accounted for 4% of the total emissions (ECCC, 2016a).

For carbon monoxide, the only existing benchmarks are those of the NAAQO as neither the new proposed CAAQS nor the WHO's guidelines include any recommendations for carbon monoxide. Currently, there are two existing NAAQO for CO: one averaged over one hour and another averaged over 8 hours. Since adverse health effects occur as a result of short exposure to CO, no annual objective is set for its concentration. The 1-hour maximum desirable level for CO concentration is 13 ppb; the 8-hour level is 5 ppb.

Figure 28: Sources of emissions of carbon monoxide in Canada, 2014

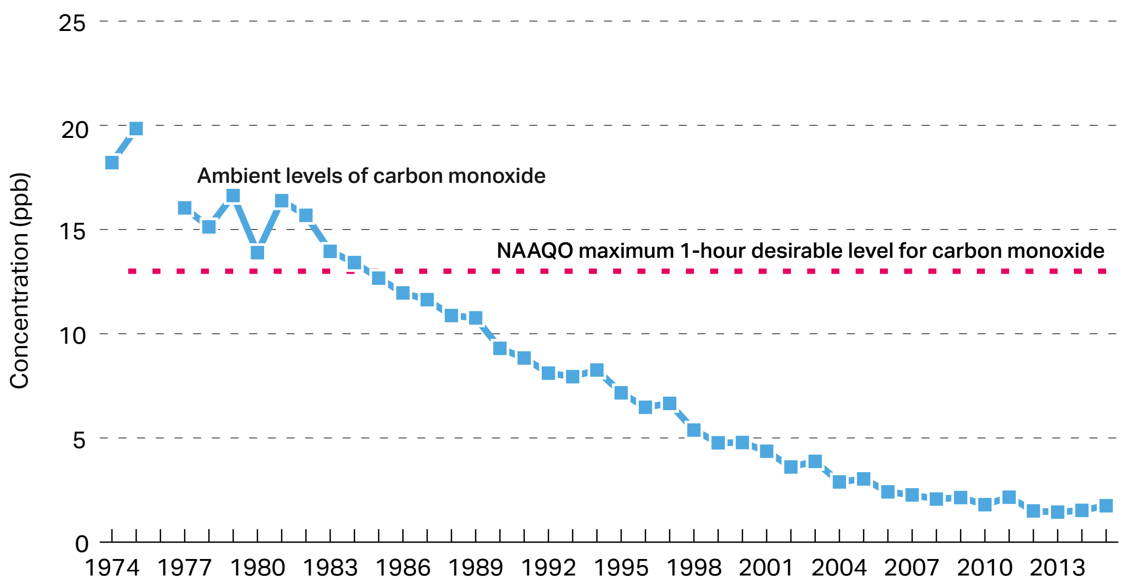


Note: Other sources include incineration and miscellaneous, home firewood burning, and open sources.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

Assessing concentrations of carbon monoxide

Figure 29 displays the average of the annual maximum 1-hour average concentrations from all stations across Canada over the period from 1974 to 2015, [12] compared against the 1-hour NAAQO maximum desirable level for carbon monoxide. Over this period of time, ambient levels of CO in Canada decreased by 90.4%. Canadian ambient levels of CO fell below the strictest level for NAAQO in 1985 and have remained there ever since. In addition, a decreasing annual trend of −0.45 ppb for CO concentrations was detected within the same period.

