The Alberta GPI Accounts: Energy Use Intensity, Greenhouse Gas Emissions and Air Quality

Report # 25

by

Sara Wilson
Mary Griffiths
Mark Anielski

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Pembina Institute
for Appropriate Development

About the Pembina Institute

The Pembina Institute is an independent, citizen-based organization involved in environmental education, research, public policy development and corporate environmental management services. Its mandate is to research, develop, and promote policies and programs that lead to environmental protection, resource conservation, and environmentally sound and sustainable resource management. Incorporated in 1985, the Institute's main office is in Drayton Valley, Alberta with additional offices in Calgary and Ottawa, and research associates in Edmonton, Toronto, Saskatoon, Vancouver and other locations across Canada. The Institute's mission is to implement holistic and practical solutions for a sustainable world.

The Green Economics Program is dedicated to designing and implementing practical, street-smart economic tools that would reorient society back to the original meaning of the word "economy"—the care and management of the wealth of the household. By developing new tools for measuring the true wealth or well-being of nations, we can help guide Canadians and Albertans to a sustainable future.

For more information on the Pembina Institute's work, please visit our website at **www.pembina.org**, or contact:

The Pembina Institute
Box 7558
Drayton Valley, AB T7A 1S7
tel: 780-542-6272 fax: 780-542-6464
e-mail: info@pembina.org

About this Report

This is one of 28 reports that provide the background for the Genuine Progress Indicators (GPI) System of Sustainable Well-being Accounts. It explains how we derived the air quality index that was earlier published in *"Sustainability Trends 2000: The Genuine Progress Statement for Alberta, 1961 to 1999."* The research for this report was completed near the end of 2000. The appendices provide further background and explanation of our methodology; additional details can be obtained by contacting the authors. Appendix A includes a list of all GPI background reports.

This report examines the emissions and/or ambient concentrations of particulate matter, nitrogen oxides, volatile organic compounds, sulphur dioxide and the levels of ground level ozone in Alberta cities. It answers the questions:

1. How does air quality in Alberta compare with national levels and guidelines?
2. Is air quality in Alberta improving?
3. What is the impact of air quality on health?
4. Does air quality affect agricultural production?

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About the Authors

Sara Wilson joined the Pembina Institute in August 2000, as a member of the Green Economics Program. She works on establishing measurements of ecological well-being and community sustainability reflected in genuine progress indicators using time series analysis and valuation methods. Sara aims to promote better physical and economic accounts that will reflect our natural capital, quantitative and qualitative degradation, and the ecological and social costs of losses in ecological integrity. Before joining the Green Economics team, Sara completed the water account and forest account for the Nova Scotia GPI. In addition, she has three years' experience as a forest ecology researcher and three years' experience in environmental education. Sara holds the following degrees: MSc.F. (Mixed Boreal Forest Disturbance Ecology), University of Toronto and B.A. Hon. (International Development Studies and Environmental Geography), University of Toronto.

Mary Griffiths joined the Pembina Institute as an Environmental Policy Analyst in May 2000. She brings strong research and policy analysis skills as well as an extensive background and in-depth understanding of a wide range of environmental issues. Mary works with the Energy Watch team on environmental and energy advocacy issues and with the Institute's Green Economics Program on genuine progress indicators for Alberta. She has long been an advocate for the protection of the environment, both in her previous employment and in her volunteer activities. Mary holds a Ph.D. (Medical Geography), University of Exeter, UK and a B.A. (Geography), University of Exeter, UK.

Mark Anielski is Director of the Green Economics team, and has considerable experience in public policy analysis including natural resource, energy, royalty and fiscal policy issues in both the public (Alberta Government) and private (GPC- Government Policy Consultants) sector. He also serves as Senior Fellow to the U.S. economic policy think-tank Redefining Progress in Oakland, California and authored the 1999 U.S. GPI report with journalist Jonathan Rowe. He currently advises the National Round Table on Economy and the Environment's Sustainable Development Indicator Steering Committee on the development of indicators for measuring sustainability in Canada. Mark teaches business and the environment in the University of Alberta's School of Business. His expertise is varied and broad including accounting for sustainable development, natural resource accounting, public policy analysis, business planning and performance measurement. Mark pioneered the development of natural capital accounts for Alberta's timber, oil, gas, coal and other natural capital as well as having experience in the development of performance measurement systems, land use planning and non-market resource valuation, royalty policy analysis (forestry, oil and gas), and analysis of subsidies for both government and private forestry, energy and financial service industries. He holds a Masters degree in forest economics, plus bachelor degrees in economics and forestry.

Acknowledgements and Disclaimer

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In addition, we thank Kim Sanderson for editing assistance with the project reports. Finally, the Pembina Institute appreciates the vision of Western Economic Diversification in supporting this project—the first of its kind for Alberta, if not internationally.

The contents of this report are the responsibility of the Pembina Institute and do not necessarily reflect the views and opinions of those who are acknowledged above. We have made every effort to ensure the accuracy of the information contained in this document at the time of writing. However, the authors advise that they cannot guarantee that the information provided is complete or accurate and that any person relying on this publication does so at their own risk. Given the broad scope of the project and time constraints, it has not been possible to submit the entire report for peer review. The material should thus be viewed as preliminary and we welcome suggestions for improvements that can be incorporated in any later edition of the work.

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1 Executive Summary

Our current system of accounting—the Gross Domestic Product—does not recognize the degradation of airsheds from pollution and release of greenhouses gases as a cost. Rather, GDP and national accounts treat every increase in pollutants emitted and the costs of cleaning them up as a gross benefit to economic growth. For example, the more gasoline that is consumed in commuting, the more jet fuel that is burned in flight, and the more sulphur dioxide, carbon dioxide, and particulate matter that are emitted from industrial production and refining of oil and gas, the more the GDP rises. This seems counter-intuitive and even violates basic accounting principles by ignoring the depreciation of living, natural capital as a genuine reduction in the well-being of current and future generations.

In contrast to the GDP, the GPI takes into account the changes in the condition and the full costs of degrading natural capital and environmental services such as air and other resources. By treating natural capital like manufactured capital assets, GPI accounts would regard the costs associated with air pollution as a net deduction against GDP, thus providing a more genuine measure of economic welfare. The Alberta GPI accounts related to air account for energy use intensity, greenhouse gas emissions and air quality. They consider the trends in physical condition over time and also estimate the full economic costs associated with air pollution and greenhouse gas emissions. The following sections summarize the findings of our GPI study for Alberta with respect to energy use intensity, greenhouse gas emissions and air quality.

1.1 Energy Use Intensity

There are two types of reporting on energy use—primary energy use and secondary energy use. Primary energy use includes energy used by final consumers (secondary energy use), intermediate uses of energy, energy to convert one form of energy to another (e.g., coal to electricity), and energy used by suppliers in providing energy to the market (e.g., pipeline fuel). Secondary energy use is the portion of primary energy consumed by end users in residential, commercial, industrial, and agricultural sectors. Our study shows that between 1961 and 1999, Alberta's energy use increased by an estimated 395 percent, from 451 petajoules (PJ) in 1961 to 2,234 PJ in 1999. On a per capita basis, primary energy use intensity increased 123 percent, from 338 gigajoules (GJ) per Albertan in 1961 to 753 GJ in 1999. Secondary energy use is a helpful measure of the final consumption or end use of energy, leaving out the energy used to extract sources of energy, transform energy from one form to another, and transport energy to final consumers.

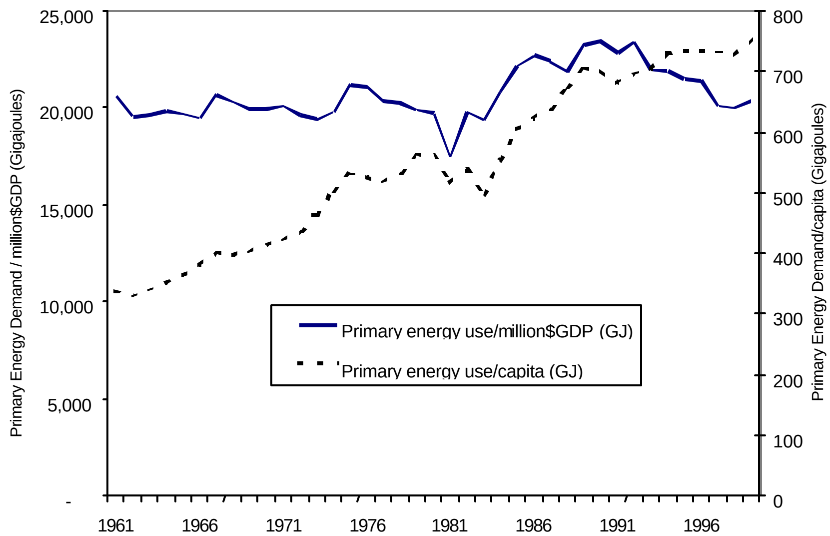
Noteworthy

- Alberta's peak total primary energy use (2,234 PJ) and peak primary energy use per person (753 GJ) occurred in 1999.
- The amount of energy used in relation to economic output (i.e., GDP) was fairly steady between 1961 and 1984, averaging 19,950 GJ per million dollars of GDP. Since then, a slightly higher energy use per dollar of GDP has ensued, for an average of 21,960 GJ/million$GDP.
- Total secondary energy use increased 20.8%, or 228.7 PJ between 1990 and 1998. During this time, the industrial sector secondary energy use increased by 31%, transportation by 18%, agriculture by 11%, the commercial sector by 1%, and the residential sector by 13%.
- Alberta's secondary energy use increased by 6% from 432 GJ per person in 1990 to 457 GJ per person in 1998. Industrial secondary energy use per person increased 14% and transportation increased 4%, whereas secondary energy use in the agriculture sector decreased 3% per person, the commercial sector decreased by 12%, and residential decreased by 1% per person.
- Statistics Canada data on primary energy use are only available for 1978 to 1999. To complete our GPI time series from 1961 to 1999, we estimated primary energy use between 1961 and 1978 on the basis of the annual percentage change in Alberta's gross domestic product.

Secondary energy use in Alberta (based on Natural Resources Canada data from 1990 to 1998) increased by 20.8 percent, from 1,100 PJ in

1990 to 1,329 PJ in 1998; it increased 5.9 percent per Albertan over the same period. The greatest increase was in the industrial sector, followed by the transportation sector; secondary energy use per Albertan decreased in the agricultural, commercial and residential sectors.

Alberta's Primary Energy Use per Capita and per Million Dollars of Gross Domestic Product (GDP), 1961 to 1999



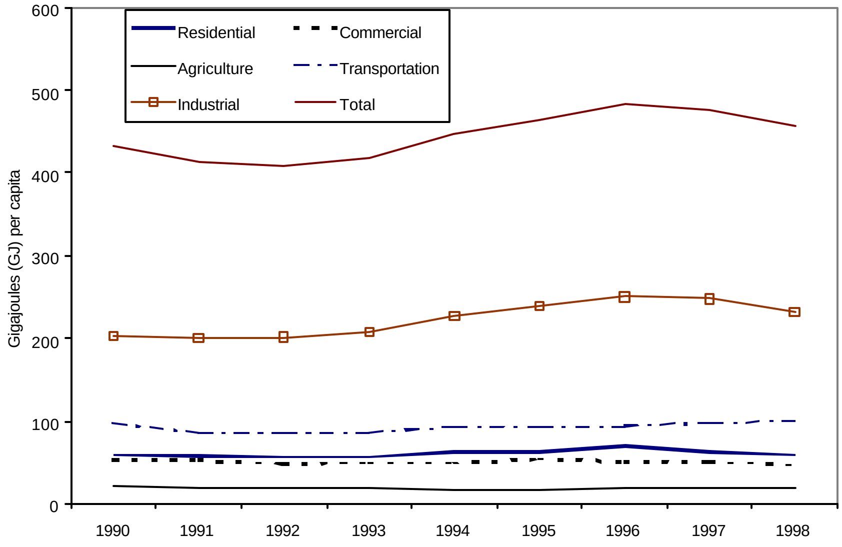
Source: Primary energy demand data (1978-1999) from Statistics Canada; Percentage change per annum in Alberta's GDP is used to estimate Energy Use 1961 to 1977; Calculations by authors; Gigajoule (GJ)= 10^6 joules

Energy use in Canada and Alberta is increasing steadily, particularly by industrial and transportation sources. If no significant changes occur in the patterns of energy production and use, Alberta's total greenhouse gas emissions will be 40.4 percent higher by 2010. Our current energy resources are mainly from non-renewable sources, for which several sources are being depleted (see *GPI Report #18, Energy*). About 2.5 percent of Alberta's energy is from low-impact renewable sources, and another 9.5 percent is from large-scale hydro. However, recent estimates suggest that, in general, low impact renewable energy capacity (i.e., wind, micro-hydro and solar) could be increased to 30 percent of current total energy production, and if we include biomass and large-scale hydro sources, it could be increased to 100 percent. A shift to more renewable energy sources would diversify Alberta's energy economy and reduce the future financial liabilities associated with greenhouse gas emissions.

The continuing increase in fossil fuel burning has been linked to increasing temperatures and is projected to cause radical global climate changes over the next decade, according to the Intergovernmental Panel on Climate Change. More fossil fuel burning also results in more air pollution and associated health problems and costs.

Because primary energy use is a more comprehensive measure of energy use intensity, we used it to construct the GPI energy use intensity index. The index is based on the primary energy use per Albertan from 1961 to 1999. The index uses 1962, the best year in terms of the lowest primary energy use per capita (328.7 GJ per person), as the benchmark. Therefore, 1962 is 100 on the index, and the other years are rated on the index scale of zero to 100 in relation to this benchmark year. The index declined from a high in 1962 (100 on the index), to 43.6 in 1999.

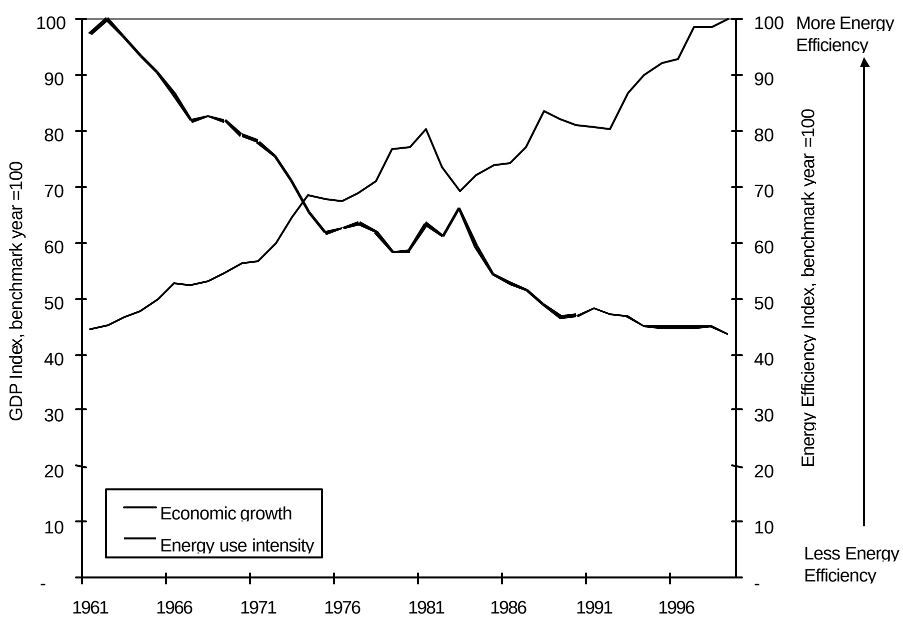
Alberta's Secondary Energy Use per Person, by Sector, 1990 to 1998



Source: Data from Office of Energy Efficiency, NRCan; calculations by authors

On a scale of 0 to 100, where 100 is the year in which primary energy use intensity per Albertan was lowest, the status of primary energy use intensity ranked 43.6 in 1999 compared to 100 in 1962.

Alberta's Primary Energy Use Intensity Index, 1961 to 1999



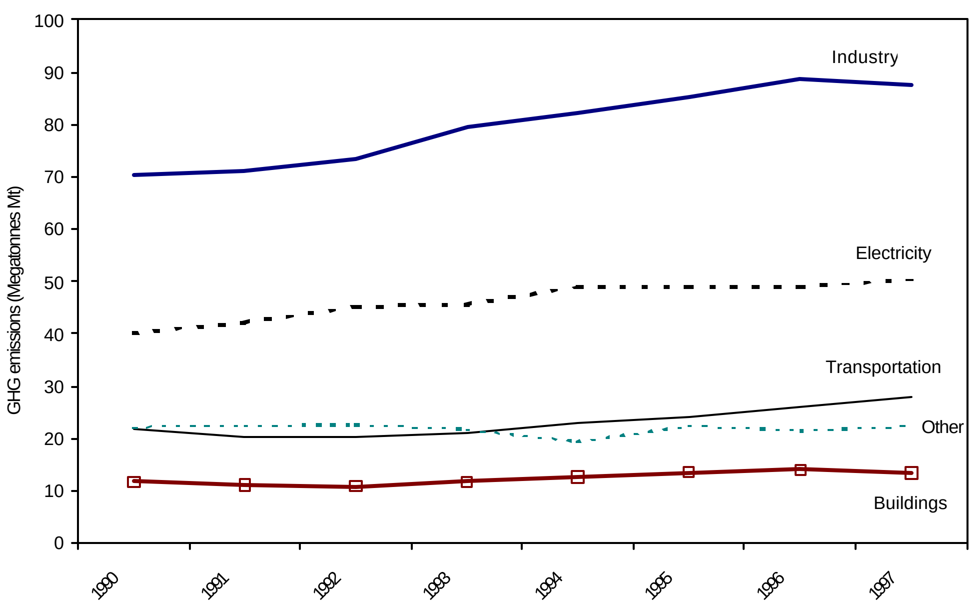
1.2 Greenhouse Gas Emissions

Canada is the world's second largest consumer of fossil fuels on a per capita basis. Despite a national commitment to decrease our emissions to six percent below 1990 levels by 2008 to 2012, Canada's greenhouse gas (GHG) emissions increased by 13 percent between 1990 and 1998, and were projected to have increased 15 percent by 2000. Our emissions are projected to be 41 percent higher by 2020. Based on the projections of the national GHG inventory, Alberta's emissions were expected to increase 23.5 percent between 1990 and 2000; by 2010, emissions are expected to be 40.4 percent higher than in 1990. As shown in the figure below, the largest proportion of emissions in Alberta in 1997 came from the industry sector (43.5 percent), followed by electricity (25 percent), and transportation (13.8 percent). Between 1990 and 1997, the largest percentage increase in emissions was in the transportation sector (26.5 percent), followed by a 25.4 percent increase in electricity generation (mostly coal-fired) emissions, and a 24.4 percent increase in industrial emissions. Residential emissions increased 11 percent. Using Statistics Canada data of Alberta's primary energy demand and energy-to-emissions conversion factors, we estimated the change in greenhouse gas emissions from 1990 back to 1961. This estimate indicates that 29.5 megatonnes of GHGs were emitted in 1961. GHG emissions per Albertan increased three-fold, from 22 tonnes per capita in 1961 to 68.7 tonnes by 1999.

Noteworthy

- Alberta's total primary energy use increased by 108% between 1978 and 1999.
- Greenhouse gas emissions from secondary energy use increased by 16% between 1990 and 1998.
- The average car generates 4.72 tonnes of carbon dioxide per year, based on a total distance of 20,000 km traveled per year at a fuel consumption rate of 10 km/L.
- The benefits of greenhouse gas (GHG) emission reductions include reductions in other air pollutants. Improved energy efficiency reduces greenhouse gas emissions and produces financial savings and new jobs.
- *Canadian Solutions - Practical and Affordable Steps to Fight Climate Change (Pembina Institute and David Suzuki Foundation, 1998)* provides a detailed implementation plan to meet Canada's Kyoto target, focusing on improving energy efficiency and conservation; shifting from high carbon fossil fuels such as coal, to less carbon-intensive fossil fuels as a transition to renewable energy; and increasing the use of renewable energy sources such wind, solar, and biomass energy.

Alberta's Greenhouse Gas Emissions by Sector, 1990 to 1997

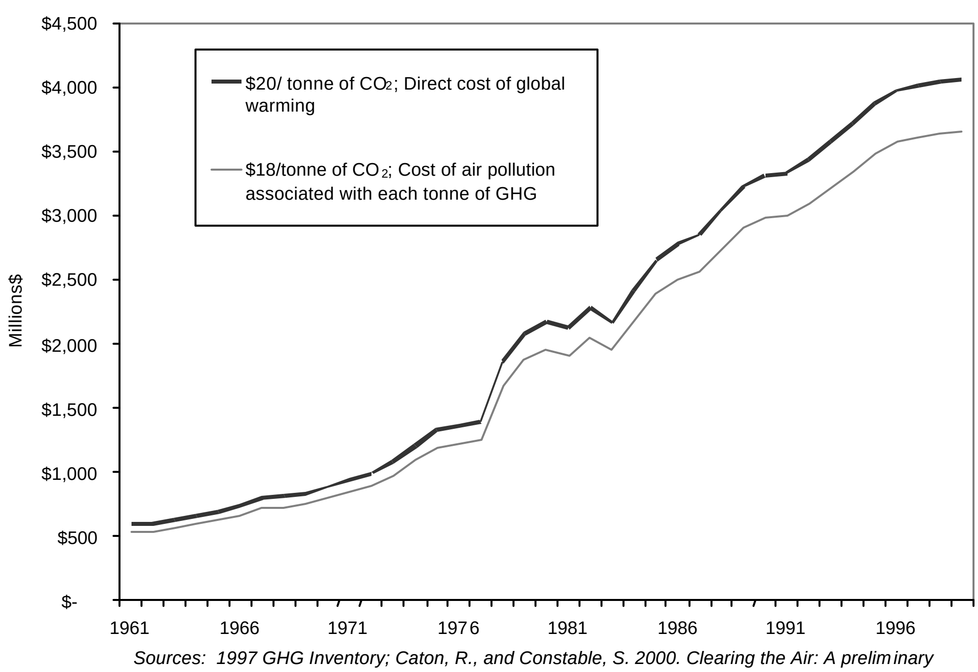


Source: Data from 1997 GHG Inventory

As Alberta expands its extraction of natural gas and its oilsands production, its global carbon footprint will also grow. The continuing increase in burning of fossil fuels will generally also increase air pollution (to a greater or lesser degree, depending on fuel efficiency and technology) as well as associated health problems and costs. Air pollution reduction is connected to greenhouse gas mitigation efforts because a reduction in fossil fuel use leads to decreased emissions of sulphur dioxide, particulate matter, nitrogen oxides, heavy metals (mercury, lead, cadmium), volatile organic compounds, and the formation of ground level ozone. One study found that six selected measures that would reduce GHG emissions by nine percent from projected levels in 2010 would also produce co-benefits worth an estimated $1.2-billion (1998$) in the year of implementation (at $18/tonne of CO_2).

