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# The environmental burden of disease in Canada: Respiratory disease, cardiovascular disease, cancer, and congenital affliction

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**Abstract**

*Background:* Exposure to environmental hazards contributes to many chronic diseases, yet the magnitude of their contribution to the total disease burden in Canada is not well understood.
*Objectives:* To estimate the environmental burden of disease (EBD) in Canada for respiratory disease, cardiovascular disease, cancer, and congenital affliction. Quantifying the contribution of environmental exposures to the overall burden of disease could play an important role in shaping public health and environmental policy priorities.
*Methods:* The World Health Organization (WHO) recently estimated the environmental burden of disease globally by using a combination of comparative risk assessment data and expert judgment to develop environmentally attributable fractions (EAFs) of mortality and morbidity for 85 categories of disease. We use the EAFs developed by the WHO, EAFs developed by other researchers, and data from Canadian public health institutions to provide an initial estimate of the environmental burden of disease in Canada for four major categories of disease.
*Results:* Our results indicate that: 10,000–25,000 deaths; 78,000–194,000 hospitalizations; 600,000–1.5 million days spent in hospital; 1.1 million–1.8 million restricted activity days for asthma sufferers; 8000–24,000 new cases of cancer; 500–2500 low birth weight babies; and between $3.6 billion and $9.1 billion in costs occur in Canada each year due to respiratory disease, cardiovascular illness, cancer, and congenital affliction associated with adverse environmental exposures.
*Conclusions:* The burden of illness in Canada resulting from adverse environmental exposures is significant. Stronger efforts to prevent adverse environmental exposures are warranted, including research, education, and regulation.


*Keywords:* Asthma; Cancer; Cardiovascular disease; Congenital affliction; Environmental burden of disease; Environmentally attributable fraction; Pollution; Respiratory disease

## 1. Introduction

Canada is widely perceived, both at home and abroad, as a relatively clean and pristine land. Recent reports, however, reveal the presence of dozens of toxic chemicals in Canadian adults and children, including heavy metals, pesticides, dioxins, flame retardants, and other persistent organic pollutants (Neumann et al., 2005, 2006). In fact, the chemical body burden of Canadians is similar to the body burden of Americans (Houlihan et al., 2003, 2005; US Centers for Disease Control and Prevention: Department of Health and Human Services, 2005). In light of the substantial evidence linking environmental hazards to adverse health effects, various organizations, including the US Centers for Disease Control and the World Health Organization (WHO), are attempting to quantify the environmental burden of disease (EBD)—the morbidity and mortality caused by exposure to preventable environmental hazards. The purpose of this study is to provide an

*Abbreviations:* COPD: chronic obstructive pulmonary disease; DALY: disability adjusted life year; EAF: environmentally attributable fraction; EBD: environmental burden of disease; OECD: Organization for Economic Cooperation and Development; WHO: World Health Organization

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initial estimate of the EBD in Canada from respiratory disease, cardiovascular illness, cancer, and congenital affliction. We use the word "environmental" to refer specifically to various forms of adverse environmental exposure such as chemical exposure and pollution, not the broader meaning sometimes used in the medical community to refer to all factors outside of an individual's genetic makeup.

Most chronic diseases are multi-factorial resulting from lifestyle, socioeconomic, environmental, cultural, and genetic determinants interacting over the course of a person's lifetime. Therefore, it is a challenge to accurately determine the burden of disease attributable to adverse environmental exposures. The potentially long induction time between environmental exposures and the onset of health effects adds to the difficulty of establishing causation. As a British environmental scientist recently stated, "The complexities involved in the link between environmental pollution and health, and the uncertainties inherent in the available data on mortality and morbidity, in existing knowledge about the aetiology of diseases, and in environmental information and estimates of exposure, all mean that any attempt to assess the environmental contribution to the global burden of disease is fraught with difficulties" (Briggs, 2003).

Despite the challenges and imperfections, quantifying the EBD is an important endeavour because it highlights the magnitude of environmental harm and may identify specific risk factors that affect public health. This information can be used to: direct research; inform public education efforts; assist physicians in providing advice to patients; guide health and environmental policy-making; and evaluate the effectiveness of policies, programs, and other interventions.

The first EBD studies, published in the late 1990s, estimated that 25–33% of the global burden of disease may be caused by environmental factors (Smith et al., 1999). Developing countries suffer a higher burden of communicable disease and injury associated with environmental factors, while industrialized nations have a higher burden of some chronic illnesses such as cardiovascular disease. In 2001, the Organization for Economic Cooperation and Development (OECD) estimated the global EBD to be between 7.5% and 12%, with only 2–5% of the total disease burden in high-income OECD countries resulting from environmental harm (Melse and de Hollander, 2001). Using updated information and a broader definition of "environmental risk factor" that included occupational exposures, work-related stress, and injuries from environment-related motor vehicle accidents, the World Health Organization (WHO) concluded in 2006 that 23% of all mortalities and 24% of all disability adjusted life years (DALYs) globally are linked to preventable environmental risk factors (Prüss-Üstün and Corvalán 2006).