Figure 29: Ambient levels of carbon monoxide in Canada, 1974–2015



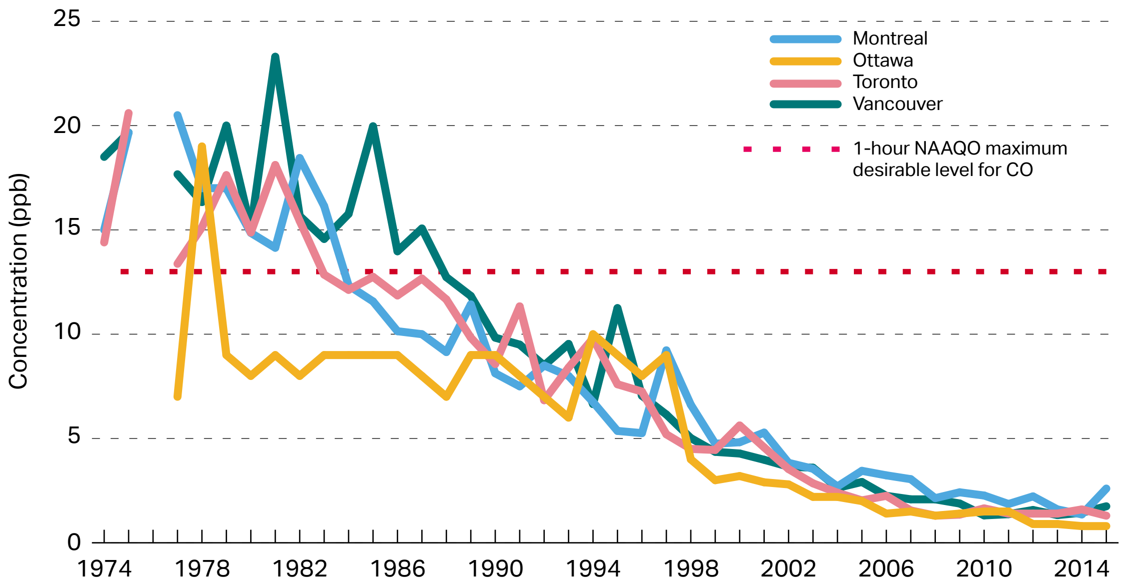
Notes: Ambient levels are an average of the annual maximum 1-hour average concentrations (1974–2015) of CO at all monitoring stations across Canada. 1976: data is missing.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Montreal, Ottawa, Toronto, and Vancouver

City data reveal trends similar to the national average. All four large cities have dramatically decreased their CO levels throughout the past four decades (**figure 30**). Toronto (90.9%) and Vancouver (90.5%) experienced the greatest reductions. Ottawa (88.5%) and Montreal (82.6%) also showed significant reductions. Since 1988, carbon monoxide concentrations in all cities have remained consistently below the standard.

[12] Data for the year 1976 is missing as the NAPS archive provides no hourly data for CO concentration levels for that year.

Figure 30: Ambient levels of carbon monoxide in Montreal, Ottawa, Toronto, and Vancouver, 1974–2015



Notes: Data is missing for all cities in 1976; data for Ottawa begins in 1977.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Station-level analysis

The percentage of stations with a reading exceeding the 1-hour NAAQO CO standard has also decreased over the same period, falling from 84% in 1975 to 0% in 2015 (**figure 31**). During the same period, all provinces experienced a decline in the number of stations that were non-compliant with the standard (**table 8**). In 2015, no province had stations with readings equal to, or greater than, the standard. Indeed, since 1999 all stations in all provinces conformed to the standard, with the exception of one station in Saint John, New Brunswick in 2011.