The total cost of Alberta's GHG emissions due to health and environmental impacts of air pollutants associated with each unit of greenhouse gas emitted is reported in the GPI air quality section ($531.5-million in 1961 and $3.7-billion in 1999, in 1998$). In addition, the direct public health, social and environmental costs of the impacts of climate change, such as sea level change or increased temperatures, have been estimated to range from $5 to $50 or more per tonne of CO_2. Based on a conservative cost of $20 per tonne of CO_2 emitted, we estimate the cost of Alberta's greenhouse gas emissions rose from $590.5-million (1998$) in 1961 to $4.1-billion (1998$) in 1999. The $4.1-billion cost is equal to 3.7 percent of Alberta's 1999 GDP. On a scale of 0 to 100, the level of greenhouse gas emissions in 1999 ranked at 35.2.

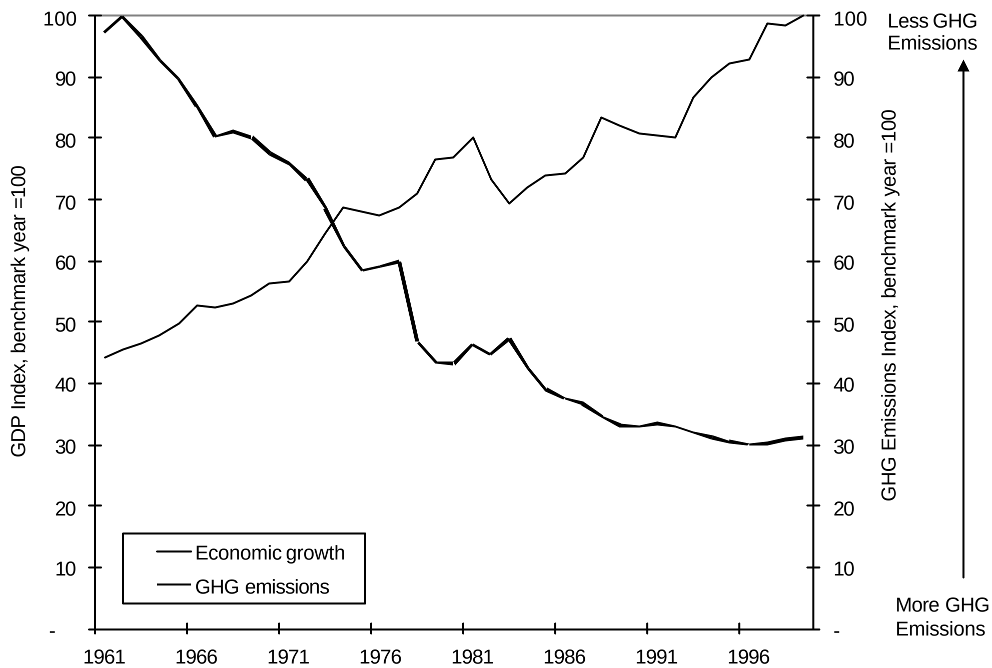
Estimated Direct Global Warming Costs and Air Pollution Costs of Alberta's Greenhouse Gas Emissions, 1961 to 1999



Sources: 1997 GHG Inventory; Caton, R., and Constable, S. 2000. Clearing the Air: A preliminary analysis of air quality co-benefits from reduced greenhouse has emissions in Canada. David Suzuki Foundation. Vancouver, B.C.

The greenhouse gas emissions index is based on the amount of greenhouse gases per Albertan derived from GHG emissions estimated prior to 1990 using percentage change per year in Alberta's primary energy demand. The index declined from 97.2 in 1961 to 31 in 1999.

Alberta's Greenhouse Gas (GHG) Emissions Index based on GHG per capita, 1961 to 1999



1.3 Air Quality

Across Canada, there was an overall improvement in air quality in major cities during the 1980s. However, these significant improvements have waned recently because of increasing numbers of automobiles and a trend toward larger, less fuel-efficient vehicles. The number of registered vehicles in Alberta has increased by 318 percent since 1961. In Alberta, air pollutant emissions did decline between 1971 and 1982. Emissions increased through the 1980s, but have stabilized throughout the 1990s. According to the National Air Issues Coordinating Committee, emissions are forecast to maintain their higher level through the next decade. However, the annual mean of coarse and fine particulate matter has decreased in Alberta's major cities, contributing to improved ambient air quality in urban areas. The latest year reported—1998—

Noteworthy

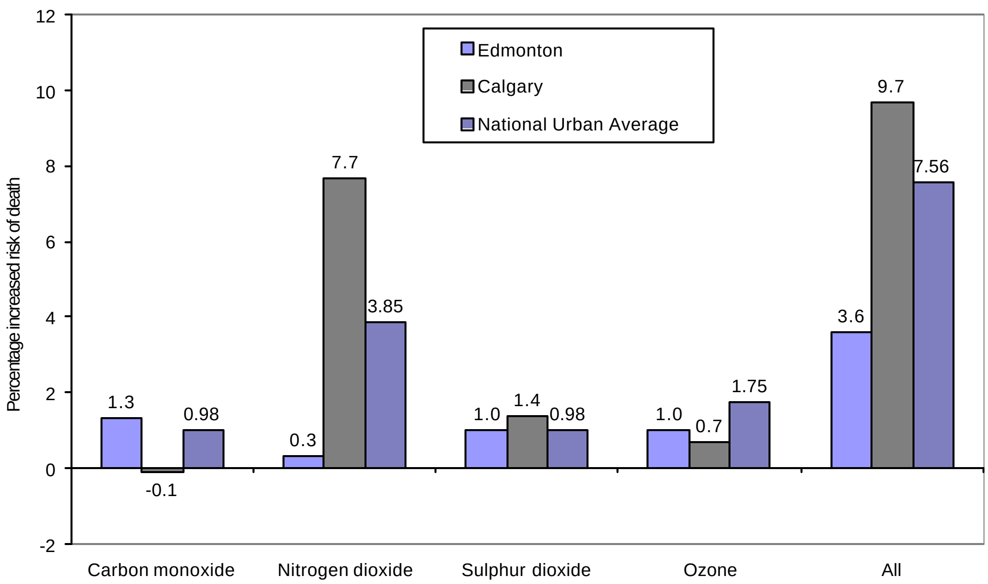
- Alberta emitted about one-quarter of the total national emissions of three major air pollutants in 1995, according to Environment Canada.
- At the ground level, ozone is created by chemical reactions in the air between volatile organic compounds (VOCs), nitrogen oxides (NOx), and sunlight. High ozone concentrations tend to occur under conditions of bright sunlight, high temperature and a stationary air mass.
- Just a few hours of exposure to high ozone levels can irritate the eyes, nose and throat, and cause respiratory problems. Exposure also makes people with asthma more vulnerable to common allergens, and increases the number of emergency hospital visits and the number of hospital admissions for respiratory complaints.
- Nitrogen oxides (NOx) are by-products of the burning of fossil fuels (e.g., gasoline, diesel fuel, natural gas, oil and coal).
- In Alberta, about 43% of NOx emissions are produced by transportation, 37% by industry (primarily oil and gas), and 18% by power plants.

was an exception, showing a dramatic increase in the annual mean and jumping above the national urban average. Canada has established a maximum acceptable guideline for ozone of 82 parts per billion over a one-hour period, one of the strictest guidelines in the world. The annual number of days that ground level ozone exceeds this objective in Edmonton and Calgary is relatively low compared to other parts of Canada, and the number has decreased since the 1980s.

Noteworthy

- Overall, VOC emissions in Alberta were fairly stable between 1990 and 2000, but are forecast to increase to 755 kilotonnes by 2010.
- Urban ambient air concentrations of VOCs have improved in Calgary since 1990 due to stricter emission controls on vehicles.
- Sulphur dioxide (SO_2) contributes to secondary fine particulates ($PM_{2.5}$).
- The main sources of SO_2 are petroleum refineries, pulp and paper mills, electrical generating plants, smelting in metal refineries, and the burning of coal and heavy oil.
- SO_2 emissions in Alberta have declined since the 1970s.
- As the main recording stations are in urban areas, there is no continuous record for ambient air quality in rural Alberta.

Percentage of Increased Risk of Death for Edmonton and Calgary Attributable to City-specific Change in Air Pollution Concentrations, Examined Simultaneously by City, 1980 to 1991



Source: Data from, Burnett, R.T., Cakmak,S., and Brook, J.R. 1998. The effect of the urban ambient air pollution mix on daily mortality rates in 11 Canadian cities. Canadian Journal of Public Health. 89: 152-156.

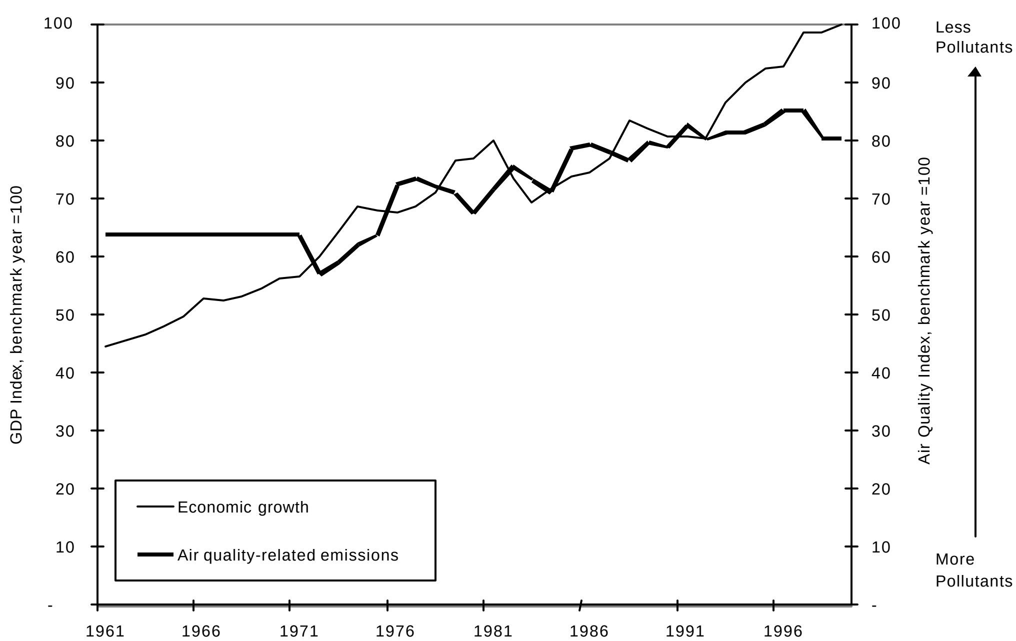
Secondary particulates are formed when acidic air emissions, such as oxides of sulphur and nitrogen, and volatile organic compounds (VOCs) are transformed into nitrates, sulphates and organic aerosols. Both ozone and particulates affect the respiratory system and decrease lung function, leading to increased mortality from respiratory and cardiovascular disease. According to Environment Canada, scientists believe there is no safe level of exposure to PM_{10} (particulate matter less than 10 microns in size). Even relatively low levels can lead to premature deaths and have been linked to a range of other health ailments.

In general, levels of fine particulate matter (less than 2.5 microns) recorded in the cities in Alberta are below the proposed national standards (15-25 micrograms/m^3). The annual mean concentrations of coarse particulates (PM_{10}) in Edmonton and Calgary have generally been on par with the national urban mean concentrations, although most recently, levels have increased above the national urban mean. The annual peak concentration of coarse particulate matter was periodically higher than the urban national average between 1985 and 1996. An index for particulate matter in Alberta's two major cities based on $PM_{2.5}$ and PM_{10}, using the best year benchmark, resulted in a score of 51.5 in 1985 and 60.3 in 1999.

A recent study in the *Canadian Journal of Public Health* found that even in Calgary and Edmonton there was an increase in premature mortality due to ambient air pollution. This study attributed about 8 percent of non-traumatic deaths in 11 Canadian cities between 1980 and 1991 to the concentrations of ambient gaseous air pollutants. The percentage increase in risk of premature mortality due to the change in ambient air pollutants in Edmonton was 3.6 percent, low relative to the national urban average (7.56 percent). Calgary's overall percentage increase in risk of premature mortality was 9.7 percent, 2.14 percent above the national urban average. Most of the increased risk (7.7 percent) was a result of the change in ambient measurements of nitrogen dioxide.

The health and environmental costs of air pollutants (calculated per tonne of greenhouse gas emissions) were an estimated $3.7-billion ($18/tonne of CO_2 emitted) (1998$), equal to 3.4 percent of Alberta's 1999 GDP. On a scale of 0 to 100, where 100 is best, the status of air quality ranks 80.3 in 1999.

Air Quality Index: Where are we today?



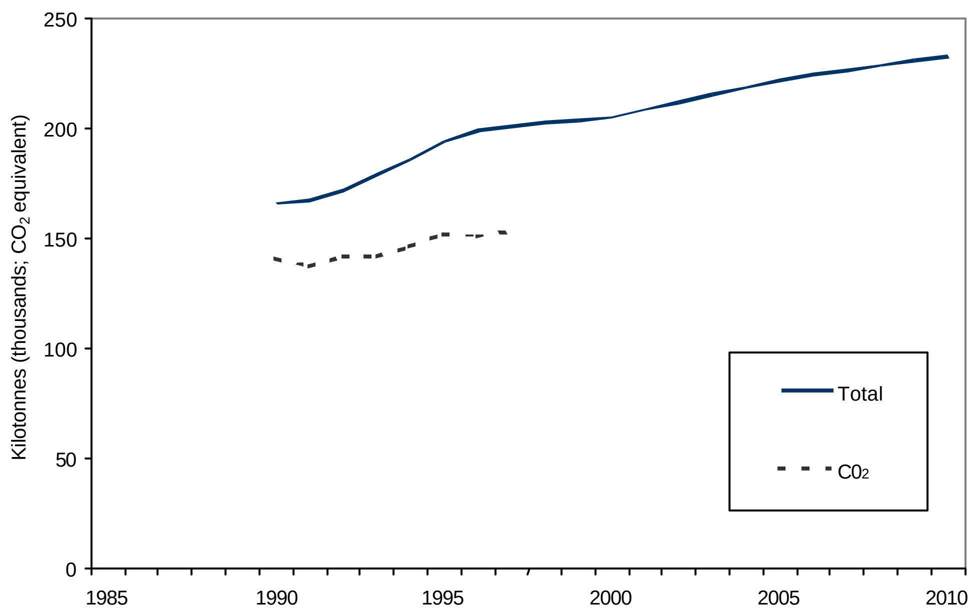
2 Energy Use and Greenhouse Gas Emissions

> "*On a per capita basis, Canada is the second largest consumer of energy in the world and the second largest producer of greenhouse gases. With a population of less than 30 million, we use as much energy as the entire continent of Africa, home to 700 million people, and contribute 2 per cent of overall global emissions.*"[1]

2.1 Greenhouse Gas Emissions

Alberta's greenhouse gas (GHG) emissions grew 21 percent between 1990 and 1997. Based on the national GHG inventory, Alberta's emissions were projected to grow 22.7 percent between 1990 and 1999, and to increase by 40.4 percent by 2010. Alberta's total GHG emissions were 166 megatonnes[a] in 1990, rising to 201 megatonnes in 1997, and they are predicted to increase to 233 megatonnes by 2010 (see Figure 1). National projections indicate that they will continue to increase over the next decade.

Figure 1: Alberta's CO_2 and Greenhouse Gas Emissions, 1990 to 1998, with Projections of Greenhouse Gas Emissions to 2010

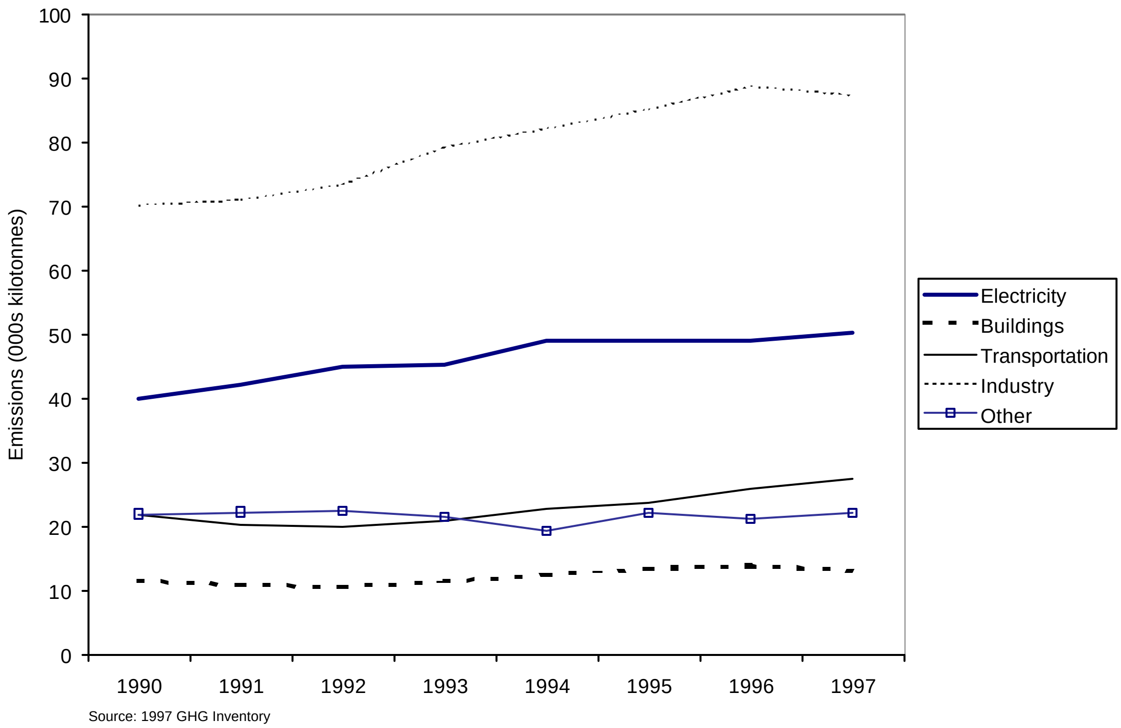


Source: Total GHG Emissions from 1997 GHG Inventory with inventory projections from 1998 to 2010

The largest proportion of emissions is from the industry sector in Alberta, followed by electricity, transportation, and other sectors. The industry sector's emissions increased the most between 1990 and 1997 (by 17.1 megatonnes), likely because of the large energy industry in the province.

[a] A megatonne (Mt) is one million tonnes.

Figure 2: Alberta's Greenhouse Gas Emissions by Sector, 1990 to 1997



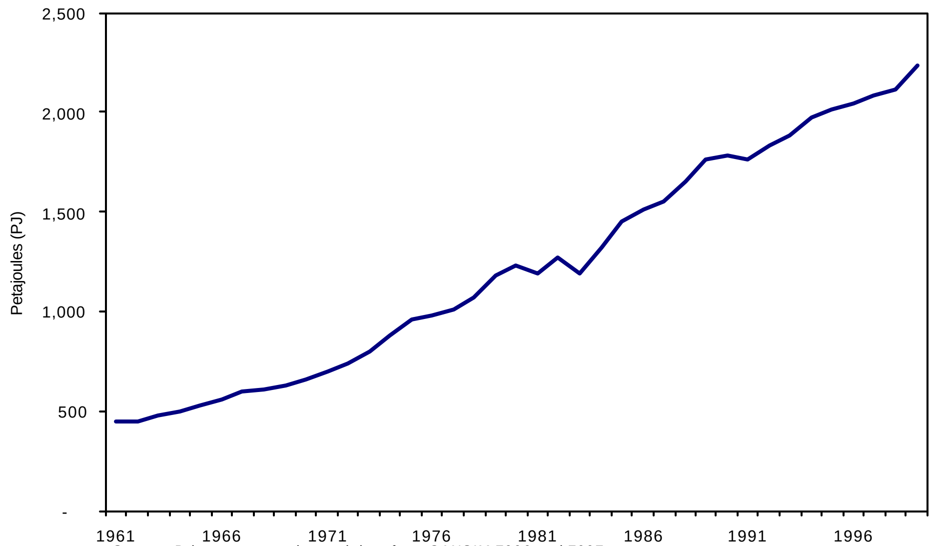
2.2 Alberta's Historical Greenhouse Gas Emissions Estimated by Primary Energy Demand

2.2.1 Primary Energy Use

Provincial total GHG emissions are only available for 1990 to 1997, however, we can use Alberta's energy demand trend to indicate the trend in GHG emissions. Primary energy demand represents the total requirements for all uses of energy.[b] Alberta's total primary energy demand increased by 108 percent between 1978 and 1999, from 1,076 petajoules (PJ)[c] in 1978 to 2,234 PJ in 1999 (Figure 3). Using the percentage change per annum in Alberta's GDP, primary energy demand was extrapolated back from 1978 to 1961. Thus, our estimates show an increase of 395 percent between 1961, when the estimated energy demand was 451 PJ, and 1999 when the energy demand was 2,234 PJ.