In addition, researchers have carried out EBD studies in the US and Europe (Davies and Hauge, 2005; Landrigan et al., 2002; Massey and Ackerman, 2003; Mathews and Parry, 2005; Shuler et al., 2006). The WHO has assessed the environmental burden of paediatric disease in Europe (Valent et al., 2004). Although Canada recently initiated a national burden of disease study to assess the relative importance of various factors adversely affecting the health of Canadians, the EBD in Canada has not yet been determined (Public Health Agency of Canada, 2006).

## 2. Methods

There are two main approaches to estimating the environmental burden of disease—the exposure-based and the outcome-based approach (Kay et al., 2000; Prüss-Üstün et al., 2003). The exposure-based approach requires three kinds of data: identification of outcomes associated with relevant environmental risk factors; exposure assessment of the population; and dose–response relationships. The most reliable indicator of actual human exposure is via biological measure of people's body burden. Because of the lack of adequate Canadian data on environmental exposures, we chose to rely on the outcome-based approach. The outcome-based approach also requires three kinds of data: identification of outcomes associated with relevant environmental risk factors; statistics on morbidity and mortality; and the environmentally attributable fraction.

We also rely on the pioneering work done by the WHO in estimating the EBD. The WHO's methodology for assessing the EBD relies on a combination of comparative risk assessment and expert judgment to estimate the environmentally attributable fraction (EAF) of mortality and morbidity (Kay et al., 2000; Prüss-Üstün et al., 2003). The EAF is defined as "the percentage of a particular disease category that would be eliminated if environmental risk factors were reduced to their lowest feasible levels" (Smith et al., 1999). In other words, the EAF is the proportion of each health condition that can reasonably be attributed to exposure to environmental hazards, such as air pollution or contaminated water. For example, the WHO estimated that 5% of birth defects (range of 2–10%) are caused (in whole or in part) by maternal exposures to harmful chemicals (Prüss-Üstün and Corvalán, 2006). To determine appropriate ranges of the EAF for 85 diseases, the WHO relied on the most recent comparative risk assessment data available and consulted more than 100 leading environmental health, epidemiology, and toxicology experts. At least three independent experts were consulted for each disease. The experts provided a point estimate and a 95% confidence interval for the EAF. Their estimates were pooled to obtain a combined probability function for the EAF, providing an arithmetic mean as well as a range based on 95% confidence intervals (Prüss-Üstün and Corvalán, 2006).

This study uses the latest WHO estimates of EAFs as a starting point to estimate the EBD in Canada for respiratory disease, cardiovascular disease, cancer, and congenital affliction. The WHO's EAFs are compared with EAFs used in other EBD studies and evaluated in conjunction with available knowledge regarding the environmental contribution to disease in Canada. We use a slightly narrower definition of environmental risk factor than the WHO, in that we limit the meaning of environmental risk factors to chemical, biological, and radiological hazards. For example, the WHO includes occupational stress and infections acquired by health-care workers, risk factors that would be considered occupational rather than environmental in Canada (Prüss-Üstün and Corvalán, 2006). This difference results in our reliance on slightly lower EAFs than the WHO for some categories of disease. For each of the health outcomes examined, we review the overall burden of disease in Canada, summarize the evidence for an environmental aetiology, discuss the potential range of the EAF, and estimate the environmentally attributable portion of the burden of illness.

In view of the inherent complexity and uncertainty associated with measuring the EBD, it is not the objective of our analysis to provide definitive figures for the magnitude and costs of environmental effects on the health of Canadians. Instead, like the OECD in its EBD research, "our purpose is simply to come up with a rough estimate of the fraction of disease that will be avoided by feasible and conceivable reductions of

environmental exposures" (Melse and de Hollander, 2001). Although the WHO provides both a range and a global mean estimate of the EAF for various diseases, they warn against using the global mean for individual nations because risks obviously vary from nation to nation. Therefore we focus our analysis on EAFs in the form of a range.

This study uses Canadian data on respiratory disease, cardiovascular disease, cancer, and congenital affliction. These health outcomes were selected because of the strength of evidence for environmental aetiology and because reliable Canadian data on mortality and morbidity are available. As well, respiratory disease, cardiovascular disease, and cancer are among the most important causes of morbidity and mortality in Canada. Primary sources of health data include the Canadian Institute for Health Information, Statistics Canada, Health Canada, Canadian Lung Association, Canadian Cancer Society, and the National Cancer Institute of Canada.