Emissions and sources

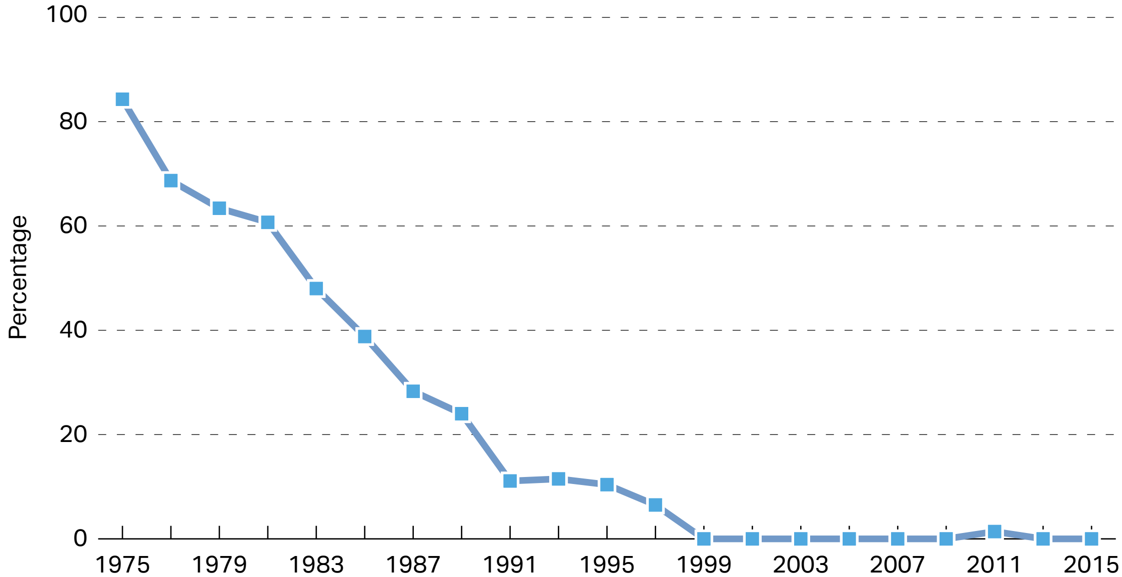
Carbon monoxide emissions are displayed by source in **figure 32** for the period from 1990 to 2014. Carbon monoxide emissions in Canada decreased 61.8% between 1990 and 2014. The largest reduction in emissions came from transportation (70%), attributed to the introduction of more efficient and cleaner technology in vehicles. Further reductions were seen from industrial sources, where emissions fell by 41.5%, and home firewood burning, where they fell by 27.8%.

Table 8: Number of stations out of compliance with 1-hour NAAQO CO standard, by province, 1975–2015

	NF	PE	NS	NB	QC	ON	MB	SK	AB	BC
1975	0	0	0	0	4	10	2	2	4	5
Total	0	0	0	0	6	12	2	2	5	5
1977	0	0	1	0	9	12	2	1	4	4
Total	2	0	2	0	10	19	3	2	5	6
1979	0	0	1	1	8	13	1	0	5	4
Total	0	0	1	1	11	21	3	3	6	5
1981	1	0	1	1	7	13	0	1	4	3
Total	1	0	1	1	12	22	2	2	5	5
1983	0	0	1	1	7	5	0	2	5	4
Total	1	0	1	1	12	21	2	2	5	7
1985	0	0	1	0	5	5	1	0	3	6
Total	1	0	1	1	12	23	2	2	5	7
1987	0	0	0	0	2	5	1	0	4	2
Total	1	0	1	1	12	23	2	2	5	5
1989	0	0	0	0	3	4	0	1	4	1
Total	1	0	1	1	13	23	2	2	5	5
1991	0	0	0	0	0	2	0	0	3	0
Total	1	0	1	2	13	20	2	2	7	5
1993	0	0	0	0	0	3	0	0	3	0
Total	1	0	1	1	12	19	2	2	8	6
1995	0	0	0	0	0	0	0	0	4	1
Total	1	0	1	1	8	19	2	2	8	5
1997	0	0	0	0	1	0	0	0	2	0
Total	1	0	0	1	7	18	2	2	8	6
1999	0	0	0	0	0	0	0	0	0	0
Total	1	0	0	3	9	19	2	2	7	14
2001	0	0	0	0	0	0	0	0	0	0
Total	2	0	1	3	11	21	2	2	9	21
2003	0	0	0	0	0	0	0	0	0	0
Total	3	0	1	3	11	20	2	2	9	23
2005	0	0	0	0	0	0	0	0	0	0
Total	3	0	2	3	11	9	2	2	12	27
2007	0	0	0	0	0	0	0	0	0	0
Total	3	0	1	3	11	10	2	1	11	26
2009	0	0	0	0	0	0	0	0	0	0
Total	4	0	0	3	8	8	2	2	12	23
2011	0	0	0	1	0	0	0	0	0	0
Total	4	0	2	3	11	4	2	2	11	26
2013	0	0	0	0	0	0	0	0	0	0
Total	5	0	2	3	8	4	2	2	12	21
2015	0	0	0	0	0	0	0	0	0	0
Total	5	0	2	3	10	4	2	2	13	21