[b] Including energy used by the final consumer (secondary energy use), non-energy uses, intermediate uses of energy, energy in transforming one energy form to another (e.g., coal to electricity), and energy used by suppliers in providing energy to the market (e.g., pipeline fuel).
[c] A petajoule is 10^{15} joules; a gigajoule is 10^{9} joules.

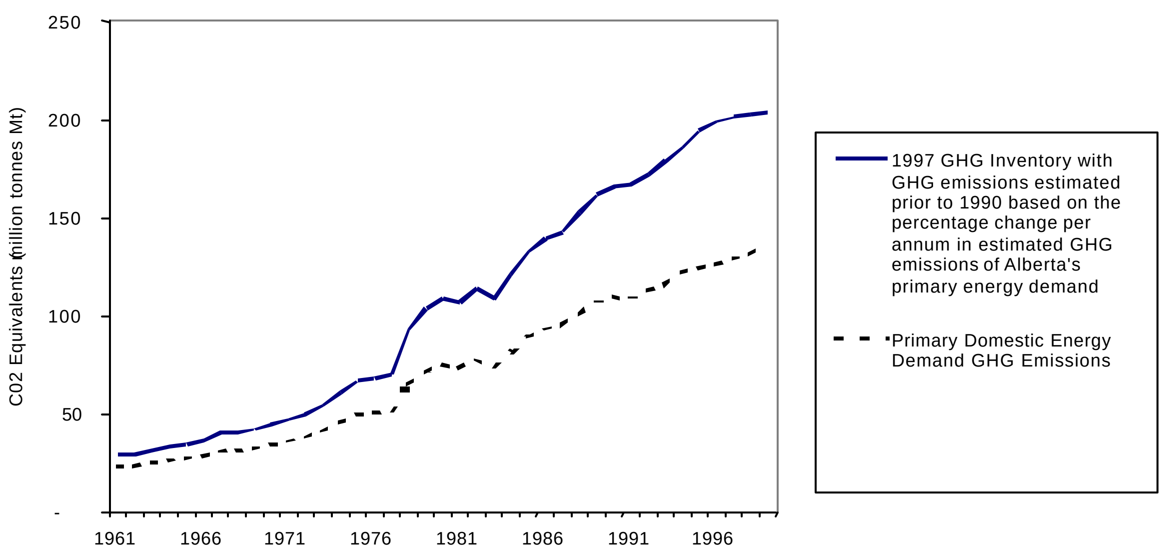
Figure 3: Alberta's Total Primary Energy Demand, 1961 to 1999



Source: Primary energy demand data from CANSIM 7996 and 7997

Using the estimated primary energy demand figures and greenhouse gas emission factors, an estimated trend in GHG emissions was calculated (Figure 4).[2] Although these calculations do not represent a full GHG inventory, they do provide a representation of the historical trends in Alberta's energy demand and GHG emissions. According to the estimates, since 1961, GHG emissions had increased by 462 percent by 1990 (from 29.53 Mt to 166 Mt), and by 590 percent by 1999 (from 29.53 Mt to 203.67 Mt).

Figure 4: Alberta's Estimated Greenhouse Gas Emissions based on Alberta's Primary Domestic Energy Demand, using Emission Factors



Note: Primary Energy Demand data from Statistics Canada CANSIM - Matrix 7996 AND 7997 (1978 to 1999). Primary energy demand prior to 1978 is estimated using percentage change per annum in Alberta's GDP. Calculations are by authors using emission factors from Canada's Emissions Outlook: An update, *December 1999.*

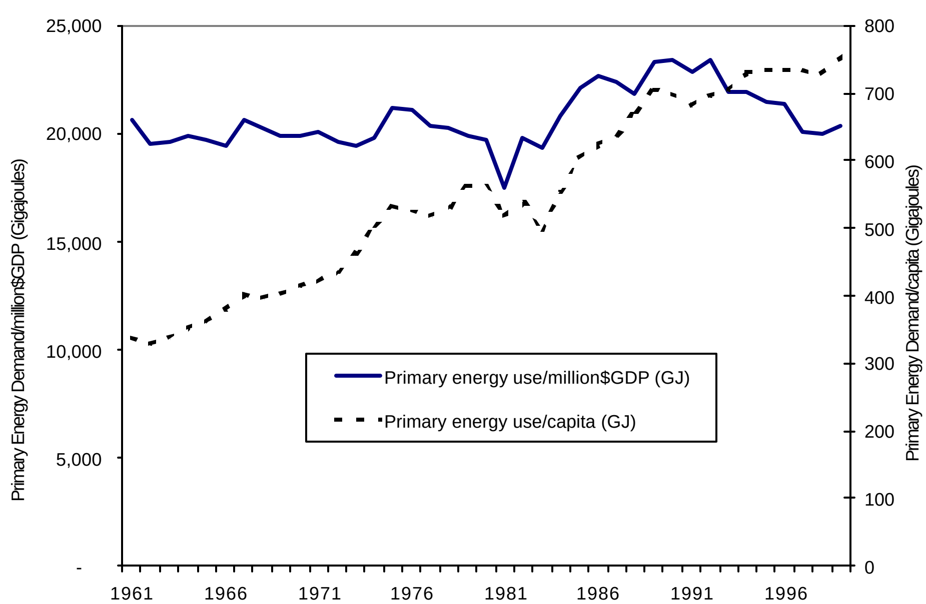
Canada's GHG emissions increased by 13 percent between 1990 and 1998, and were projected to have increased 15 percent by 2000. If significant changes in government policies on energy production and use do not occur, our emissions are projected to be 41 percent higher by 2020.

2.3 Energy Use Intensity

Between 1978 and 1999, primary energy demand per capita rose from 532.3 gigajoules (GJ) to 753.6 GJ per person in Alberta, an increase of 42 percent (Figure 5). The peak primary energy demand occurred in 1999 (753.6 GJ per capita). However, because primary energy demand includes energy used in transforming one form of energy to another, a portion of the growth in energy demand is due to the increase in Alberta's energy industries. As a result, the primary energy demand is not based solely on the energy demand of Albertans, as it includes energy produced for consumption elsewhere.

The primary energy demand per dollar of gross domestic product (GDP) did not increase as much. Between 1978 and 1999 there was a 0.5 percent increase in primary energy demand per dollar of GDP (20,260 GJ per dollar GDP in 1978, and 20,364 GJ per dollar GDP in 1999). This trend represents the amount of primary energy demand generated per unit of Alberta's economic activities. Therefore, in Alberta in 1999, about 104 more gigajoules of energy were used per dollar of economic activity than in 1978. Based on peak energy demand per dollar of GDP, which occurred in 1991 (22,867 GJ per $ GDP), there has been a 10.9 percent decrease in the energy demanded per unit of economic activity.

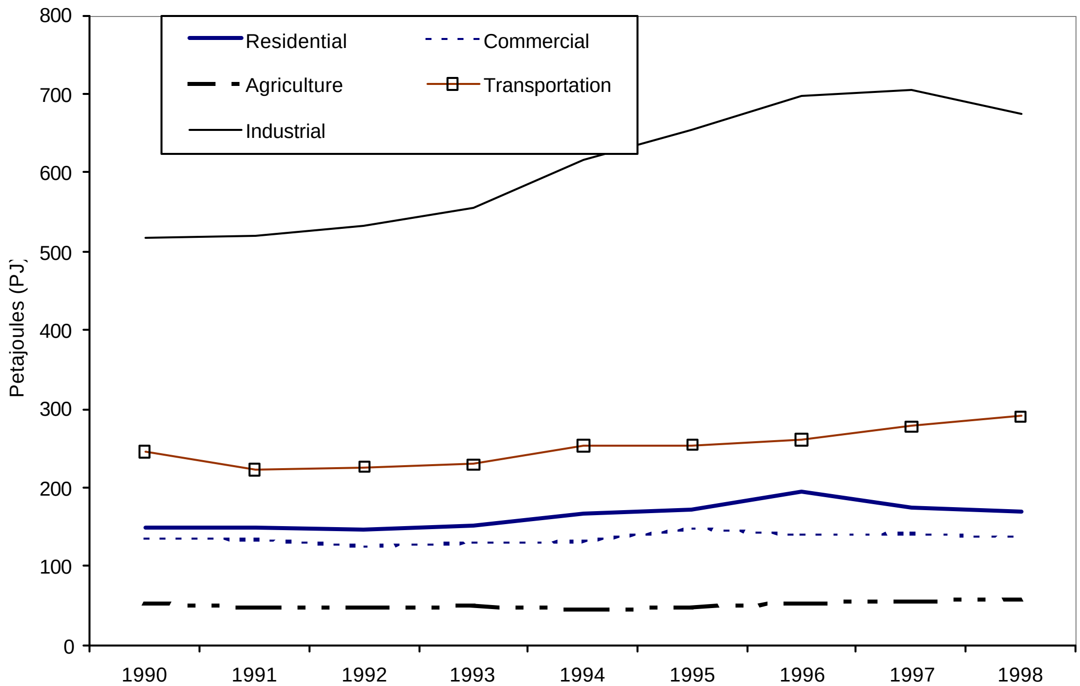
Figure 5: Alberta's Total Primary Energy Demand per Capita and per Dollar of Gross Domestic Product (GDP), 1961 to 1999



Source: Primary energy demand data (1978-1999) from Statistics Canada; Percentage change per annum in Alberta's GDP is used to estimate Energy Use 1961 to 1977; Calculations by authors; Gigajoule (GJ)= 10^9 joules

Secondary energy use is the energy used by final consumers for residential, agriculture, commercial, industrial and transportation purposes. The Office of Energy Efficiency in Natural Resources Canada compiles secondary energy use data from Statistics Canada and converts the data to greenhouse gas emissions. In Figure 6, Alberta's secondary energy is shown as a total and by sector. Total secondary energy use increased 20.8 percent, or by 228.7 petajoules between 1990 and 1998. During this time period, the industrial sector secondary energy use increased by 31 percent, transportation by 18 percent, agriculture by 11 percent, the commercial sector by 1 percent, and the residential sector by 13 percent.

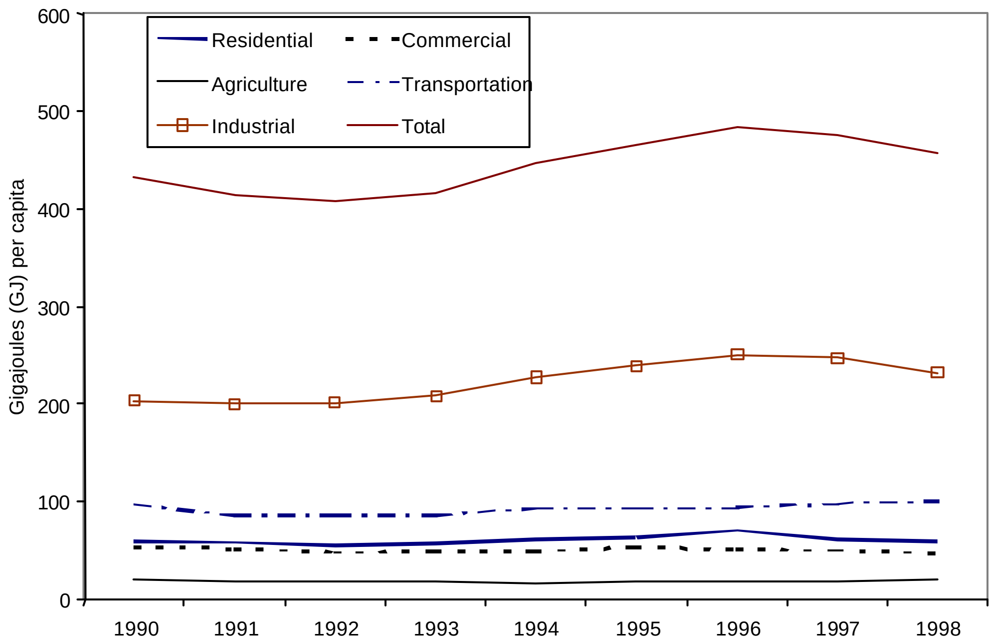
Figure 6: Alberta's Secondary Energy Use, 1990 to 1998



Source: Data from Office of Energy Efficiency, Energy Use Database

Alberta's secondary energy use increased by six percent from 432 GJ per person in 1990 to 457 GJ per person in 1998. Industrial secondary energy use per person increased 14 percent and transportation increased 4 percent, whereas secondary energy use in the agriculture sector decreased by 3 percent per person, the commercial sector decreased by 12 percent, and residential energy use decreased by 1 percent per person (Figure 7).

Figure 7: Alberta's Secondary Energy Use Per Capita, 1990 to 1998



Source: Data from Office of Energy Efficiency, NRCan; calculations by authors

2.4 The Costs of Greenhouse Gas Emissions and the Benefits of Reductions

Canada is the second largest global consumer of fossil fuels on a per capita basis. Despite national commitments made in 1997 in Kyoto to decrease our emissions below 1990 levels, Canada's greenhouse gas emissions have increased by 13 percent since 1990; if no significant changes occur in our patterns of energy production and use, our emissions will be 36 percent higher by 2020. The continuing increase in fossil fuel burning will also increase air pollution and associated health problems and costs.

> *It is evident from studies examined ... that climate change has the potential to seriously degrade the health and well-being of people around the world. In fact, the scope of expected health effects could go beyond anything previously faced in the history of humanity. By reducing the rate of fossil fuel combustion we can counter global warming and prevent many of these effects. In addition ... we can improve the health and well being of tens of thousands of Canadians*.[3]

Air pollution reduction is connected to greenhouse gas mitigation efforts because a reduction in fossil fuel use decreases emissions of sulphur dioxide (SO_2), particulates, oxides of nitrogen (NO_x), volatile organic compounds (VOCs), other air toxics, and ozone as well as greenhouse gases. In 1995, Canada's Climate Action Network estimated that a 147-megatonne reduction of CO_2 emissions would also see SO_2 emissions reduced by 376 kilotonnes (24 percent), VOCs by 135 kilotonnes (13 percent), and NO_x by 281 kilotonnes (16 percent). The amount of fine particulates ($PM_{2.5}$) would be reduced because each of these pollutants contributes to their formation in the air.[4]

The co-benefits of reducing GHG emissions include:

- reductions in other air pollutants and secondary pollutants that will result in less smog (thus avoiding health, crop and forest damage), less acid rain that causes ecosystem damage, improved visibility, and less damage to buildings;
- reductions in cases of respiratory diseases and premature deaths due to air pollution;
- avoided flooding and other damages; and
- improved energy efficiency resulting in job creation and new energy efficiency industries.[5]

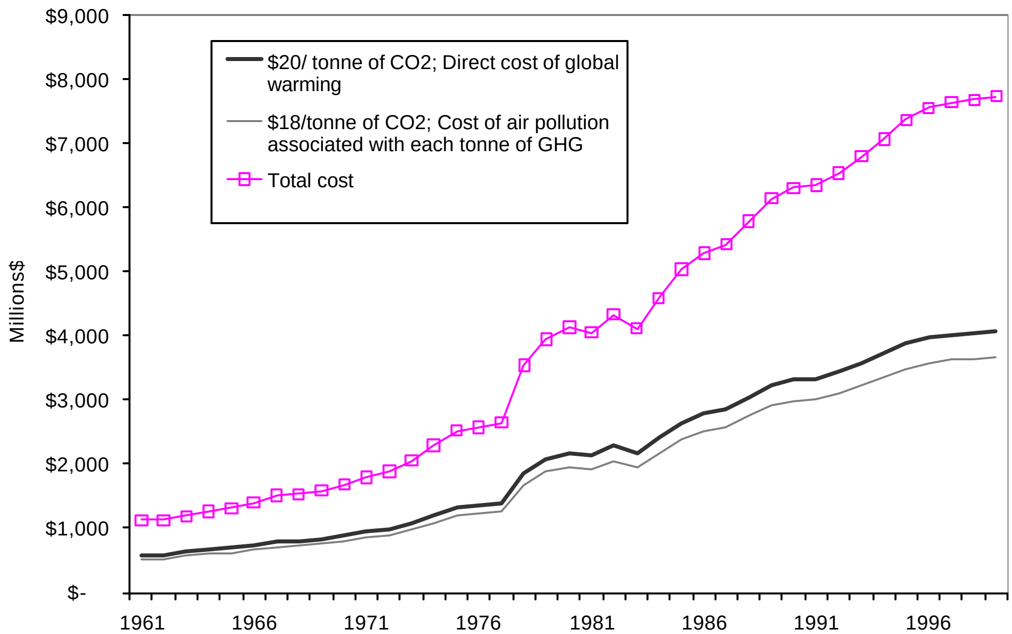
The David Suzuki Foundation and the Pembina Institute created a plan to bridge the gap between current GHG emissions and our Kyoto targets.[6] *Canadian Solutions - Meeting our Kyoto Commitment: Climate Action Basics for Canada* lays out a detailed implementation plan to meet national targets, focusing on three main types of action: 1) improving energy efficiency, including conservation, to reduce fossil fuel usage; 2) shifting from high carbon fossil fuels such as coal, to less carbon-intensive fossil fuels as a transition; and 3) increasing the use of renewable energy sources such wind, solar, and biomass energy. These reductions not only will result in avoiding the damage costs of the predicted changes in climate, they will also provide benefits such as fewer premature deaths associated with poor air quality and a decrease in respiratory diseases. Increased energy efficiency will lower energy costs for consumers and businesses.

Recent studies in the U.S. and Canada have considered the damages avoided on a global scale and the human health benefits that can be realized by cutting our GHG emissions. A 1997 study estimated that the monetized co-benefit of air pollution associated with GHG reductions ranges from $10 to $32 per tonne of CO_2.[7] As a result, studies have concluded that the implementation costs of the requirements of the U.S. *Clean Air Act* are greatly exceeded by the benefits that will be realized.[8]

A Canadian study by Caton and Constable[9] found that six selected measures that would reduce GHG emissions by nine percent of the projected national emissions (or 36 percent of the estimated reduction necessary to meet Canada's Kyoto commitment in 2010), would result in co-benefits worth an estimated $1.2-billion in that year (at $18/tonne of CO_2). In 1996, Alberta's GHG emissions were approximately 30 percent of Canada's total emissions. Thus, an estimated $360-million per year in benefits could be realized by Alberta, not including the estimated health, social, and environmental value of the avoided impacts of global warming such as sea level rises—which is an additional cost estimated to range from $10 to $25 per tonne of CO_2.

If there is no mitigation then these avoided costs and co-benefits will not be realized and can be interpreted as the costs of Alberta's GHG emissions. The total cost of Alberta's GHG emissions due to the health and environmental costs of the air pollutants associated with each unit of greenhouse gas emitted were an estimated $531.5-million in 1961, and $3.7-billion in 1999 ($18/tonne of CO_2 1998$). In addition, the direct public health, social and environmental costs of the impact of climate change, such as sea level change or increased temperatures have been estimated to range from $5 to $50 or more per tonne of CO_2. Based on a conservative cost of $20 per tonne of CO_2 emitted, we estimate the cost of Alberta's greenhouse gas emissions rose from $590.5-million (1998$) in 1961 to $4.1-billion (1998$) in 1999 (see Figure 8). In total, the cost of Alberta's 1999 emissions was conservatively estimated at $7.74-billion.

Figure 8: Direct Global Warming Costs And Air Pollution Costs of Alberta's Greenhouse Gas Emissions, 1961 to 1999

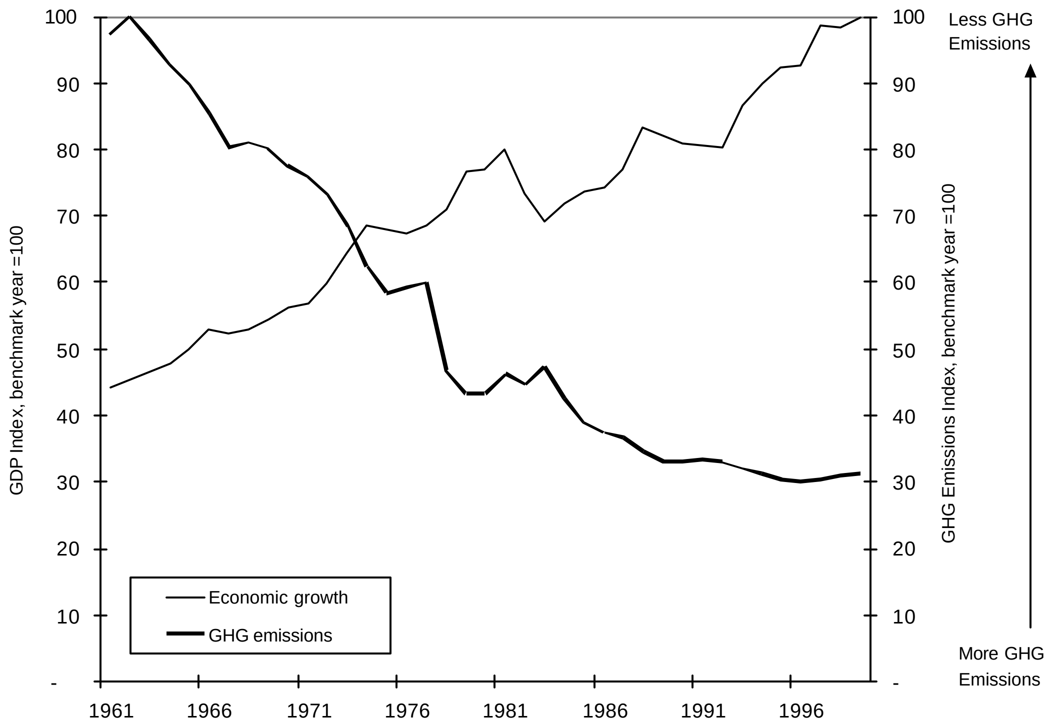


Sources: 1997 GHG Inventory; Caton, R., and Constable, S. 2000. Clearing the Air: A preliminary analysis of air quality co-benefits from reduced greenhouse gas emissions in Canada. David Suzuki Foundation. Vancouver, B.C.