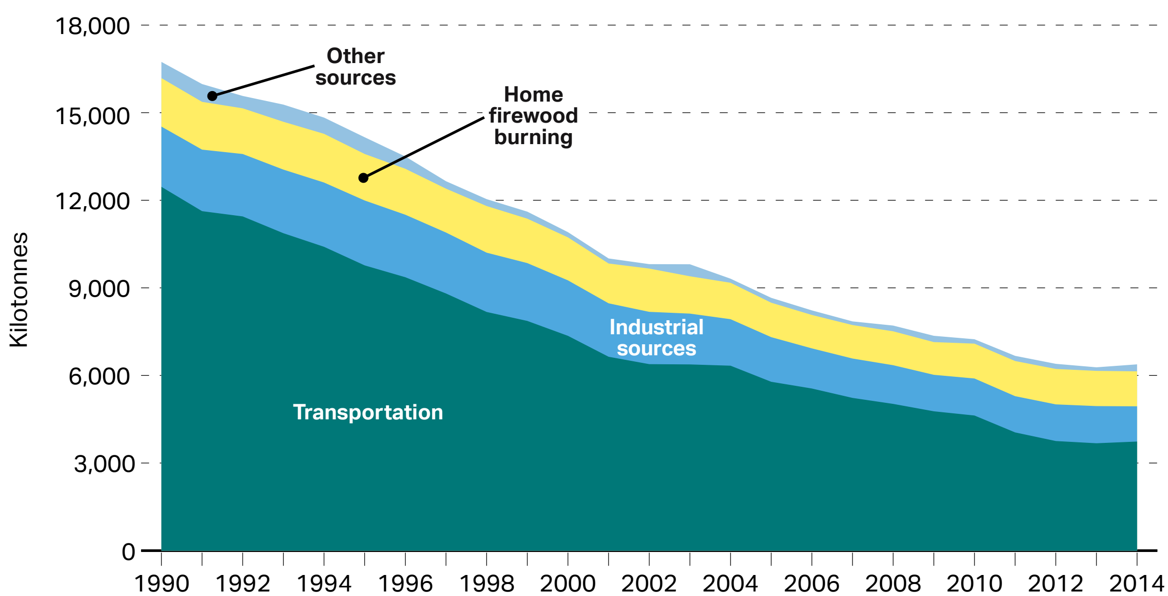
Note: Rows headed by dates (e.g.,1975) give the number of stations, by province, that had readings exceeding, or equal to, the 1-hour NAAQO CO standard. Rows headed by "Total" give the total number of stations, by province, during the interval.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 31: National percentage of stations out of compliance with the 1-hour NAAQO for carbon monoxide, 1975–2015



Note: Percentages are calculated considering stations that have at least one 1-hour average CO concentration greater than, or equal to, the 1-hour NAAQO for carbon monoxide.
Source: Environment and Climate Change Canada, 1974–2015, *NAPS Data Products*.