2.5 Greenhouse Gas Emissions Index

The greenhouse gas emissions index is based on greenhouse gases per Albertan, derived from GHG emissions estimated prior to 1990 using percentage change per year in Alberta's primary energy demand. The index declined from 97.2 in 1961 to 31 in 1999 (see Figure 9).

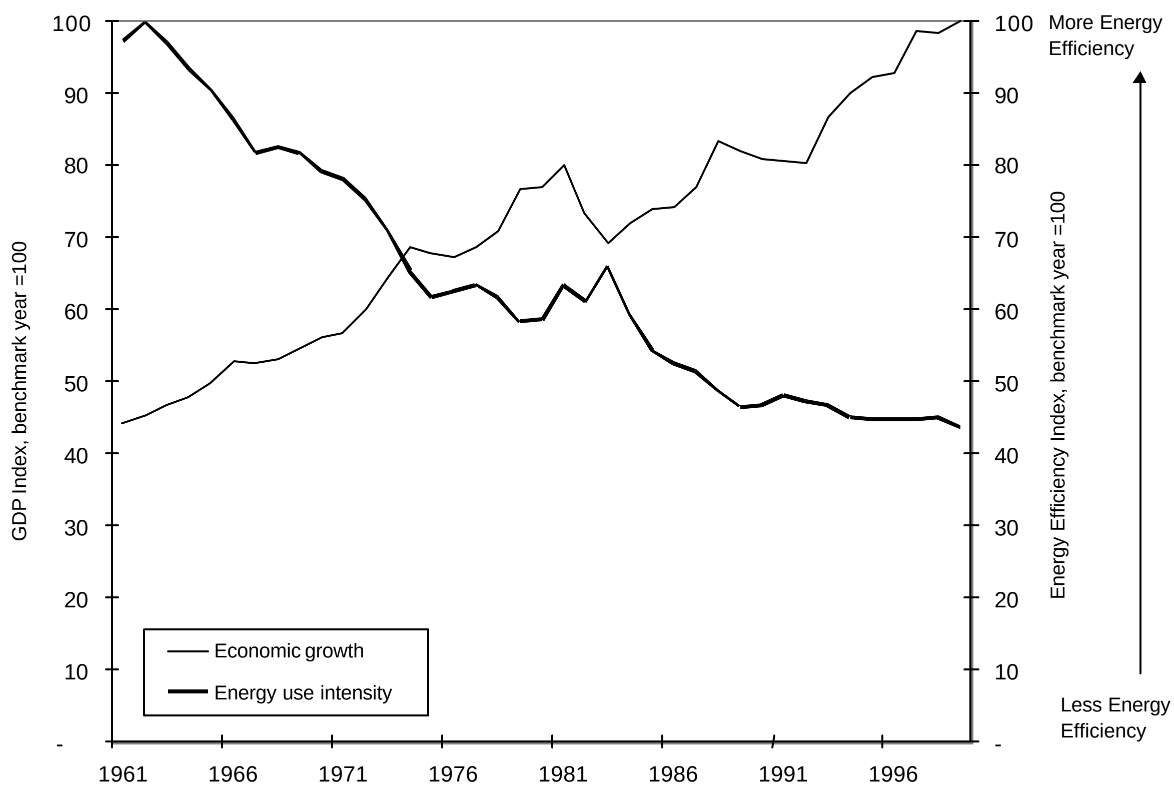
Figure 9: Alberta's Greenhouse Gas Emissions Index Based on Greenhouse Gas Emissions per Capita, 1961 to 1999



2.6 Energy Use Intensity Index

Because primary energy use is a more comprehensive measure of energy use intensity, we used it to construct the GPI energy use intensity index. The index is based on the primary energy use per Albertan from 1961 to 1999. The index uses 1962, the best year in terms of the least primary energy use per capita (328.7 GJ per person), as the benchmark. Therefore, 1962 is 100 on the index, and the other years are rated on the index scale of zero to 100, in relation to this benchmark year. The index declined from a high of 100 in 1962 to 43.6 in 1999 (see Figure 10).

Figure 10: Alberta's Primary Energy Use Intensity Index, 1961 to 1999



3 Air Quality

Across Canada, overall air quality improved in major cities during the 1980s. Between 1974 and 1992, annual means decreased for each major individual air pollutant: suspended particulates[d] by 54 percent, sulphur dioxide[e] by 61 percent, carbon monoxide[f] by 70 percent, and nitrogen dioxide[g] by 38 percent.[10] However, these significant improvements have waned over the past decade because of increasing numbers of automobiles and a trend toward larger, less fuel-efficient vehicles such as vans, trucks, and sport utility vehicles (SUVs).

> *Automobile ownership in Canada has increased from 310 vehicles per 1,000 people in 1970 to 484 per 1,000 in 1994. In 1980, purchases of vans, trucks, SUVs and commercial vehicles made up 26 percent of new vehicle purchases. Today these heavier vehicles comprise 48 percent of new purchases. As a result of these trends, during the past decade there have been little or no improvements in the ambient concentrations of* O_3 *[ozone] and fine particulates, and in some regions average concentrations have increased. At the same time,* CO_2 *[carbon dioxide] emissions have risen substantially.*[11]

The number of registered vehicles in Alberta has increased by 318 percent since 1961. This increase is substantially larger than the increase that Canada as a whole has experienced: 144 percent. While there were 0.3 vehicles per person in Alberta in 1961, in 1999 there were 0.56 vehicles per person. This too is greater than the 0.48 registered vehicles per person in Canada.

3.1 Air Pollutant Emissions and Ambient Concentrations

Particulates, ground level ozone, carbon monoxide, sulphur dioxide, and nitrogen oxides are the most commonly measured outdoor air pollutants because they are the principal components or precursors of smog and acid rain.[12] Environment Canada reported that about one-quarter of the total Canadian emissions of major air pollutants were emitted in Alberta. For example, as shown in Figure 11:

- Alberta's nitrogen dioxide emissions were 25 percent of the total Canadian emissions in 1995;
- Alberta's volatile organic compounds emissions were 27 percent of the Canadian emissions in 1995; and
- Alberta's sulphur dioxide emissions were 23 percent of the total Canadian emissions in 1995.[13]

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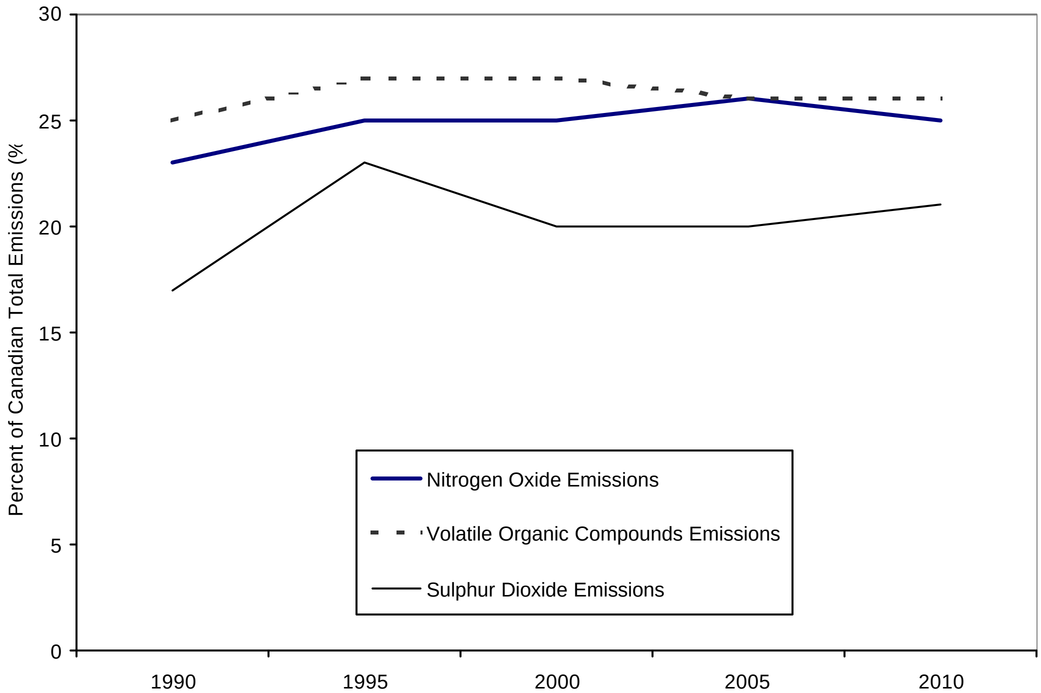
[d] Suspended particulates include dust, smoke, pollen and other substances emitted by natural sources and human activities, such as transportation, mining operations, thermal power generation plants and waste incinerators.
[e] Oil and gas processing, ore smelting and burning of coal and heavy oil are the major generators of sulphur dioxide.
[f] Carbon monoxide is a toxic, colourless and odourless gas generated from burning material containing carbon. Most carbon monoxide is created by motor vehicles, heating of dwellings and industrial pollution.
[g] Nitrogen dioxide is generated through fuel combustion.

Figure 11: Alberta's Air Pollutant Emissions as a Percent of the Canadian Total, 1990 to 2010



Source: Data from NAICC Forecast, Pollution Data Branch, Environment Canada

3.1.1 Nitrogen oxides

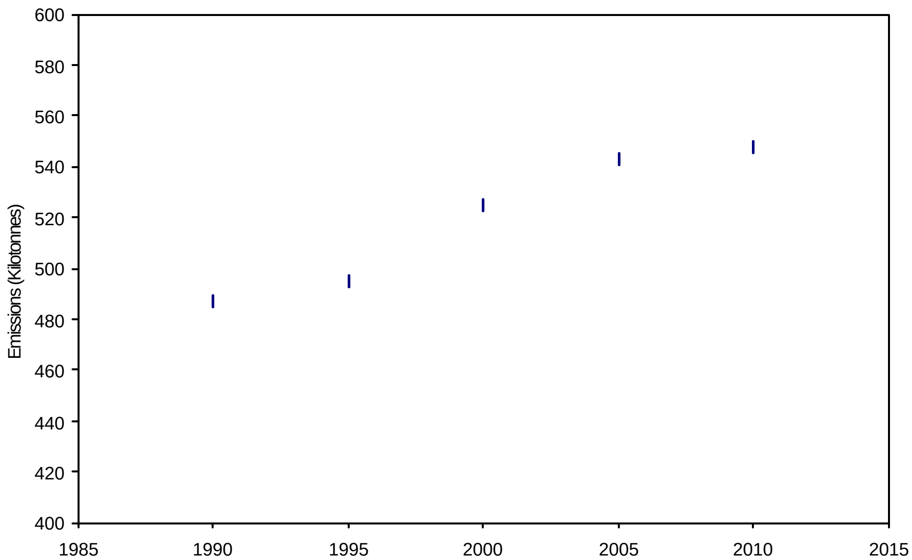
The nitrogen oxides (NO_x) monitored for air quality purposes are nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x plays a major role in creating ground level ozone. These emissions are by-products of the burning of fossil fuels (e.g., gasoline, diesel fuel, natural gas, oil and coal) for transportation, residential and industrial purposes. Average levels of nitrogen dioxide in Canadian cities declined by 28 percent between 1979 and 1993 because of improved fuel efficiency, the increased use of emission control devices, stricter new car emission control standards and voluntary emission reduction agreements from automobile manufacturers.[14]

In Alberta, NO_x emissions are produced by:

- transportation, primarily vehicles (43 percent of total emissions);
- industry, primarily oil and gas industries (37 percent of total emissions); and
- power plants (18 percent of total emissions).[15]

Despite the overall national decrease in NO_x emissions reported by Environment Canada between 1974 and 1992,[16] emissions were forecast to increase over the last decade and to maintain their higher level through the next decade (Figure 12). In 1990, approximately 487 kilotonnes of NO_x were emitted, whereas in 2000, 525 kilotonnes of emissions were forecast, and about 548 kilotonnes are forecast for 2010.

Figure 12: Alberta's Reported and Forecast Total Nitrogen Oxide NOx Emissions, 1990 to 2010

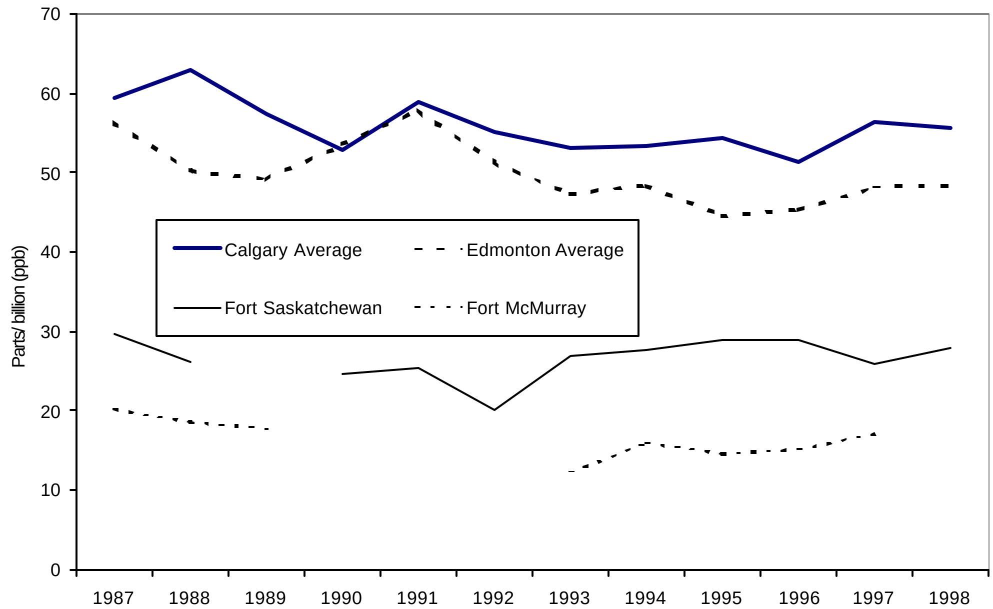


Source: Total emission data from NAICC Forecast, Pollution Data Branch, Environment Canada

The annual mean concentration (parts per billion, or ppb) taken as ambient measurements at urban stations in Alberta (Figure 13) indicates that NO_x concentrations in cities remained fairly steady between 1987 and 1998.[h] These data correspond with the total emission data between 1990 and 1995, during which time there was only a slight increase in the emissions, from 487 kilotonnes in 1990 to 495 kilotonnes in 1995. However, if the forecasted trend of emissions does occur, this may lead to an increase in ambient concentrations.

[h] Emissions are measured as the amount of a pollutant emitted from sources, whereas ambient concentrations are the measurements of the detected concentration of the pollutant at a particular site.

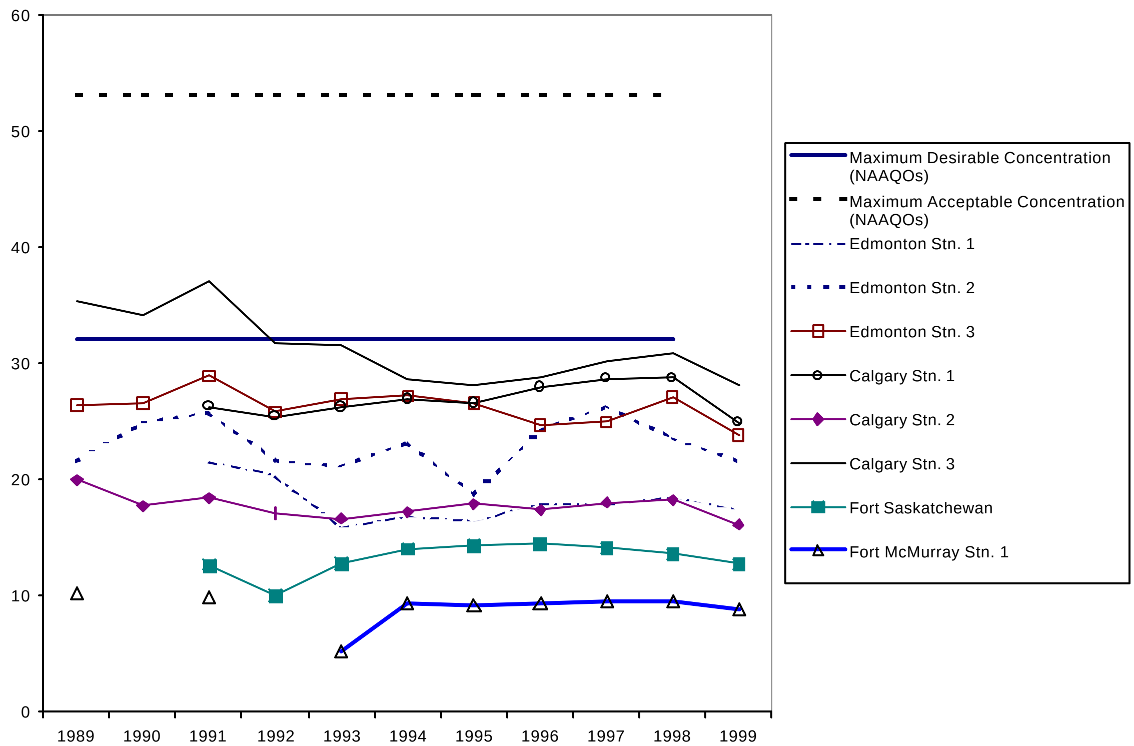
Figure 13: Annual Mean Ambient Nitrogen Oxides (NO_x) Concentration by Site, 1987 to 1998



Source: Data from Environment Canada

The maximum desirable guideline for the annual mean concentration of nitrogen dioxide (NO_2) is 32 ppb, and the maximum acceptable concentration is 53 ppb, according to the National Ambient Air Quality Objectives. In Figure 14, both guidelines are shown. All the urban centres are below the maximum acceptable and desirable objectives, except one of the Calgary stations, which was above the desirable objective between 1989 and 1991. Although the Calgary average trend has improved, the construction of a new gas-fired power plant approved by the Alberta Energy and Utilities Board, will result in a 35.5 percent increase in industrial sources of NO_x emissions in the area. Unfortunately, the plant will not be built using the best available technologies, and will emit higher rates of nitrogen oxides relative to plants using the better technology.[17] The plant will emit an estimated 485 tonnes of nitrogen oxides per year. Edmonton, on average, has been below the maximum acceptable concentration since 1992.

Figure 14: Nitrogen Dioxide (NO_2) Ambient Concentration Measurements in Alberta's Urban Areas, and the Maximum Desirable/Acceptable Concentration Objectives, 1989 to 1999



3.1.2 Volatile organic compounds

Volatile organic compounds (VOCs) contribute to ground level ozone. Benzene is a VOC that escapes to the air, for example during the refueling of gas tanks or due to the incomplete combustion of fossil fuels. Across Canada, airborne benzene emissions are four times higher in urban than in rural areas. Other VOCs include trichloroethylene, tetrachloroethylene, and methylene chloride but many of these are present in solvents and other substances used in the workplace so are of prime concern for indoor air quality.[i] The data in this section are for outdoor VOCs.

Atmospheric emissions of VOCs in Alberta increased between 1990 and 1995. According to Environment Canada, VOCs were forecast to stabilize between 1995 and 2000, and then increase over the next decade (Figure 15). Emissions were 707 kilotonnes in 1990 and 720 kilotonnes in 1995, and are forecast to increase to 755 kilotonnes by 2010.

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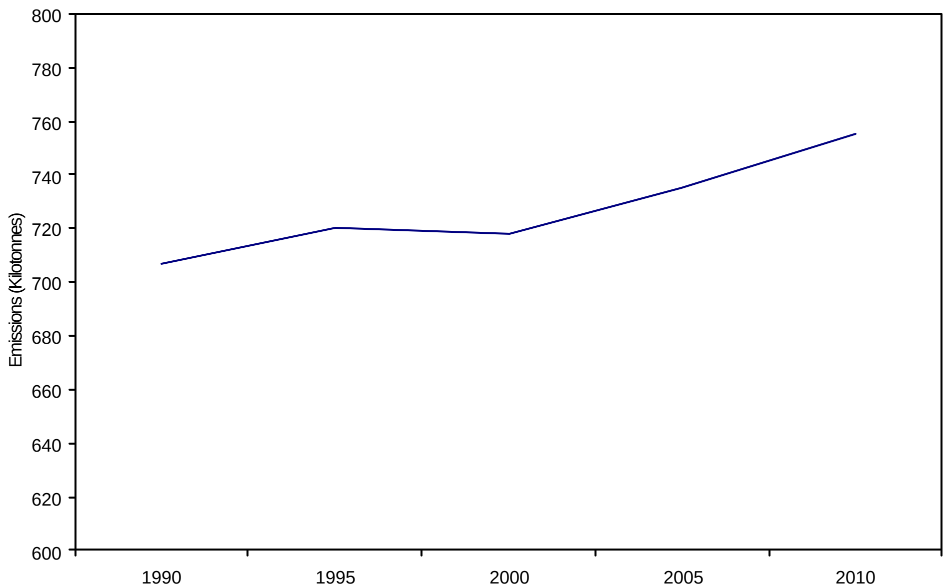
[i] Most of the exposure to trichloroethylene, tetrachloroethylene and methylene chloride is through indoor sources such as the workplace. Trichloroethylene and tetrachloroethylene are synthetic compounds used mostly as a solvent in the metal degreasing and dry cleaning industries, but also present in some household products (e.g., correction fluids, rug cleaners, paint removers and strippers, adhesives, spot removers). Methylene chloride is a commercial chemical used primarily in paint removers, foams and aerosols.

Figure 15: Alberta's Reported and Forecast Total Volatile Organic Compounds (VOCs) Emissions, 1990 to 2010

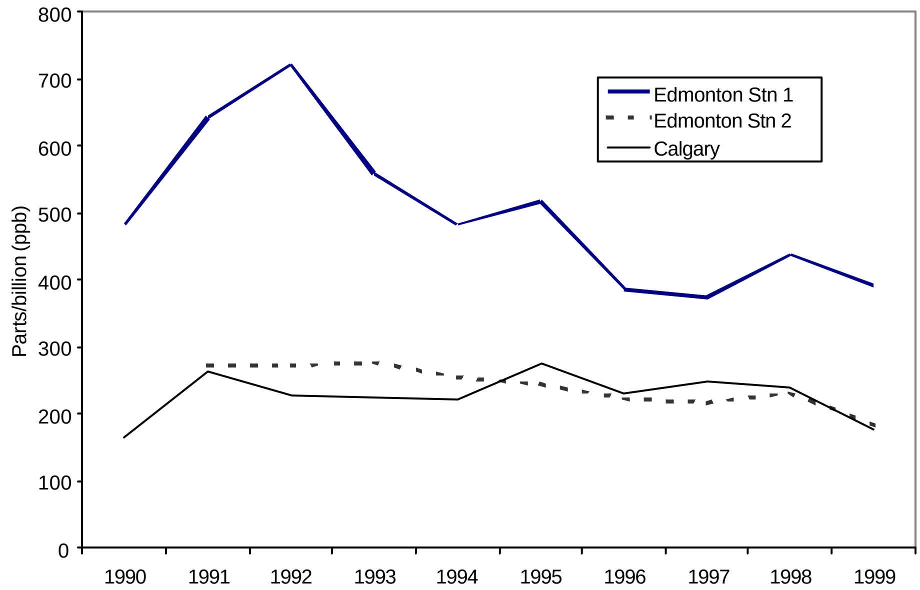


Source: NAICC Forecast, Pollution Data Branch, Environment Canada

The trends in annual mean ambient concentrations of VOCs showed fairly stable concentrations between 1990 and 1999 at one of two stations in Edmonton and in Calgary. The second Edmonton station demonstrates a decline in annual ambient mean concentrations from 482 ppb in 1990, to 391 ppb in 1999 (Figure 16). Improvements in urban centres are a result of stricter emission controls on vehicles.[18]

In 1989, the Canadian Council of Ministers of the Environment established the NO_x/VOC Management Plan, which includes strategies for energy efficiency improvements, fuel reformulation, changes in fuel combustion and production processes, improvements in emission control devices and the prevention of vapour leakage from fuel storage tanks to help control emissions.[19]

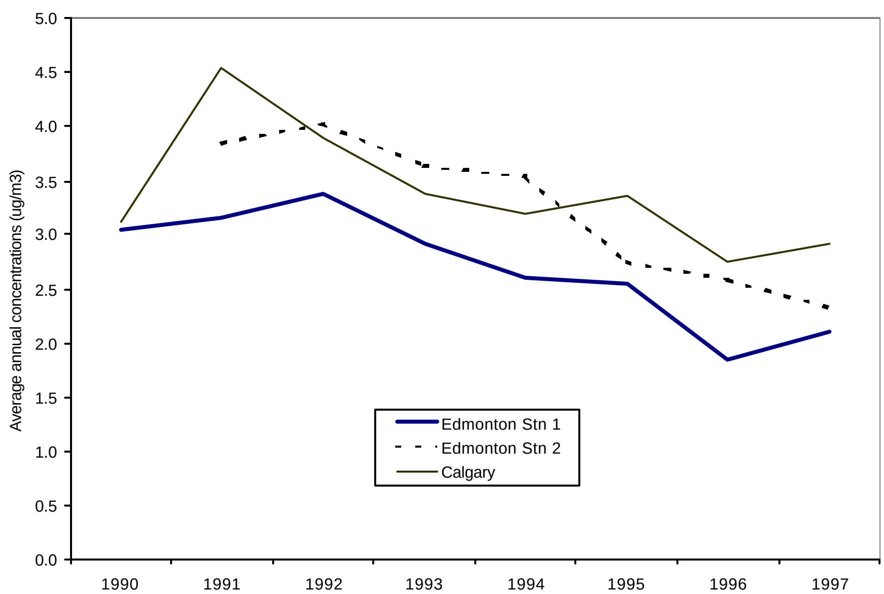
Figure 16: Ambient Mean Concentration of Volatile Organic Compounds (VOCs) by Year (ppb) in Edmonton and Calgary, 1990 to 1999



Source: Data from Environment Canada

Similarly, the average annual benzene concentrations (ambient measurements) in Edmonton and Calgary have declined since 1990 (Figure 17). However, as shown in the report on hazardous wastes, total releases of benzene to the atmosphere from industrial sources are much higher in Ft. McMurray than in Edmonton.

Figure 17: Average Annual Benzene Concentrations in Edmonton and Calgary, 1990 to 1997



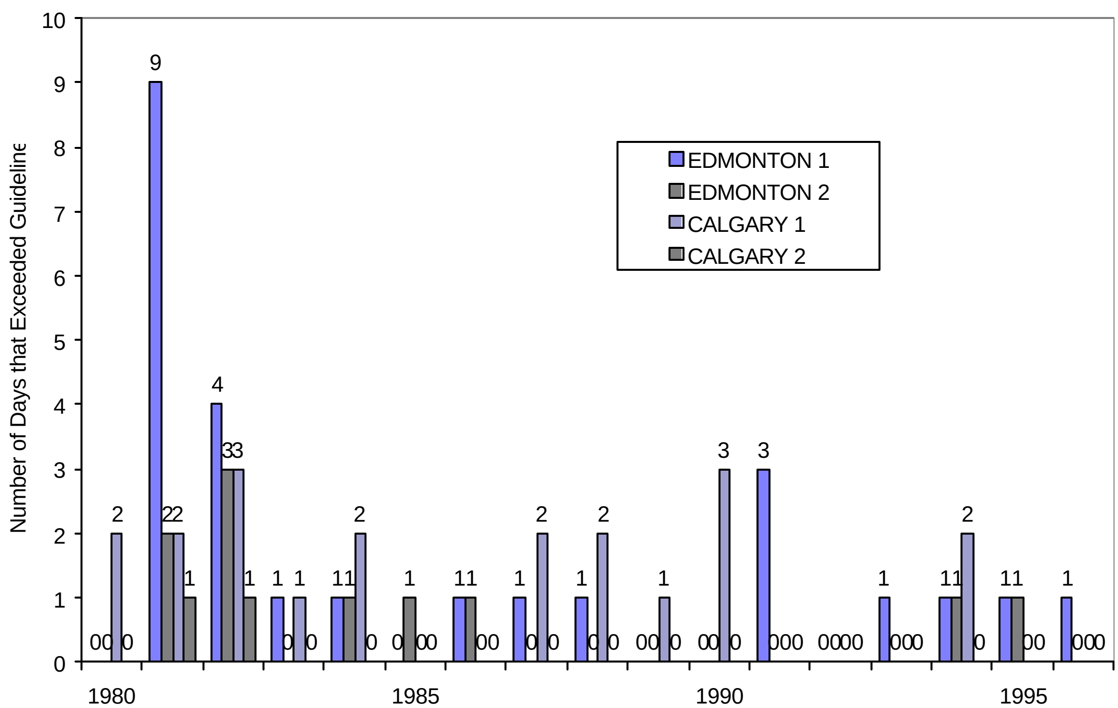
Source: Data from the Environmental Technology Centre, Environment Canada

3.1.3 Ground level ozone

Ozone in the upper atmosphere plays a vital role by protecting people from harmful ultraviolet rays. At ground level, ozone is created by chemical reactions in the air between volatile organic compounds, nitrogen oxides and sunlight. High ozone concentrations tend to occur under conditions of bright sunlight, high temperature and a stationary air mass. Ground level ozone is the major component of photochemical smog, and contributes to the "greenhouse effect" by trapping solar energy in the form of heat.[20]

Between 1979 and 1993, the Canadian average concentrations of ground level ozone in urban areas climbed by 29 percent, although at the same time, there was a 50-percent reduction in severe ozone episodes. Canada has established a maximum acceptable guideline for ozone of 82 ppb over a one-hour period, one of the strictest guidelines in the world.[21] The annual number of days that ground level ozone exceeds this objective in Edmonton and Calgary is relatively low compared with other parts of Canada, and has decreased since the 1980s (Figure 18). Short-term exposure (i.e., a few hours) to ozone can irritate the eyes, nose and throat and can cause respiratory problems. High ozone levels increase the vulnerability of people with asthma to common allergens and are associated with an increase in the number of emergency hospital visits, and the number of hospital admissions for respiratory complaints.[22]

Figure 18: Annual Number of Days Ground Level Ozone Exceeded Objective of 82 Parts per Billion (ppb) for at Least One Hour during the Day, 1980 to 1996



Source: Data from the Environmental Technology Centre, Environment Canada

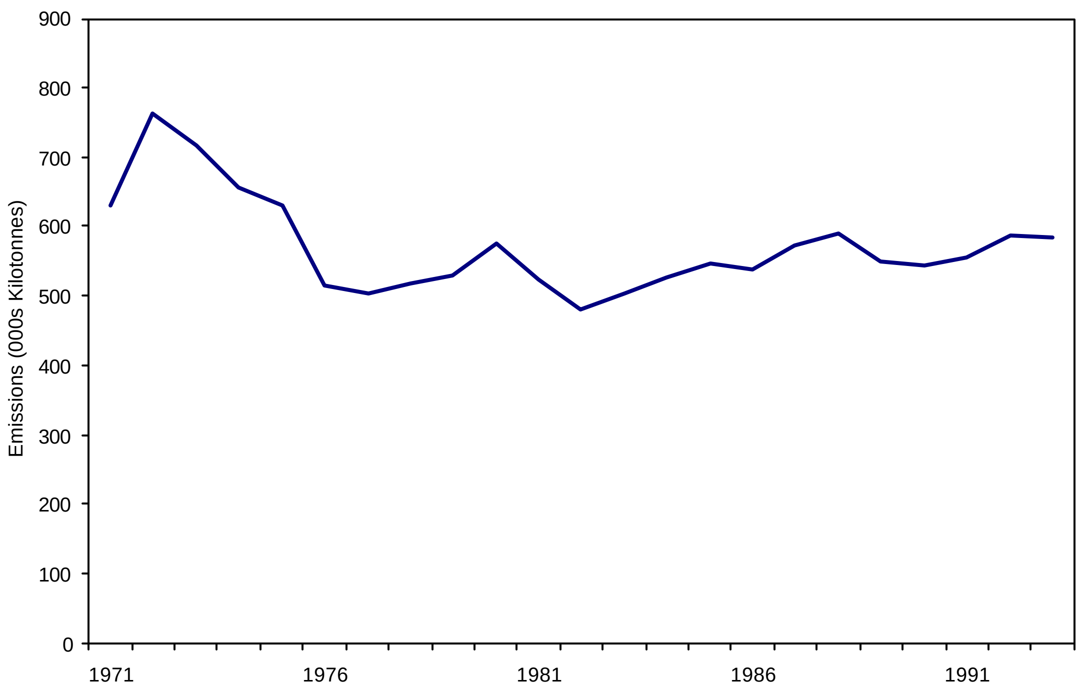
Although high ozone readings do occur in urban areas, the 24-hour guideline for ozone is most frequently exceeded at rural and small urban monitoring stations. Ozone is high in pristine locations due to the natural ozone generating process.[23]

3.1.4 Sulphur dioxide

The main source of sulphur dioxide (SO_2) is from the industrial use of fossil fuels in petroleum refineries, pulp and paper mills, and electrical generating plants, as well as from smelting in metal refineries, and the burning of coal and heavy oil. It is a persistent pollutant that combines with water molecules to form sulphuric acid, resulting in what is known as "acid rain," contributing to secondary fine particulates ($PM_{2.5}$).

Sulphur dioxide emissions in Alberta have declined since the 1970s (Figure 19). The highest annual emissions were reported in 1972 at 762,600 kilotonnes, falling to 583,600 kilotonnes in 1993, for a decline of 179,000 kilotonnes (23 percent).

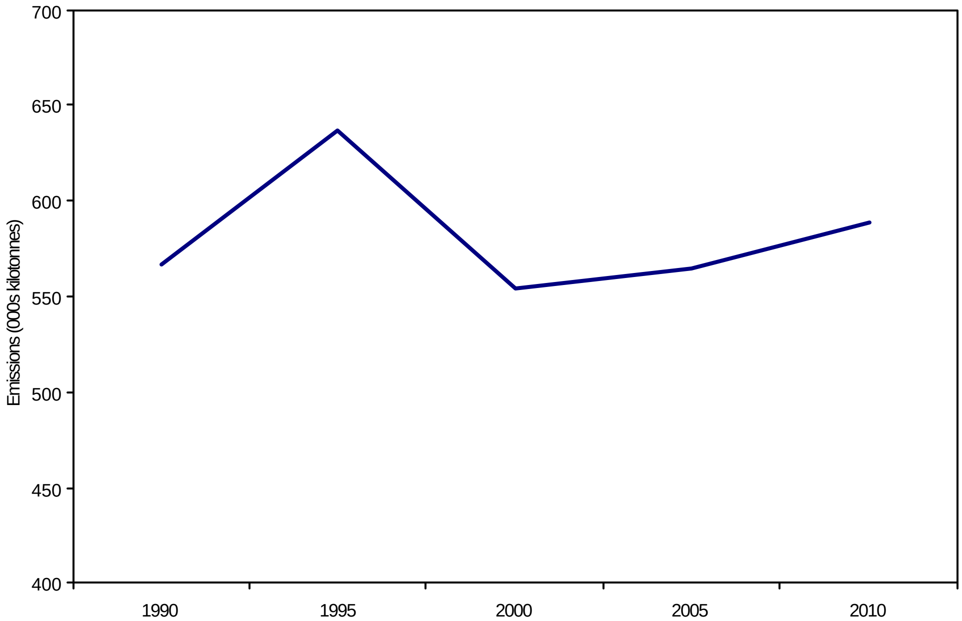
Figure 19: Alberta's Sulphur Dioxide (SO_2) Emissions, 1971 to 1993



Source: Data from, Slubik, Dave (1996). Emissions Inventories of Sulphur Dioxide, Nitrogen Oxides and Ammonia in Alberta 1963 to 1995: A Review. Edmonton, Alberta.

However, in a 1996 inventory and forecast of air pollutant emissions by Environment Canada, Alberta's SO_2 emissions increased by 70,000 kilotonnes between 1990 and 1995, but emissions are forecast to drop below 1990 levels by 2000, followed by a slight increase of 22,000 kilotonnes above 1990 levels, to reach 589,000 kilotonnes in 2010 (Figure 20).

Figure 20: Reported and Forecast Sulphur Dioxide Emissions (SO_2) for Alberta, 1990 to 2010



Source: Data from NAICC Forecast, Pollution Data Branch, Environment Canada

3.1.5 Particulate matter

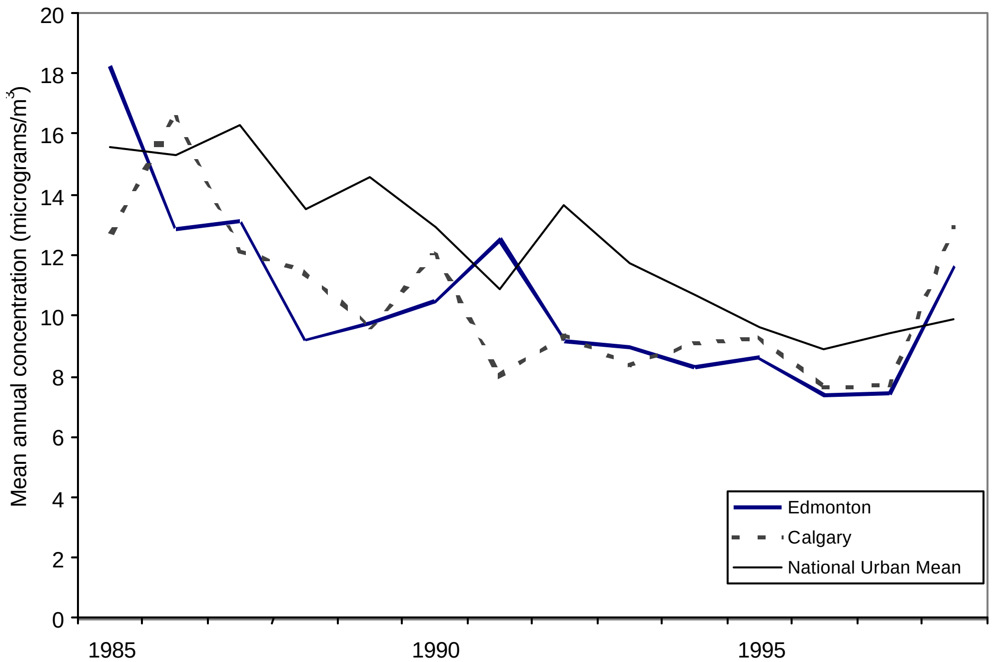
Outdoor airborne particulate matter results from natural sources, such as wind-blown dust, soil, pollen, and soot from forest fires, as well as from human sources, such as vehicle exhaust emissions, industrial emissions, road dust, agriculture, construction, wood burning, mining, smelting, pulp and paper processing, metal processing, and transportation. Average levels of airborne particulates in Canada's urban areas declined by 38 percent between 1979 and 1993, as a result of controls on vehicle and industrial emissions.[24]

> *Because of its small size, PM≤10 (microns) can penetrate deep into human lungs, where it becomes trapped. It has been linked with chronic respiratory disease and a range of other health ailments including cardiovascular disease. Scientists now believe that there is no safe level of exposure to PM≤10, and even relatively low levels can lead to premature deaths from cardiovascular causes.*[25]

Secondary particulates form when acidic air emissions, such as oxides of sulphur and nitrogen, and volatile organic compounds (VOCs) are transformed into nitrates, sulphates and organic aerosols. Both ozone and particulates affect the respiratory system and decrease lung function, leading to increased mortality from respiratory and cardiovascular disease.[26] These pollutants generally accumulate in the air of industrial regions and urban areas where automobile exhaust fumes are high. While there are no figures for Alberta, in Ontario, it is estimated that approximately 1,800 premature deaths and 1,400 hospital admissions per year are due to the effects of inhalable particles.[27] In rural areas, levels are likely to be high when dusty conditions occur.

In general, levels of fine particulate matter[j] recorded in Alberta cities are below the proposed national standards (15-25 ì g/m^3).[28] However, given that scientists now believe there is no safe level of exposure and that PM levels are rising, as shown at the end of the time series in Figure 21, particulate matter should be monitored very closely. The annual mean concentration of fine inhalable airborne particles ($PM_{2.5}$) has been measured at stations in Edmonton and Calgary since 1985. Over this time, the annual mean concentration decreased for both cities (Figure 21), until the latest year reported, 1998, which indicates a dramatic increase in the annual mean, exceeding the national urban mean. The annual peak concentrations measured in Edmonton and Calgary also declined, although they too increased in 1998 (Figure 22).

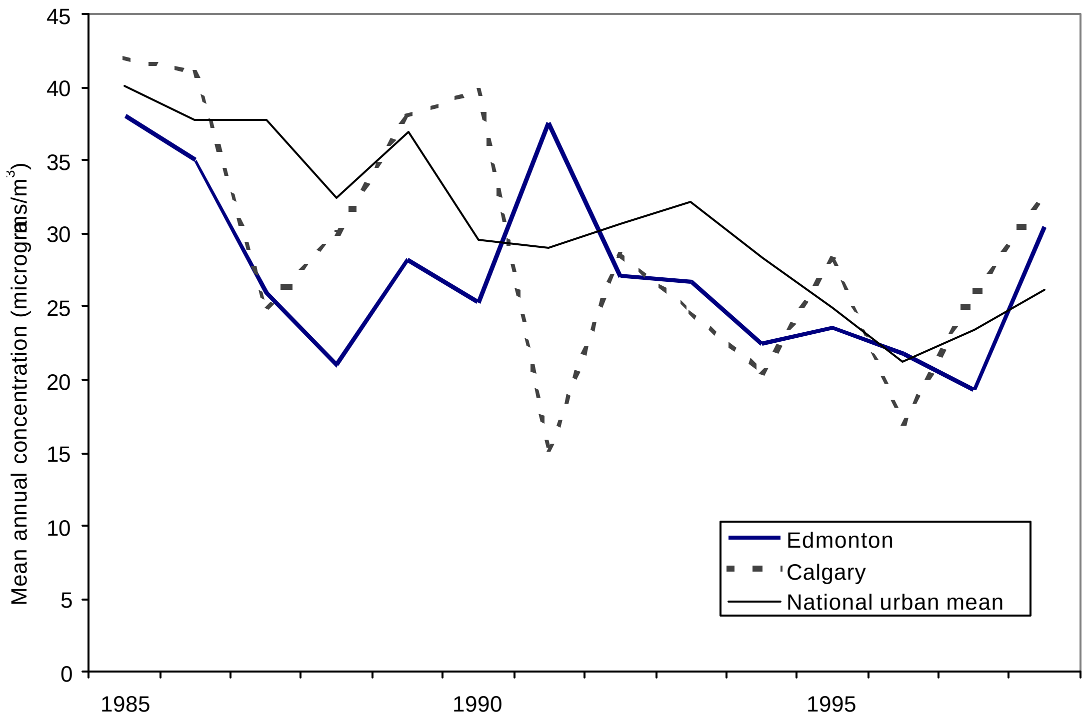
Figure 21: Annual Mean Concentration of Fine Inhalable Airborne Particles ($PM_{2.5}$) Measured in Edmonton and Calgary, 1985 to 1998*



*Source: Environmental Technology Centre, Environment Canada; * Ambient Measurements*

[j] $PM_{2.5}$ is particulate matter less than 2.5 microns in diameter; a micron is one-millionth of a metre.