Figure 32: Emissions of carbon monoxide, by source, 1990–2014

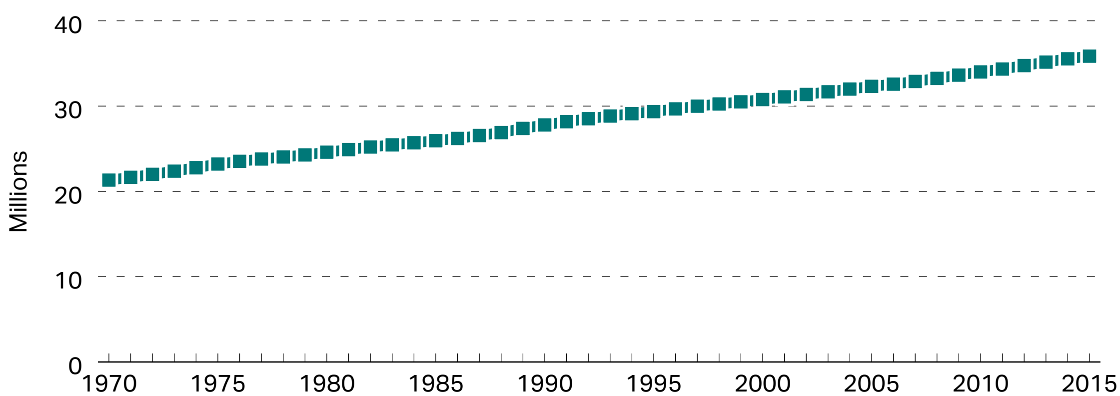


Note: Other sources include incineration and miscellaneous, fuel for electricity and heating, and open sources.
Source: Environment and Climate Change Canada, 2016a, *Air Pollutant Emission Inventory*.

8 Socioeconomic Trends

The previous sections clearly show that air pollution has improved in Canada since the 1970s. This took place while the main indicators of economic activity in Canada have risen substantially. Contrasting socioeconomic and environmental indicators makes clear the extent to which Canada has decoupled economic growth from environmental pollution. From 1970 to 2015, Canada's population increased 68.1% (**figure 33**). Over the same interval, real gross domestic product (GDP) grew by over 240% (**figure 34**). From 1980 to 2015, consumption of motor fuel in Canada rose by 26.3% (**figure 35**) and, from 1995 to 2015, total energy use rose by about 21% (**figure 36**). [10]

Figure 33: Population of Canada, 1970–2015

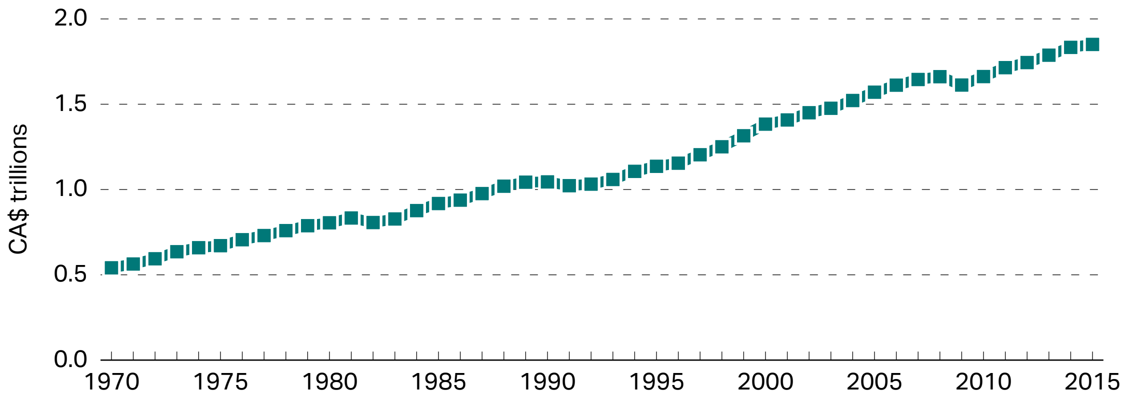


Source: World Bank, 2016.

Overall, the significant decline in emissions and ambient concentrations of the five major air pollutants discussed above has occurred despite growth in Canada's population, economy, energy use, and motor-fuel consumption over the past few decades. It is important, therefore, not to assume that economic growth is harmful to the environment, nor that environmental protection requires reductions in energy usage.