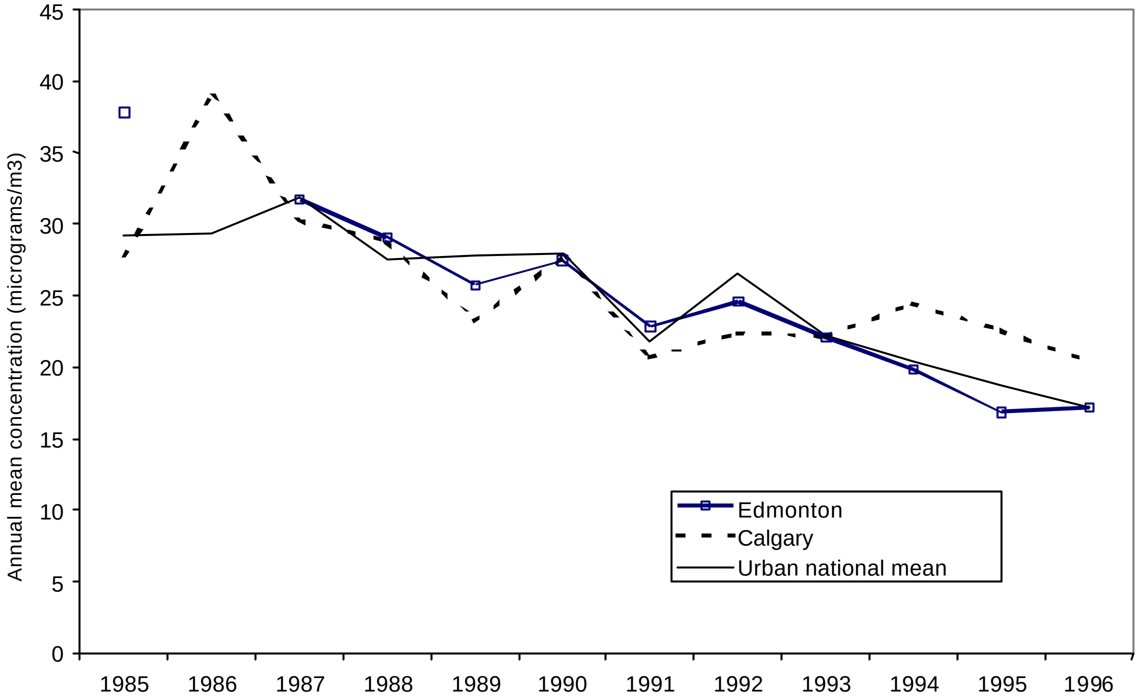
Figure 22: Annual Peak Concentration of Fine Inhalable Airborne Particles ($PM_{2.5}$) Measured in Edmonton and Calgary, 1985 to 1998*



*Source: Environmental Technology Centre, Environment Canada; * Ambient Measurements*

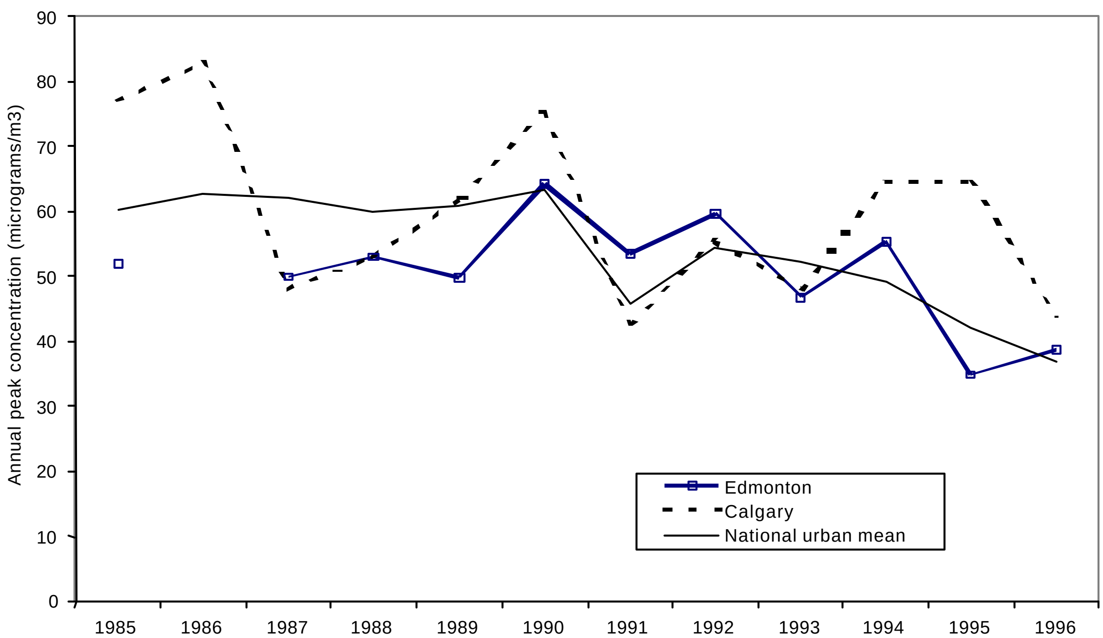
The annual mean concentrations of coarse particulates (PM_{10}) in Edmonton and Calgary have generally been on par with the national urban mean concentrations (Figure 23). In 1995 and 1996, the latest years reported in Environment Canada's dataset, levels were above the national urban mean. The annual peak concentration of coarse particulate matter has periodically been higher than the national urban mean over the same time period (1985 to 1996) (see Figure 24).

Figure 23: Annual Mean Concentration of Coarse Inhalable Airborne Particles (PM_{10}) Measured in Edmonton and Calgary, 1985 to 1996*



*Source: Environmental Technology Centre, Environment Canada; * Ambient Measurements*

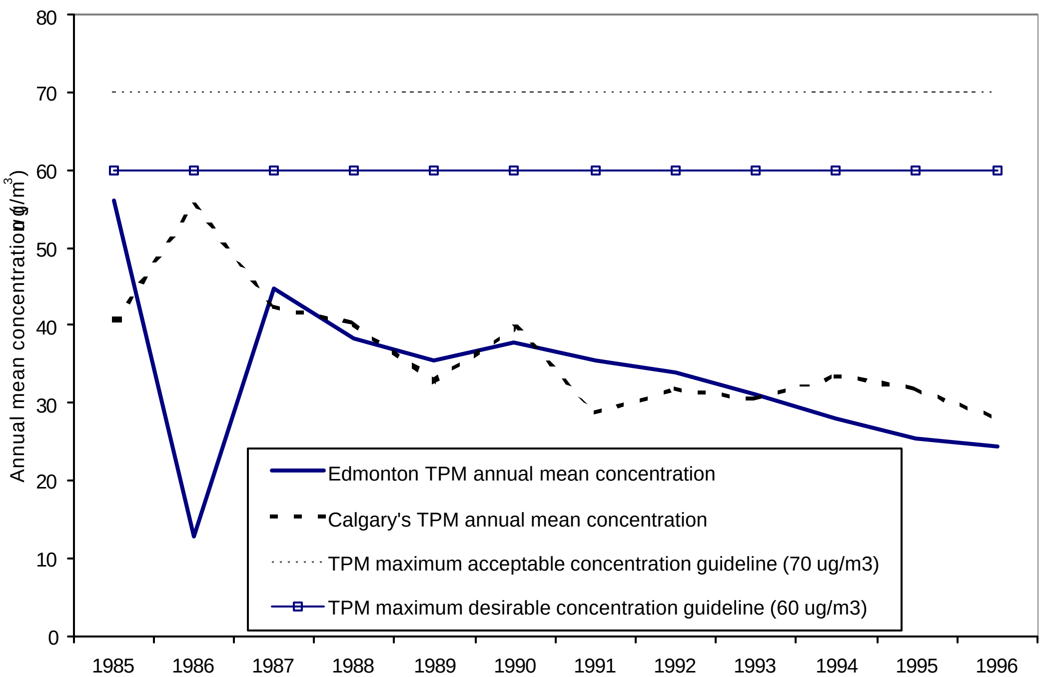
Figure 24: Annual Peak Concentration of Coarse Inhalable Airborne Particles (PM_{10}) Measured in Edmonton and Calgary, 1985 to 1996*



*Source: Environmental Technology Centre, Environment Canada; * Ambient Measurements*

The annual mean of total particulate matter (fine and coarse particulate matter), is shown in Figure 25. For both cities, the total particulate matter is below the National Ambient Air Quality Objectives (NAAQOs) for maximum acceptable concentrations and for the maximum desirable concentrations. However, these guidelines are being revised as a result of the announcement that there may not be a safe level of exposure to particulate matter less than 10 microns in size.[29]

Figure 25: Edmonton and Calgary's Annual Mean Total Particulate Matter (TPM) in Relation to the Maximum Acceptable and Maximum Desirable Concentration Objectives according to the NAAQOs, 1985 to 1996

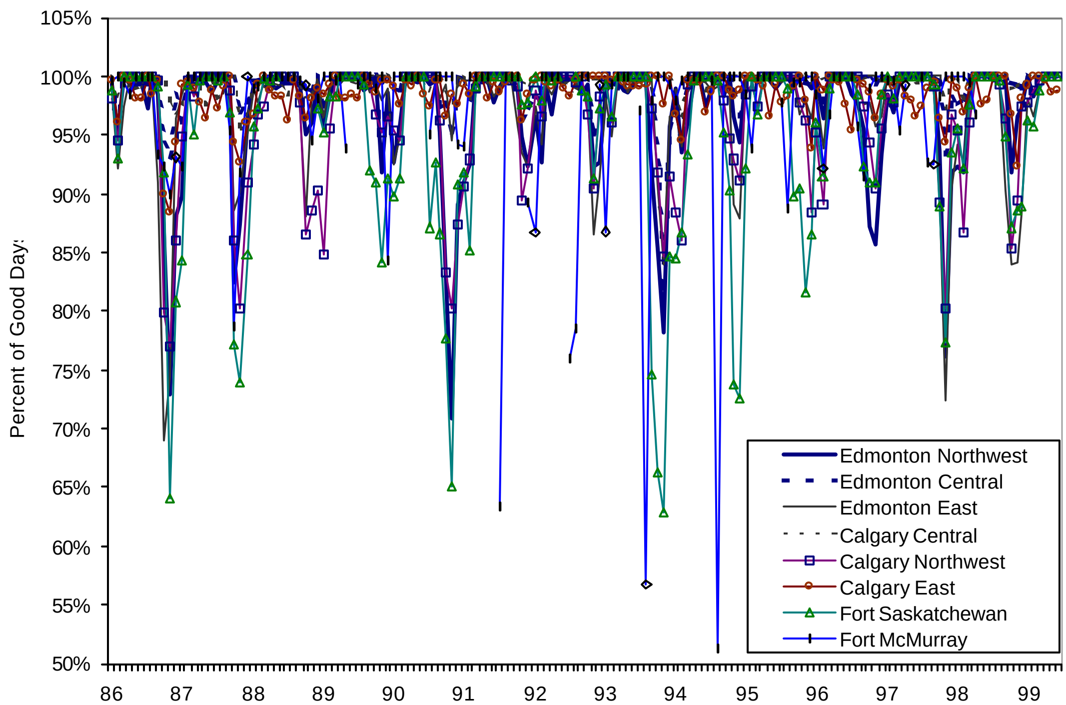


Source: Data from Environmental Technology Centre, Environment Canada; TPM calculations by authors; Guidelines are National Ambient Air Quality Objectives

3.2 Alberta Government Air Quality Index

The Alberta government provides an overall measure of air quality with its Index of the Quality of the Air (IQUA). The IQUA converts ambient measurements of pollutant concentrations for SO_2, NO_2, CO, ozone, and total suspended particulates to a common scale. The index is expressed as the number of good, fair, poor and very poor air quality days. The percentage of good air quality days each month for the IQUA of Alberta's major urban centres is shown in Figure 26. According to these monthly averages, Alberta's urban residents enjoyed good air quality on 56.7 percent to 100 percent of the days per month, between January 1989 and May 1999. In general, the percentage of good days appears to have improved during 1999, compared with the early 1990s. Locations with the poorest air quality tend to be Ft. McMurray and Ft. Saskatchewan.

Figure 26: Air Quality for Alberta's Major Urban Centres: Monthly Average of Good Air Quality Days, 1986 to 1999



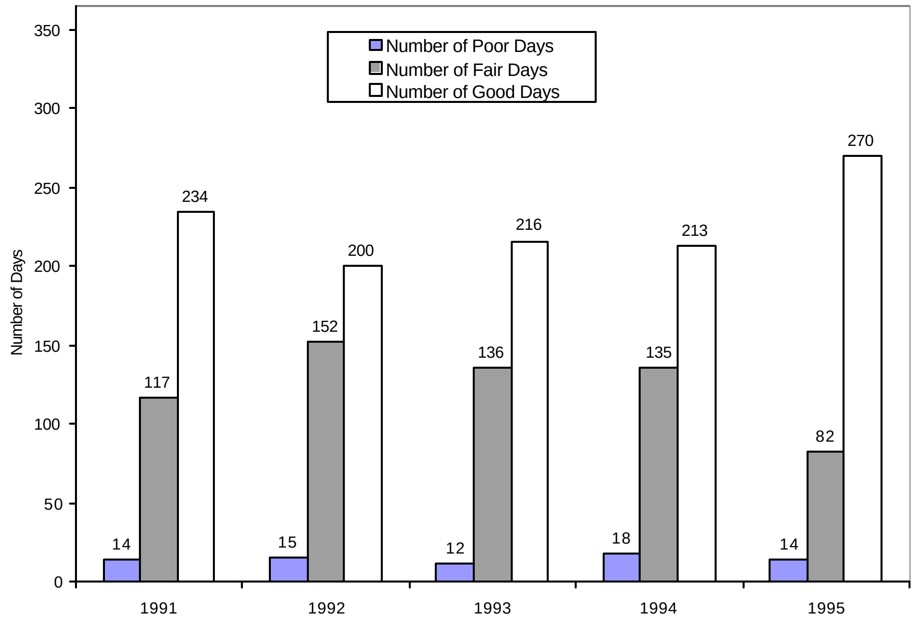
3.3 Statistics Canada Air Quality Index

Statistics Canada compiles a different air quality index. Its index is based on days (i.e., highest hour in a day) rather than hours. Figure 27 illustrates the annual number of good, fair and poor days in Edmonton between 1991 and 1995. The annual number of good days ranged from 200 in 1992 to 270 in 1995; the annual number of fair days ranged from a low of 82 in 1995 to a high of 152 in 1992; and the annual number of poor air quality days ranged from 12 to 18.

Figure 28 show similar data for Calgary, where there were usually fewer days with good air quality than in Edmonton, and more poor and fair air quality days between 1991 and 1995. The annual number of good days ranged from 174 to 219, the number of fair days ranged from 121 to 156, and the number of poor days ranged from 18 to 44.

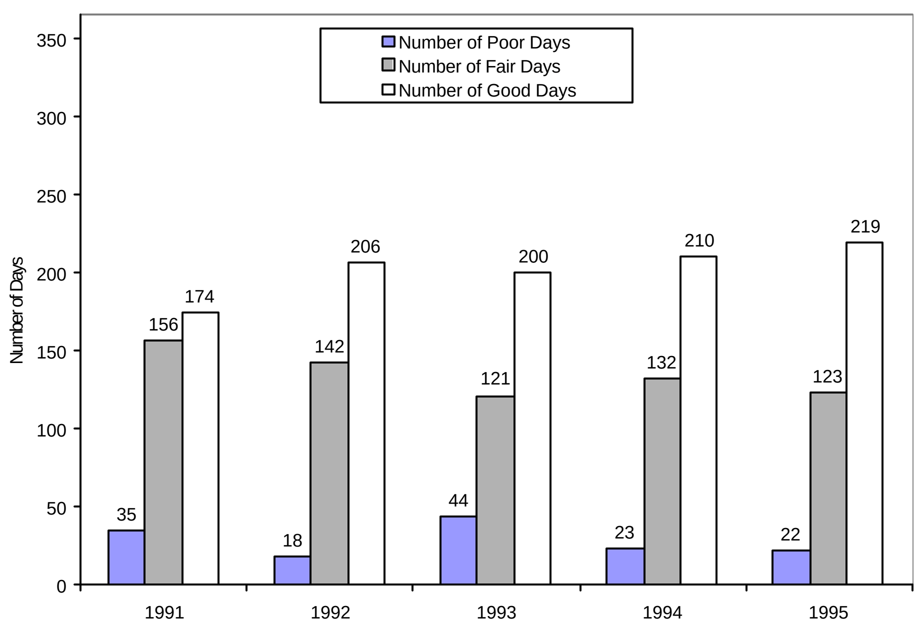
Each urban area shows fewer good air quality days during the spring and summer. High ozone levels were the main cause for unsatisfactory air quality. Dust was also a factor, especially in Calgary East and Edmonton Northwest.[30]

Figure 27: The Annual Number of Good, Fair and Poor Days According to the Air Quality Index for Edmonton, 1991 to 1995



Source: Statistics Canada

Figure 28: The Annual Number of Good, Fair and Poor Days According to the Air Quality Index for Calgary, 1991 to 1995



Source: Statistics Canada

3.4 Impact of Air Quality on Health in Alberta

> "As it currently stands, recent studies have shown that close to 8 percent of all non-traumatic mortality in Canadian cities is attributable to air pollution caused by the burning of fossil fuels."[31]

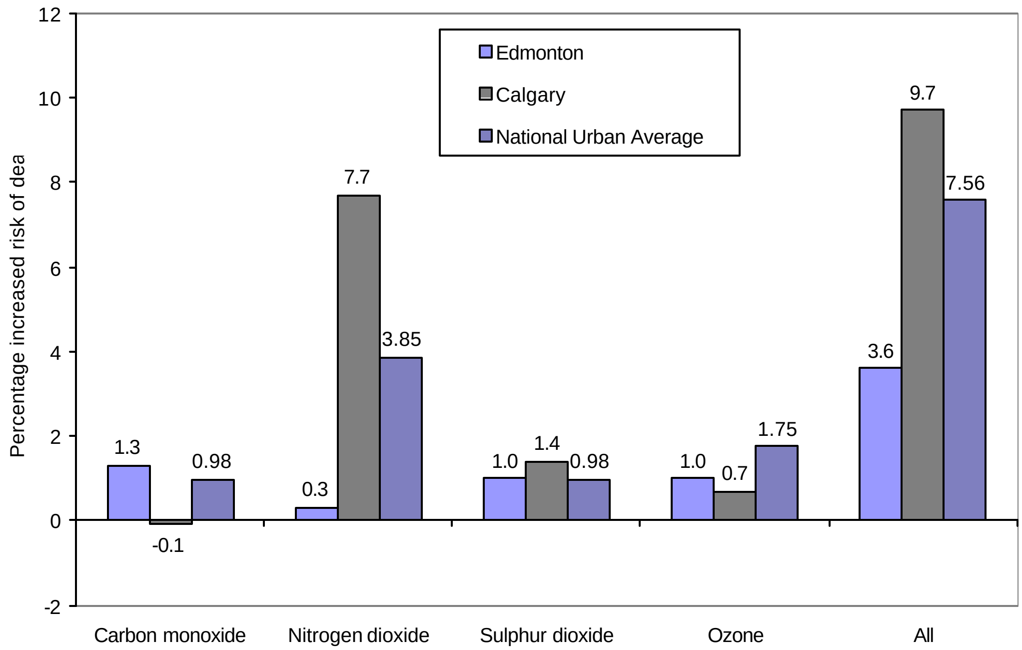
Air pollution has been recognized for its potential to harm both the environment and human health, but recently even more compelling results show independent associations between air pollutants and health problems.[32] Although sulphur dioxide (SO_2) and ground level ozone (O_3), formed by the reaction of nitrogen oxides and volatile organic compounds in sunlight, are both known to affect health, the federal government has recently focused attention on the health impacts of particulate matter. Respirable particulate matter of 10 microns or less is a key component of smog and in May 2000 was declared a toxic substance by the federal Minister of Environment.[33]

Smog occurs far less frequently in Alberta than in Toronto or Vancouver, but a study by Burnett et al. (1998) in the *Canadian Journal of Public Health* found that even Calgary and Edmonton are seeing increased premature mortality due to ambient air pollution generated from the burning of fossil fuel.[34] Using relative regression models, this study attributed about eight percent of non-traumatic death in 11 Canadian cities between 1980 and 1991 to the concentrations of ambient gaseous air pollutants. The analysis showed that nitrogen dioxide had the largest effect on mortality with a 4.1 percent increased risk, followed by ozone at 1.8 percent, sulphur dioxide at 1.4 percent, and carbon monoxide at 0.9 percent. In addition, they determined that a 0.4 percent reduction in premature mortality could be "attributed to achieving a sulphur content of gasoline of 30 ppm in five Canadian cities, a risk reduction 12 times greater than previously reported."

> *In other words, the combination of pollutants … is likely responsible for 1 of every 12 non-accidental deaths in Canada. Further, the number of these deaths will likely increase in the future as air pollution worsens due to increased fossil fuel use and global warming. In addition to synergistic effects, current evidence suggests that, for most of the fossil fuel-related pollutants (ozone, carbon monoxide, sulphur dioxide, nitrogen dioxide, PM10, PM2.5, sulphates, etc.) there is no "safe" level or "threshold." That is, there is no level below which there are no adverse health outcomes. This implies that though there may be dramatic episodes of mortality and morbidity associated with "peaks" of bad pollution, some people are quietly being admitted to hospital or dying when air pollution is at lower levels as well.*[35]

According to this study by Burnett et al., the percentage increase in risk of premature mortality due to the change in ambient air pollutants between 1980 and 1991 in Edmonton (3.6 percent overall), was low in relation to the national urban average (7.56 percent; Figure 29). Calgary's overall percentage increase in risk of premature mortality due to the change in ambient air pollutants between 1980 and 1991 was 9.7 percent, 2.14 percentage points above the national urban average. Most of the increased risk (7.7 percent) was a result of the change in ambient measurements of nitrogen dioxide.

Figure 29: Percentage Increased Risk of Death for Edmonton and Calgary, Attributable to City-specific Changes in Air Pollution Concentrations Examined Simultaneously by City, 1980-1991



Source: Data from, Burnett, R.T., Cakmak,S., and Brook, J.R. 1998. The effect of the urban ambient air pollution mix on daily mortality rates in 11 Canadian cities. Canadian Journal of Public Health. 89: 152-156.

Although ambient concentrations of SO_2 have declined in most areas of Canada over the past 30 years, a recent study calculated the risk ratio between respiratory hospital admissions and increases in ozone. Results indicated that 4.5 percent more people than average are admitted to hospital for respiratory illness when ozone levels are 60 percent of the maximum acceptable level set at 62 parts per billion.[36]

As the main recording stations are in urban areas there is no continuous record for the situation in rural Alberta. However, those living downwind of gas flares have long suspected that the emissions were affecting their health. The fact that only 66 to 84 percent of the gas in the flare is burned was shown in 1996.[37] As a result, products of incomplete combustion, including known carcinogens such as benzene and polycyclic aromatic hydrocarbons (PAHs) are released to the air. Sulphur emissions from sour gas (as hydrogen sulphide or, following combustion, as sulphur dioxide) can also affect health.

In recognition of health concerns associated with air pollution, the Clean Air Strategic Alliance, a multi-stakeholder group of government, industry and non-government organizations set up a framework for a Human Health Monitoring System in 1997, and proposals for its implementation were approved in 1999.[38] In 2000, the Alberta government initiated the Western Canada Study on Animal and Human Health Effects Associated with Exposure to Emissions from Oil and Natural Gas Field Facilities, with the involvement of British Columbia, Saskatchewan and Manitoba. The study began in 2001.[39] Often ignored in discussions about climate change and air pollution is that the combustion of fossil fuels for energy is the major cause of both. Furthermore, as the climate warms, air pollution in cities will likely worsen because heat and sunlight are critical factors in causing urban smog.[40]

3.5 Air Quality and Agriculture

While the impacts of flares and other emissions from oil and gas operations may not be clearly documented in humans, various studies have shown that air emissions from these sources can negatively affect livestock.[41] [42] [43] In 1999, the Clean Air Strategic Alliance Animal Health Project Team held a workshop to provide more insight into the issues and relationships between air quality and animal health.[44] A survey among farmers and other stakeholders indicated that about 20 percent of the 154 respondents had experienced problems with air quality impacts on animal health.[45] At the time of writing, a new study is being set up into the animal health effects associated with exposure to emissions from oil and natural gas field facilities (see endnote 39).

There is also evidence that air quality in Alberta has some effect on agricultural crops. For example, the Acid Deposition Research Program found (using an alfalfa growth model coupled to air quality data) that a slight reduction in alfalfa yields in the region northwest of Edmonton could be due to sulphur dioxide and possibly ozone. It was suggested that future increases in acidic deposition and ozone could make this worse and that further research was needed.[46]

The West Central Airshed Society, established in 1995 to manage the first regional airshed management zone in Alberta, has been monitoring two sensitive crops at several sites in its region. At one site, "evidence indicated that the injury observed on saskatoons [berries] was due to repeated exposures to low levels of sulphur dioxide and may have been exacerbated by the presence of ozone and nitrogen oxides."[47] The report added that inherent levels of sulphur in the soil may have made the saskatoon berries susceptible to such injury and that no similar injury was observed on alfalfa, the other crop studied.

The West Central Airshed Society has been studying the growth rates and harvested yield of alfalfa at three study plots since 1995. They state that, "with very limited data at this time, a mathematical model indicates that ozone, sulphur dioxide, and oxides of nitrogen can be important variables affecting alfalfa growth."[48] While some effects can be observed, the impact on plant growth in this region is probably not great.[49] Although pesticides have been measured in rain in the Lethbridge area, the effect on crops is not yet known.[50]

While air quality has some impacts on agriculture, agriculture also affects air quality. Odours and emissions from intensive livestock operations are the most obvious example, but particulate matter from tillage, wind erosion and grain industries is also important.[51] These issues are dealt with in GPI report #19 on agriculture.

3.6 Cost of Air Pollution

The annual economic costs of air pollution to human health, households, infrastructure, and the environment are another example of environmental costs that are omitted from national accounts and the GDP as a legitimate environmental quality depreciation cost or regrettable expenditure. These costs can represent a significant omission from conventional economic performance accountancy. Unfortunately such economic cost estimates are rare. GPI accounting attempts to rectify these shortcomings by explicitly accounting for the physical conditions of environmental assets, including air quality and greenhouse gas emissions, and by quantifying the total monetary costs associated with the degradation of environmental assets that result from economic development.

In a recent study by the Ontario Medical Association, *The Illness Cost of Air Pollution in Ontario*,[52] the economic costs associated with air pollution in Ontario were estimated at $1-billion annually. The study found that "Air pollution costs Ontario citizens more than $1 billion a year in hospital admissions, emergency room visits, and absenteeism according to the analysis contained in the report. In addition, the report estimates the cost of pain and suffering and loss of life as a result of polluted air. These massive costs amount to billions of dollars for Ontarians." These estimates are conservative relative to U.S. estimates of air pollution costs.

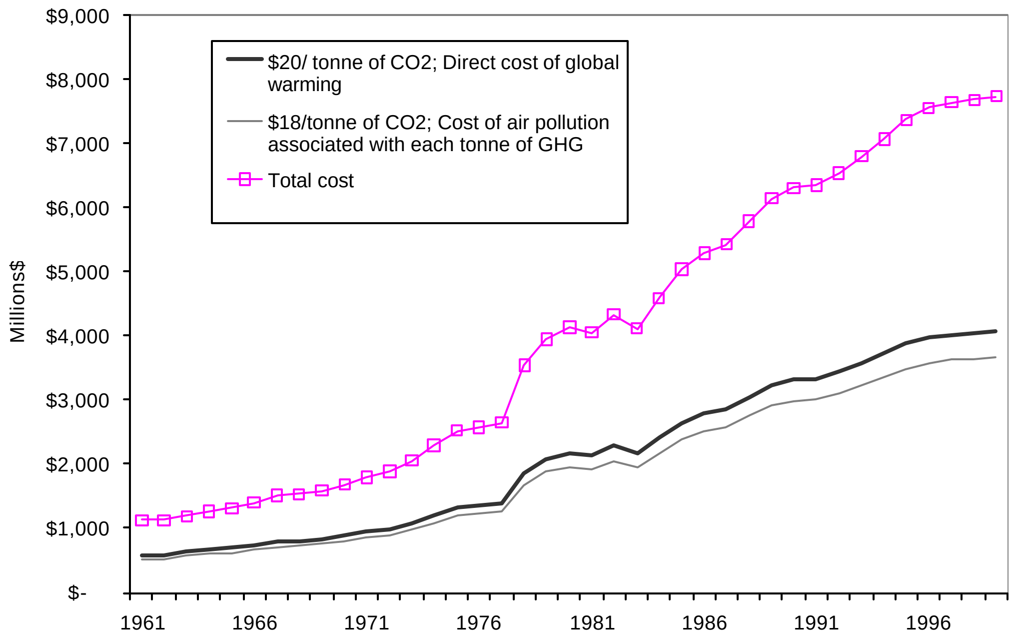
Both the U.S. and Australian GPI efforts include estimates of the costs of air pollution, deducting them from GDP to derive a net sustainable economic welfare estimate for both countries. In the case of the U.S. GPI study, estimates of the costs of U.S. air pollution ranged from US$90-billion in 1972 (the peak of air pollution) to $54.2-billion in 1997 (see Appendix C). The 1997 estimate represents roughly 0.7 percent of the 1997 real U.S. GDP of $7,269-billion (1992 chained dollars). The $90-billion estimate (based on Estes, see Appendix C) includes: 1) damage to agricultural vegetation; 2) damage to materials (paints, metals, rubber); 3) costs of cleaning soiled goods; 4) acid rain damage (aquatic and forests); 5) urban disamenities (reduced property values and wage differentials); and 6) aesthetics. They are conservative since they exclude damages to health, except those that show up indirectly in the estimate of wage differentials, which Estes has estimated at roughly US$226-billion. The $90-billion estimate also excludes increased mortality. These two items alone would add perhaps $40- to $60-billion to the 1970 cost estimate.

The Australian GPI study (see Appendix D) estimated annual costs, in terms of annual avoided health cost from the first five of six air pollutants (carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide, particulates and lead) at approximately Aus.$1.1-billion. Particles accounted for about three-quarters of this total. In addition, they estimated that reducing ambient particle levels would result in more than 500 avoided deaths each year. Another study referenced by Hamilton and Denniss estimated values in terms of avoided deaths at $3.8-billion. GPI Atlantic also estimated the cost of greenhouse gas emissions to climate change (see Appendix E).

We estimate the total health and environmental costs of Alberta's air pollutants associated with each unit of greenhouse gas emitted at $531.5-million in 1961and $3.7 billion in 1999. These numbers are based on an estimated cost of C$18/tonne[k] of CO_2 emitted in 1998$. (See Figure 30 and Appendix B for cost data from 1961 to 1999). The direct public health, social and environmental costs of the impact of climate change, such as sea level change, or increased temperatures have been estimated to range from $5 to $50 or more per tonne of CO_2. Based on a conservative cost of $20 per tonne of CO_2 emitted, we estimate the cost of Alberta's greenhouse gas emissions rose from $590.5-million (1998$) in 1961 to $4.1-billion (1998$) in 1999. Combining the estimated cost of air pollution and the costs of GHG emissions in 1999 for Alberta, we estimate a conservative combined cost of $7.74-billion, or roughly seven percent of Alberta's 1999 real GDP.

[k] The $18/tonne of $C0_2$ is based on a Canadian study by Caton and Constable (2000), which found that six selected measures that would reduce GHG emissions by nine percent of the projected national emissions or 36 percent of the estimated reduction necessary to meet Canada's Kyoto commitment in 2010, would result in co-benefits worth an estimated $1.2-billion in that year, or $18/tonne of $C0_2$.

Figure 30: Direct Global Warming Costs and Air Pollution Costs of Alberta's Greenhouse Gas Emissions, 1961 to 1999

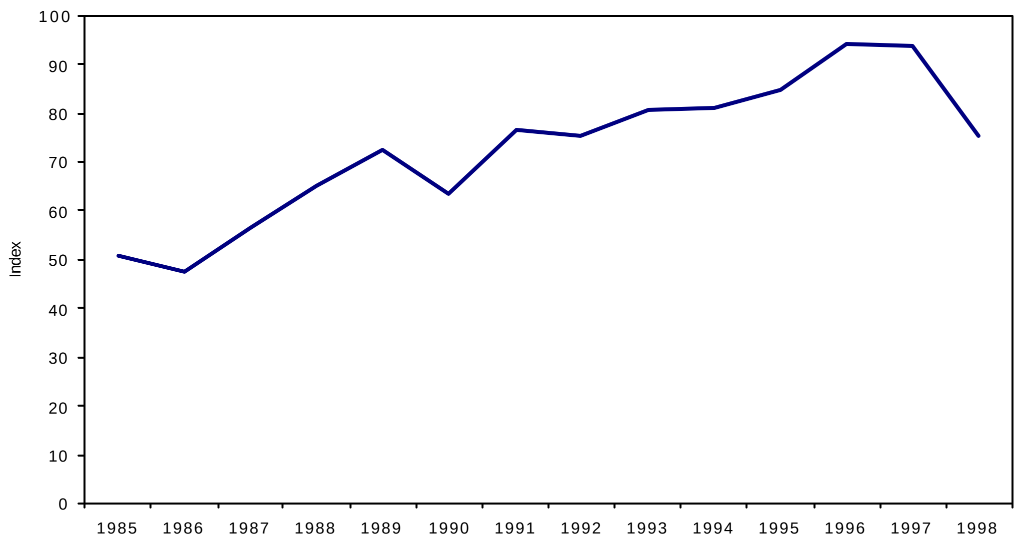


Sources: 1997 GHG Inventory; Caton, R., and Constable, S. 2000. Clearing the Air: A preliminary analysis of air quality co-benefits from reduced greenhouse gas emissions in Canada. David Suzuki Foundation. Vancouver, B.C.

3.7 GPI Air Quality Index

In formulating a GPI Index, our approach was to determine an index for each of Alberta's GPI Accounts by using either a best year as a benchmark or by using a target. Thus, in developing a GPI Index for air quality, an index for particulate matter in Alberta's two major cities was assessed. Initially, an index for $PM_{2.5}$ was determined based on the best year benchmark (i.e., the benchmark year equals 100 on the index scale, which was a 1996 Edmonton level of 7 ppb $PM_{2.5}$), and an index for PM_{10} was created based on the best year benchmark (Edmonton, 25 ppb PM_{10}, 1995). Then the two were combined as the PM average index. This index was 50.8 in 1985, and 75.3 in 1998 (Figure 31). The average index peaked at 94.3 in 1996.

Figure 31: Average Particulate Matter Index ($PM_{2.5}$ and PM_{10}), 1985 to 1998



A second GPI air quality index was developed based on the air pollutant emissions presented above. This index is an average of indices based on sulphur dioxide, carbon dioxide, nitrogen oxides, and volatile organic compound emissions. For each individual index, the best year (lowest annual emissions) was used as a benchmark. Between 1971 and 1984, the average index only represents sulphur dioxide emissions because the data for other air emissions were not readily available. From 1985 to 1999, the average index represents all the emission data (Figure 32).[1] In 1971, the emissions average index was 76.5, and in 1999, the index was 82.2. The index peaked in 1982.

For the overall GPI air quality index, an average index was constructed based on the above indices. In the overall average GPI air quality index, 1971 was 64.0, and 1999 was 80.3 (Figure 33). Data were not available prior to 1971 so we assumed the index remained the same as 1971.

[1] Sulphur dioxide emissions were assumed to remain the same as 1994 emissions for the years 1995 to 1999.

Figure 32: Average Emissions Index based on SO_2, CO_2, NO_x, and VOCs Emission Indices (Best Year Benchmark), 1971 to 1999

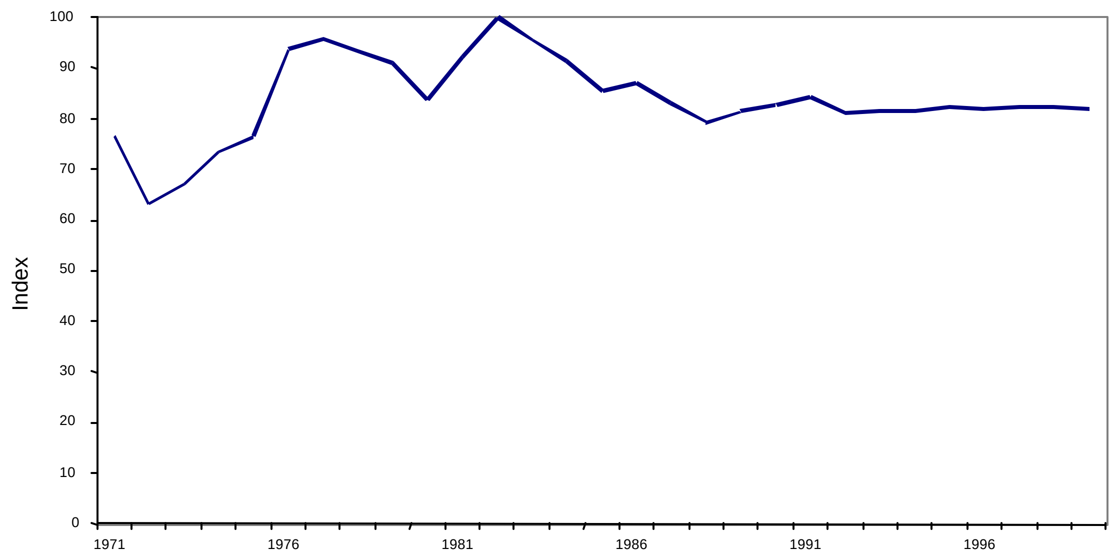
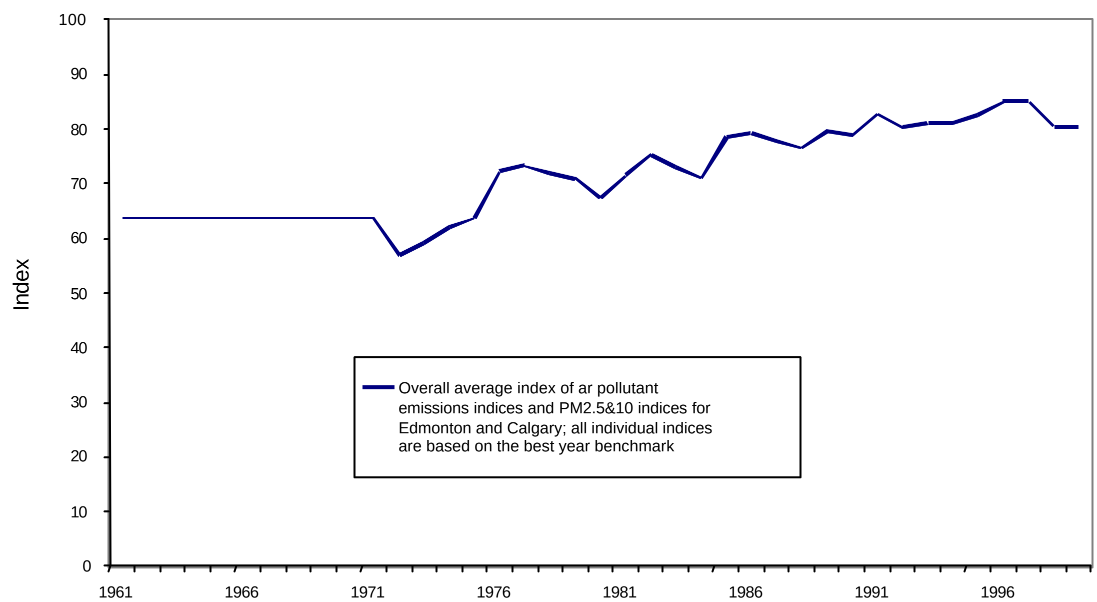


Figure 33: Alberta's Air Quality Overall Index 1961 to 1999 (based on SO_2, CO_2, NOx, and VOC Emission Indices, 1971 to 1999, and $PM_{2.5}$ and PM_{10} indices, 1985 to 1998)



Appendix A. List of Alberta GPI Background Reports

A series of Alberta GPI background reports accompanies the *Alberta Sustainability Trends 2000* report and this report. These documents are being released in late 2001 and early 2002 and will be available on the Pembina Institute's website at www.pembina.org.