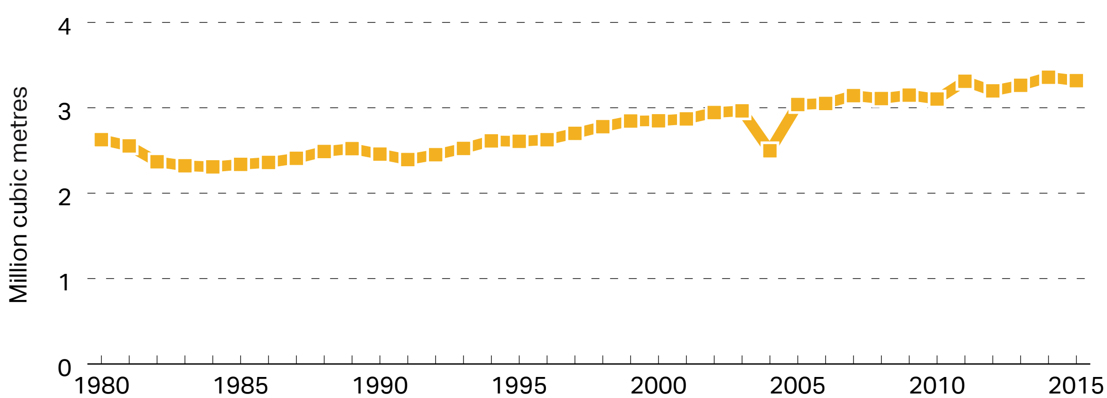
[10] Data on energy use prior to 1995 also exist through Statistic Canada's CANSIM table 128-0002. However, that data is based on a different survey method and cannot be combined with the data for the period from 1995 to 2015.

Figure 34: Real GDP of Canada, 1970–2015



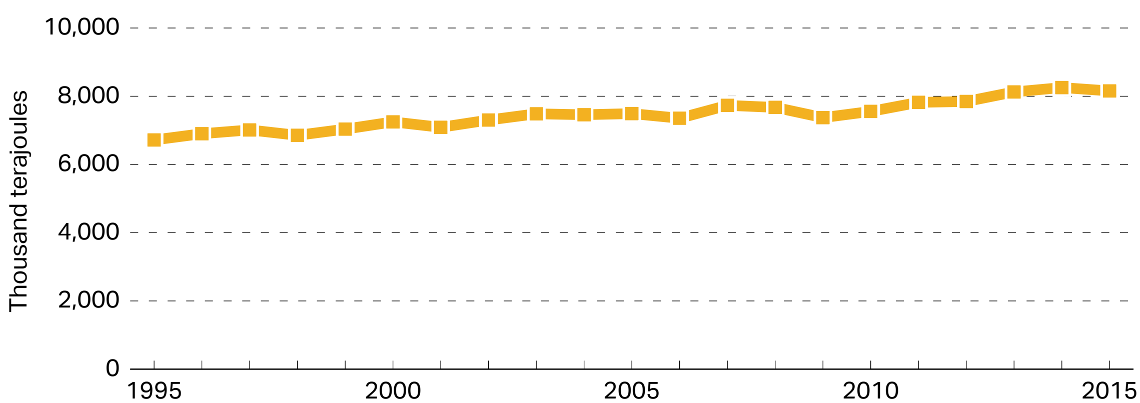
Note: The reference year is 2010.
Source: OECD, 2017.

Figure 35: Consumption of motor fuel in Canada, 1980–2015



Note: Motor fuel includes all gasoline-type fuels for internal combustion engines, other than those used in aircraft.
Source: Statistics Canada, 2017b, CANSIM table 134-0004..

Figure 36: Energy use in Canada, 1995–2015



Note: Motor fuel includes all gasoline-type fuels for internal combustion engines, other than those used in aircraft.
Source: Statistics Canada, 2017a, CANSIM table 128-0016..

9 Conclusion

This study has examined the state of air quality in Canada by analyzing data for five major air pollutants. The analysis period began in the 1970s, which is when air quality monitoring commenced in Canada.