Alberta GPI Background Reports and Sustainability Indicators

GPI Background Reports	GPI Accounts Covered by Report
1. Economy, GDP, and Trade	• Economic growth (GDP) • Economic diversity • Trade
2. Personal Consumption Expenditures, Disposable Income and Savings	• Disposable income • Personal expenditures • Taxes • Savings rate
3. Money, Debt, Assets and Net Worth	• Household debt
4. Income Inequality, Poverty and Living Wages	• Income distribution • Poverty
5. Household and Public Infrastructure	• Public infrastructure • Household infrastructure
6. Employment	• Weekly wage rate • Unemployment • Underemployment
7. Transportation	• Transportation expenditures
8. Time Use	• Paid work time • Household work • Parenting and eldercare • Free time • Volunteerism • Commuting time
9. Human Health and Wellness	• Life expectancy • Premature mortality • Infant mortality • Obesity
10. Suicide	• Suicide
11. Substance Abuse; Alcohol, Drugs and Tobacco	• Drug use (youth)
12. Auto Crashes and Injuries	• Auto crashes
13. Family Breakdown	• Divorce
14. Crime	• Crime
15. Gambling	• Problem gambling
16. Democracy	• Voter participation
17. Intellectual Capital and Educational Attainment	• Educational attainment
18. Energy (Oil, Gas, Coal and Renewable)	• Oil and gas reserve life • Oilsands reserve life
19. Agriculture	• Agricultural sustainability
20. Forests	• Timber sustainability • Forest fragmentation

GPI Background Reports	**GPI Accounts Covered by Report**
21. Parks and Wilderness	• Parks and wilderness
22. Fish and Wildlife	• Fish and wildlife
23. Wetlands and Peatlands	• Wetlands • Peatlands
24. Water Resource and Quality	• Water quality
25. Energy Use Intensity, Greenhouse Gas Emissions and Air Quality	• Energy use intensity • Air quality-related emissions • Greenhouse gas emissions
26. Carbon Budget	• Carbon budget deficit
27. Municipal and Hazardous Waste	• Hazardous waste • Landfill waste
28. Ecological Footprint	• Ecological footprint

Appendix B. Energy Use, Air Quality and GHG Data

Raw data for GHG emissions index and energy use index

	Alberta's GHG emissions per capita (tonnes)	GHG Index	Alberta's Primary Energy Demand per Capita (GJ)	Energy Use Index
1961	22.12	97.23	338.0845	97.23
1962	21.51	100.00	328.7275	100.00
1963	22.26	96.60	339.1919	96.91
1964	23.17	92.80	351.9749	93.40
1965	23.95	89.81	362.9475	90.57
1966	25.18	85.41	380.345	86.43
1967	26.76	80.35	401.9129	81.79
1968	26.50	81.15	397.8981	82.62
1969	26.80	80.24	401.945	81.78
1970	27.73	77.54	414.6995	79.27
1971	28.29	76.03	421.428	78.00
1972	29.34	73.30	435.9524	75.40
1973	31.36	68.58	462.8643	71.02
1974	34.48	62.38	503.2064	65.33
1975	36.80	58.44	532.6068	61.72
1976	36.35	59.16	525.905	62.51
1977	35.80	60.07	517.6275	63.51
1978	46.03	46.72	532.3371	61.75
1979	49.58	43.38	564.0692	58.28
1980	49.64	43.32	561.1658	58.58
1981	46.44	46.31	518.2973	63.42
1982	48.15	44.66	537.9135	61.11
1983	45.31	47.46	497.5343	66.07
1984	50.54	42.55	553.7065	59.37
1985	55.22	38.95	605.1438	54.32
1986	57.36	37.49	624.1231	52.67
1987	58.59	36.70	638.4244	51.49
1988	62.07	34.65	673.8216	48.79
1989	64.78	33.20	706.272	46.54
1990	65.16	33.00	700.9616	46.90
1991	64.42	33.39	681.4932	48.24
1992	65.29	32.94	695.9058	47.24
1993	67.02	32.09	703.7453	46.71
1994	68.76	31.27	730.1572	45.02
1995	70.81	30.37	733.6032	44.81
1996	71.57	30.05	734.8397	44.73
1997	70.84	30.36	734.0754	44.78
1998	69.61	30.90	728.9886	45.09
1999	68.70	31.30	753.5576	43.62

Raw data for air quality index

	$PM_{2.5}$ and PM_{10} Index	Emissions Average Index	Overall Average Index with $PM_{2.5}$ and PM_{10}
1961			63.7
1962			63.7
1963			63.7
1964			63.7
1965			63.7
1966			63.7
1967			63.7
1968			63.7
1969			63.7
1970			63.7
1971	50.79	76.5	63.7
1972	50.79	63.2	57.0
1973	50.79	67.1	59.0
1974	50.79	73.4	62.1
1975	50.79	76.6	63.7
1976	50.79	93.7	72.2
1977	50.79	95.7	73.2
1978	50.79	93.2	72.0
1979	50.79	91.1	70.9
1980	50.79	83.7	67.2
1981	50.79	92.1	71.5
1982	50.79	100.0	75.4
1983	50.79	95.5	73.2
1984	50.79	91.4	71.1
1985	50.79	85.4	78.5
1986	47.36	87.2	79.2
1987	56.36	83.1	77.7
1988	65.15	79.3	76.5
1989	72.44	81.4	79.6
1990	63.39	82.6	78.8
1991	76.45	84.2	82.7
1992	75.54	81.3	80.1
1993	80.62	81.4	81.2
1994	80.92	81.2	81.2
1995	84.92	82.0	82.7
1996	94.26	81.9	85.0
1997	93.93	82.2	85.1
1998	75.29	82.1	80.4
1999	75.29	82.0	80.3

Estimated cost of air pollution and GHG emissions to climate change in Alberta 1961 to 1999 (in millions of 1998 dollars)

	Cost of air pollution	Cost of Greenhouse Gas Emissions related to Climate Change
1961	593.13	659.03
1962	610.01	677.79
1963	625.12	694.58
1964	635.78	706.42
1965	644.67	716.30
1966	650.89	723.21
1967	663.33	737.03
1968	678.43	753.81
1969	693.98	771.09
1970	709.53	788.37
1971	740.06	822.29
1972	752.67	836.30
1973	766.55	851.72
1974	779.56	866.18
1975	803.58	892.87
1976	830.51	922.79
1977	865.33	961.48
1978	1,011.71	1,124.12
1979	1,191.46	1,323.85
1980	1,227.93	1,364.37
1981	1,269.72	1,410.80
1982	1,298.22	1,442.47
1983	1,334.91	1,483.23
1984	1,412.76	1,569.73
1985	1,488.47	1,653.85
1986	1,500.90	1,667.66
1987	1,522.28	1,691.42
1988	1,625.54	1,806.16
1989	1,688.42	1,876.02
1990	2,988.00	3,320.00
1991	3,006.00	3,340.00
1992	3,096.00	3,440.00
1993	3,222.00	3,580.00
1994	3,348.00	3,720.00
1995	3,492.00	3,880.00
1996	3,582.00	3,980.00
1997	3,618.00	4,020.00
1998	3,642.00	4,046.67
1999	3,666.00	4,073.33

Appendix C. U.S. GPI Methodology for Cost of Air Pollution

The U. S. GPI estimates the cost of air pollution as a deduction against the GDP, considering it a regrettable cost of economic growth that reflects the depreciation of the air quality component of natural capital. These and other detailed GPI methodological descriptions for the U.S. GPI analysis can be found in Anielski and Rowe (1999).[53] The following text describes the U.S. GPI methodology used in that report.

The Cost of Air Pollution in the U.S. GPI

The annual economic costs of air pollution to households, infrastructure, the environment, and human health is a typical example of environmental costs which lie outside the production boundary of the traditional national accounts and represents a significant omission from conventional economic indicators such as GDP. Unfortunately such economic cost estimates are rare.

Following Myrick Freeman's analysis (as with water pollution), we divided the costs of air pollution into six categories (Freeman 1982). The estimated cost in 1970 (in 1992 chained dollars) for each of these categories was:

1) damage to agricultural vegetation	$ 12.1-billion
2) materials damage (paint, metals, rubber)	18.1-billion
3) costs of cleaning soiled goods	14.9-billion
4) acid rain damage (aquatic and forest)	4.5-billion
5) urban disamenities (reduced property values and wage differentials)	26.9-billion
6) aesthetics	13.5-billion
TOTAL	$ 90.0-billion

This $90-billion estimate is conservative because it excludes damages to health, except those that show up indirectly in the estimate of wage differentials. It also excludes increased mortality. These two items alone would add perhaps $40- to $60-billion to the 1970 cost estimate.

Professor Ralph Estes of the American University has devoted several years to an analysis of the external costs that corporations impose on customers, employees, communities, and society—costs that never show up in profit-loss statements that list only internalized costs. His 1995 peer-reviewed study, based on numerous related research documents, estimates the total costs to be in excess of $2.6-trillion dollars yearly.[m] He estimates that health costs associated with air pollution amount to $226-billion and concludes that, "a scorecard that ignores social costs presents a distorted picture of performance that can influence policymakers to be excessively generous with taxpayer-funded corporate benefits and overly lax in enforcing corporate regulations."

According to Chilton and Huebner (1997) the American Lung Association estimates that, on average, particulate air pollution reduces life expectancy by two years.

[m] Estes' $2.6-trillion estimate is broken down as follows: price-fixing conspiracies, monopolies, and deceptive advertising ($1.16-trillion); deaths from workplace cancer ($278-billion); health costs-air pollution ($226-billion); Discrimination ($165-billion); Workplace injuries and accidents ($141-billion); unsafe vehicles ($136-billion); white collar crime including income tax fraud, bribery, extortion, kickbacks and federal regulation violations ($165-billion).

Notwithstanding these other estimates, we used Freeman's figure of $30-billion in 1972, converted to $90.0-billion 1992 chained dollars. This figure is used in the estimates of air pollution costs over the time series.

The figures for changes in air pollution damage over time are based on the U.S. Environmental Protection Agency's (EPA) data and estimates of ambient air pollution. We used these estimates to construct an index of ambient air pollution to estimate the costs of air pollution during this period. Starting in 1975, indexes were constructed (with 1975 = 100) for ambient levels of particulates, sulphur dioxide and nitrogen dioxide (U.S. EPA National Air Pollutant Emissions Trends, 1970-1996).[n] These indexes were in turn combined to create a single index number for each year. We used the annual change in the index number to extrapolate the costs of air pollution during a given year, using the 1972 estimate of $69.3-billion as the base.

At the time of the last GPI revision, data were available only from 1975 to 1991. For earlier years, ambient air conditions are assumed to have deteriorated by one percent per year in the 1950s and by 2.4 percent per year in the 1960s, and to have improved by 3.0 percent per year from 1971 to 1977, as a result of the *Clean Air Act* of 1970. All 1997 figures for NO_x, SO_2 and particulates are projected based on the trend from 1990 to 1996.

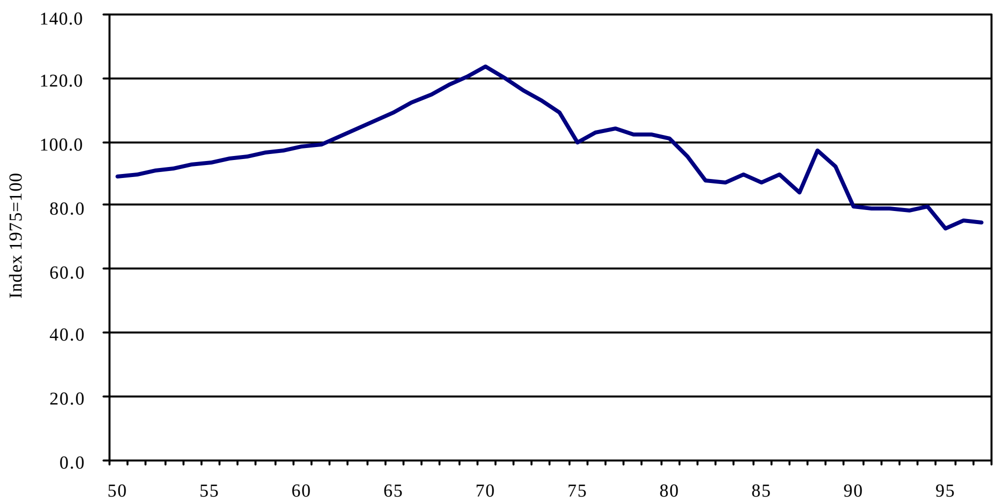
First, an ambient air pollution index was calculated based on the absolute emissions figures reported by the EPA for 1975-1997. The year 1975 was used as the benchmark year against which historical and future indexes are estimated because it was the first year in which the EPA gathered ambient air pollution emission data. The index was created by taking the absolute emissions of SO_2, NO_x and particulates, weighting them equally and setting 1975 = 100. Future indexes were similarly constructed, comparing with the 1975 benchmark. An index greater than 100 implies an increase in air pollution while an index less than 100 signifies a decline in air pollution.

To calculate the cost of air pollution, we took the ambient air pollution index multiplied by the 1992 chained dollar estimate of pollution costs ($90.0-billion), divided by the pollution index number for 1970. This value goes into the GPI.

[n] The figures for changes in air pollution damage over time are also summarized in the *Statistical Abstract*.

Figure 14

Ambient Air Pollution Index
(Sulphur Dioxide, Nitrogen Dioxide, Particulates)



The application of an air quality index (using relative changes in air quality since 1975, the benchmark year) to the estimated costs would appear to be a reasonable approach given that it reflects changes in air pollution (i.e., emissions) while assuming a constant economic cost of those emissions. Since 1975, the decline in absolute emissions of sulphur dioxide and particulates (which outweigh the small increase in nitrogen dioxide emissions) suggests a declining economic cost of air pollution for these three emissions. The figure above shows the improvement in the ambient air quality (using sulphur dioxide, nitrogen dioxide and particulate matter levels of emissions converted to an index where 1975 levels equal 100).

The air pollution damages accounted for in the U.S. GPI deal primarily with damages associated with acid emissions)sulphur dioxide and nitrogen dioxide) and particulates. The EPA, however, reports on five air quality parameters that affect long-term air quality: carbon monoxide, lead, nitrogen dioxide, ozone, particulates (PM_{10}),[o] and sulphur dioxide. Also excluded in our analysis is VOC (volatile organic compounds). Ideally, the damages due to carbon monoxide and ozone should also be considered in an expanded air pollution cost accounting. Indeed as Neumayer (1998, http://www.foe.co.uk:8070/ServletISEW) notes in the case of the UK ISEW, a better way to account for costs would be to account separately for the costs of each type of emission and then sum up the costs. In the absence of separate cost accounting for each emission, we continue to use Freeman's original estimates, with the caveat that these exclude undoubtedly significant health costs associated with air pollution.

[o] The EPA changed its accounting for particulate matter beginning in 1985. Prior to 1985 only PM_{10} particulate emissions were inventoried. Beginning with 1985, substantial refinements in methodology were instituted, and the scope of the inventory was expanded to include PM_{10} from agricultural activities, and so-called fugitive dust. Fugitive dust contributes a significant portion of the new total particulate matter emission (e.g., in 1985, 4.09 billion tons of PM_{10} emitted compared with roughly 36 billion tons of fugitive dust for a total particulate emission of 40.889 billion tons). The 1975-85 figures use the 1995 GPI data estimates for both PM_{10} and fugitive dust emissions. 1985-1996 figures are from EPA National Air Pollutant Emissions Trends, 1970-1996.

The most recent and definitive studies of air pollution costs are by McCubbin and Delucchi (1996, Tables 11-A-1 and 11-A-2). They estimate that the annual cost of emissions from gasoline-powered vehicles ranges from $19-billion to $330-billion per year for health damage (which includes a statistical value of life) plus $3-billion to $8-billion for esthetic and crop damage (in 1995 dollars). They break down air pollution costs by type of emission as follows (in 1995 dollars):

CO (carbon monoxide)	$1.1- to $9.3-billion
NO_x (nitrogen oxides)	$1.0- to $5.3-billion
O_3 (ozone)	$0.2- to $1.9-billion
PM_{10} (particulates)	$17- to $314-billion

Their studies show that most of the health costs associated with air pollution come from particulates, a fact that was not known when Freeman did his study in the 1970s. We have not used the McCubbin and Delucchi estimates, given the wide range of their cost estimates and their inclusion of the value of life, which we chose not to include.

Future estimates may be forthcoming from Resources for the Future (Washington, D.C.) from their air pollution research studies. An RFF study entails developing a modeling infrastructure to assess the ancillary benefits and costs of climate policies, and evaluating several leading policies addressing emissions of greenhouse gases for their ancillary benefits, primarily resulting from changes in emissions of criteria air pollutants. The infrastructure for this evaluation is derived from the Tracking and Analysis Framework (TAF), which the U.S. Department of Energy has helped to fund on behalf of the National Acid Precipitation Assessment Program (NAPAP). TAF is an integrated assessment model used to track changes in sulphur dioxide (SO_2) and nitrogen oxides (NO_X) emissions from electric utilities, the secondary formation of sulphates and nitrates, the deposition of sulphur and nitrogen, the environmental and public health impacts and economic benefits of such changes, and control costs. In this project, researchers will extend TAF to include representations of other criteria air pollutants as well as emissions of mercury, carbon dioxide (CO_2), and methane from electric utility sources, industrial sources, area sources and mobile sources.

The GPI account estimates the cost of air pollution has been steadily declining due to an improvement in overall air quality, resulting in an estimated cost of $54.2-billion in 1997 (in 1992 dollars) compared with an all-time high cost of $90.0-billion in 1972.

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Appendix D. Australian GPI Methodology for Cost of Air Pollution

This appendix outlines the Australia GPI cost of air pollution as described in *Tracking Well-being in Australia: The Genuine Progress Indicator 2000*. Appendix A of that report contains a complete set of Australia GPI data organized into a series of columns. Thus, references to "columns" in the description below relate to the columns as presented in the above-mentioned publication. For complete details see *Tracking Well-being in Australia: The Genuine Progress Indicator 2000* prepared by Clive Hamilton and Richard Denniss, Australia Institute, 2000. The Australian GPI for 2000 estimated by Hamilton and Denniss estimate the cost of land (soil) degradation and the cost of irrigation water use, which they deduct against GDP to derive the GPI estimates. The following summarizes their methodological approach. All references are cited in the Hamilton and Denniss document, available online at www.gpionline.net.

Costs of air pollution in Australia's GPI

This component is concerned with the costs of so-called noxious air pollutants, which are poisonous or otherwise damaging to humans, other animals and plants. Some of these pollutants also cause corrosion and aesthetic degradation (e.g., soot deposition) to buildings and other structures. The most important pollutants in this group include sulphur dioxide, carbon monoxide, lead, particles of various sizes and compositions, oxides of nitrogen, and volatile organic compounds other than methane (DEST 1996b: 5-7). The two last-named groups of pollutants are joint precursors of photochemical smog, the most important constituent of which is ozone. The principal sources of these pollutants are combustion of fuels (including both fossil fuels and biomass fuels such as wood) and some specific industrial processes, such as the smelting of metal ores and the manufacture of certain chemical products.

In general terms, as with other pollutants, these noxious air pollutants only impose measurable costs when the quantities emitted by human activities clearly exceed the capacity of the natural environment to absorb them. In Australia, both human populations and sources of emissions are highly concentrated in a relatively small number of discrete areas within which measurable costs are imposed. These areas include the larger cities and a small number of non-urban regions that contain a high concentration of power stations, metal smelting and other large polluting industries.

The National Environment Protection Council has recently released a lengthy discussion paper, which draws on a series of commissioned studies to examine the costs and benefits of proposed new uniform national ambient air quality standards for the principal noxious pollutants (NEPC 1997). The discussion paper contains estimates of the annual health and other human costs that would be avoided if concentrations of the major air pollutants throughout Australia were reduced to the levels specified in the proposed new standards. In very general terms, the data presented in the paper suggest that the proposed new standards approximate the levels at which the marginal cost of further control of each pollutant would equal the marginal avoided health cost. Therefore the estimates of avoided costs given in the discussion paper approximate the human costs of air pollution not included in conventional national accounting aggregates.

The six pollutants proposed to be subject to stricter standards are carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide, particulates and lead. The estimated annual avoided health cost from the first five of these is approximately $1.1-billion. Particles account for about three-quarters of this total. In addition, it is estimated that reducing ambient particle levels would avoid more than 500 deaths each year. One study quoted in the discussion paper values these avoided deaths at $3.8-billion.

In the case of the sixth pollutant for which new standards are proposed—lead—the major human cost is reduced measured intelligence, resulting in loss of lifetime earnings. The NEPC discussion paper presents data derived from a 1995 national survey of lead in Australian children, from which it can be calculated that the current cost of reduced IQ caused by lead pollution is approximately $1.5-billion per annum.

Allowance has already been made for defensive expenditure on health, which includes the direct health costs of all sources of air pollution. However this adjustment does not make allowance for the costs of additional deaths caused by particulates, or for the cost of reduced IQ caused by lead pollution, or for any of the other damage costs of noxious air pollution, such as to crops, garden plants, natural vegetation and buildings. Such damage arises not only from pollutants, such as ozone, included in the proposed new ambient air quality standards, but also from other pollutants such as fluoride. There are no published estimates at the national level of the costs of damage to crops and other vegetation, or to buildings and the like.

The annual health costs of particle emissions in Brisbane have been estimated to be between $255-million and $462-million (arising from an additional 46-83 deaths). However this study used a lower cost of increased mortality than accepted by the NEPC (Simpson and London 1995, p. 6.2; NEPC 1998, p. 132). The NEPC uses a methodology similar to that used by the U.S. EPA, applying an economic value of $7-million for each additional death.

A more recent assessment of fine particle pollution in Sydney has estimated that 397 premature deaths per year (out of a total of 21,500) are caused by particles (NEPC 1998, p. 127). By extrapolating to the entire Australian population the NEPC attributes 2,400 deaths each year to particles. To account for differences in particle levels between major urban areas and the rest of Australia the NEPC suggests that half of this figure (1,200) is a more reasonable estimate (NEPC 1998, p. 132). Using the NEPC's estimates of the cost of a lost human life, the annual economic cost of exposure to particles in Australia is estimated to be $8.4-billion per year.

This is a point estimate derived from current or recently past ambient levels of the various pollutants, and has been scaled up by 50 percent to account for the effects of pollutants other than particles. To obtain cost estimates for previous years we have used total consumption of fossil fuels (coal, petroleum and natural gas) plus biomass fuels (wood and bagasse) as a proxy. This measure of pollutant level has been chosen because combustion of these fuels is by far the largest single source of emissions. Data sources used are Bush et al. (1999) for the period 1974-1999, Department of National Development and Energy (1982) for the period 1961-1973, and Saddler (1981) and the sources referenced therein for the period 1950-1960. The figure for 2000 is estimated using the mean growth rate for the previous three years.

Finally, we note that current ambient levels of air pollutants in some areas are much lower than they were in previous decades, as a result of previous control measures imposed on sources of pollution. These measures include both successively stricter motor vehicle exhaust emission standards, and control measures imposed on major point sources of air pollution, such as power stations and factories. Our figures may therefore underestimate the cost of air pollution in earlier years.

It should be noted that global costs of air pollutants, including greenhouse gas emissions and depletion of the stratospheric ozone layer, are not included in this column but are costed separately in Columns U and V respectively.

Appendix E. GPI Atlantic

Researchers at GPI Atlantic, headed by Dr. Ron Colman, are also advancing the methodological framework for assessing the cost of air pollution and the costs of greenhouse gas emissions as part of a set of GPI accounts for Nova Scotia. These methodological advancements are critical in advancing GPI accounting. Their reports pertaining to unpaid work can be purchased at www.gpiatlantic.org and include:

- Reducing Greenhouse Gas Emissions in Freight Transport; May 1999, 69 pages
- Introduction to GPI Greenhouse Gas Account; October 1999, 12 pages

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