Ground-level ozone (O_3)

The results indicate that national ambient concentration of ground-level ozone has shown a decreasing trend since the year 2000 and a reduction of 27% from 1979 to 2015. Ozone concentrations fell below the new government-established stringent quality standard in 2005 and have remained there. Major Canadian cities have significantly lower ozone concentrations than they had during the late 1970s. Montreal, among the four large cities, showed the largest improvement over the same period. While 73% of stations across Canada reported concentrations exceeding the ozone standard during the interval from 1977 to 1979, that number fell to 16% during the 2013-to-2015 interval. The non-conforming stations over the recent period of 2013 to 2015 were mostly located in Alberta and in Ontario, which had the most serious problem with ozone among the provinces as 65% of its stations recorded exceeding values during this period.

Fine particulate matter ($PM_{2.5}$)

National ambient concentrations of fine particulate matter consistently remained lower than the new stringent air-quality standards, even though no specific trends were detected. Ambient annual levels of $PM_{2.5}$ in Toronto, Ottawa, and Vancouver were found to be consistently below the annual standard from 2000 to 2015; in Montreal, however, ambient levels did not fall below the standard until 2013. During the early 2000s, 42% of stations throughout Canada recorded readings that did not meet the standard for short-term exposure to fine particulate matter. However, over the recent period from 2013 to 2015, that number fell to 10%. Station-level analysis revealed that Quebec and Alberta had greater problems with $PM_{2.5}$ than the other provinces: between 2013 and 2015, 45% of stations in Quebec recorded values out of compliance with the annual standard and 44% of stations in Alberta had values out of compliance with the 24-hour standard.

Sulphur dioxide (SO_2)

Concentrations of sulphur dioxide have decreased significantly across Canada over the past four decades, and have conformed to the strictest annual standard since 1999. Ambient annual levels of sulphur dioxide decreased 92.3% between 1974 and 2015.

Major Canadian cities also reduced their ambient levels of sulphur dioxide significantly during the same period. Among the four cities studied, Ottawa showed the largest improvement in ambient levels of SO_2 (both annual and 1-hour exposure). During the late 1970s, over 65% of stations across the country recorded concentrations out of compliance with the annual air quality objectives for SO_2. In the most recent year, 2015, only 3% of stations recorded non-conforming values. The same pattern was observed when examining the results from stations for the 24-hour quality standard for SO_2.

Nitrogen dioxide (NO_2) and carbon monoxide (CO)

In the last four decades, Canada has also experienced a substantial reduction in its levels of nitrogen dioxide and carbon monoxide. The national level of nitrogen dioxide decreased by 74.4%, and the level of carbon monoxide by 90.4%, from 1974 to 2015. The decrease is also apparent in all major Canadian cities. The percentage of stations with readings non-conforming to the strictest annual standard for NO_2 fell from 54% in 1975 to zero percent in 2015 and all stations have met the strictest annual standard since 2011. For carbon monoxide, since 1999 all stations across Canada (with the exception of one station in New Brunswick in 2011) recorded values conforming to the air-quality standard.

Overall, our results suggest that air quality has improved in Canada over the past four decades. This improvement has occurred despite growth in population, energy use, consumption of motor fuel, and the Canadian economy. It is clear from the data that economic growth is not necessarily a threat to the environment, nor does environmental protection necessarily require cuts in energy use. For this reason, discussions about the need for new policies to improve air quality should begin with the recognition that air pollution has already substantially declined in Canada and is largely in compliance with some of the strictest standards in the world.

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Acknowledgments

The authors would like to acknowledge the helpful comments and insights of several anonymous reviewers. The authors, however, are alone responsible for the report itself, its conclusions, and recommendations. As the researchers have worked independently, the views and conclusions expressed in this paper do not necessarily reflect those of the Board of Directors of the Fraser Institute, the staff, or supporters.

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Date of issue

April 2017

ISBN

978-0-88975-447-8

Citation

Ross R. McKitrick and Elmira Aliakbari (2017). *Canada's Air Quality since 1970: An Environmental Success Story*. Fraser Institute. <http://www.fraserinstitute.org>.

Cover design

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