We recognize that the mortality and morbidity data we rely upon are estimates. Each of the primary sources of mortality and morbidity data includes a full discussion of methodological and statistical issues including confidence intervals, standard errors, and bias. In addition, health-care authorities such as the Canadian Institute for Health Information investigate the accuracy and quality of the information they obtain and publish (e.g., Canadian Institute for Health Information 2002a). In general, the available data will tend to under-estimate the full extent of morbidity and mortality associated with the categories of illness we examine. For example, official estimates of mortality from COPD are believed to be under-estimates (Ernst et al., 2000).

## 3. Results

### 3.1. Respiratory disease

In Canada, the burden of respiratory disease is enormous—more than 714,000 Canadians suffer from chronic obstructive pulmonary disease (COPD), while 2.7 million Canadians (one in 12 persons) have asthma (Canadian Lung Association, 2005a, b). Recent Canadian health-care data indicate that the annual impact of COPD involves about 9773 deaths, 256,461 hospitalizations, and 1,706,106 patient days in hospital (Canadian Institute for Health Information, 2002b; Statistics Canada, 2007). The annual effects of asthma include 288 deaths, 31,000 hospitalizations, 109,414 days in hospital, and 3,591,000 restricted activity days (Canadian Institute for Health Information, 2002b; Canadian Institute for Health Information, et al., 2001; Statistics Canada, 2007).

Adverse environmental exposure is etiologically involved in a significant proportion of respiratory afflictions. It is recognized that "the two most important preventable risk factors for respiratory disease are smoking (both personal smoking and exposure to environmental tobacco smoke) and air quality (indoor and outdoor)" (Canadian Institute for Health Information, et al., 2001). Consistent with other EBD studies, we include the adverse effects of environmental tobacco smoke but not personal smoking, because the latter is self-induced, i.e., a lifestyle choice instead of an environmental hazard.

The connection between exposure to various air pollutants and adverse respiratory sequelae is well documented (Curtis et al., 2006; Krewski et al., 2005). Ozone and fine particulate matter, for example, have been linked to respiratory disease and premature mortality (Bell et al., 2005; Pope III et al., 2002). Although there continues to be considerable uncertainty about the factors leading to the initial development of asthma, there is strong epidemiological evidence indicating that both outdoor and indoor pollution can trigger and exacerbate asthma attacks and symptoms.

A panel of experts in environmental and pulmonary medicine estimated that between 10% and 35% (best estimate 30%) of acute exacerbations of childhood asthma in the United States are related to outdoor, non-biologic pollutants, such as vehicle exhaust and emissions from stationary sources (Landrigan et al., 2002). The panel's estimate did not include indoor air pollutants (e.g., household allergens, moulds, and second-hand smoke), infections, or climatic conditions. Because of these limitations, British researchers concluded "the EAF used to obtain the above estimates could be doubled to give a more realistic estimate of the burden of asthma exacerbations attributable to environmental factors" (Mathews and Parry, 2005).

The WHO's 2006 EBD study estimated the EAF for COPD in the range of 10–30%, including environmental tobacco smoke and occupational exposures to dust, chemicals, and smoke (Prüss-Üstün and Corvalán, 2006). The WHO estimated the EAF for asthma, including outdoor and indoor environmental exposures, as 44% (range 26–53%). The OECD's estimate of the EAF for chronic respiratory disease, including asthma, was 5–20% (Melse and de Hollander, 2001). The majority of other EBD studies used an EAF of 30% (range of 10–35%) for asthma, based only on outdoor environmental exposures (Table 1). We rely on the EAFs used by the WHO, which are the most recent and are consistent with the evidence recognizing the adverse effects of both outdoor and indoor air pollution.

We estimate that the burden of respiratory disease caused by modifiable environmental exposures includes 34,000–93,000 hospitalizations; 200,000–570,000 days in hospital; and between 1050 and 3100 deaths each year in Canada (Table 2). It is also evident that exacerbations of asthmatic disease related to adverse environmental stimuli have a substantial impact on the day-to-day life of many Canadians through restricted activity days (Ontario Medical Association, 2005).

Table 1
Environmentally attributable fractions for respiratory disease

| EBD study | COPD EAF | Asthma EAF |
|---|---|---|
| Davies and Hauge, 2005 | — | 30% (10–35%) |
| Landrigan et al., 2002 | — | 30% (10–35%) |
| Massey and Ackerman, 2003 | — | 30% (10–35%) |
| Mathews and Parry, 2005 | — | 60% (20–70%) |
| Melse and de Hollander, 2001 | 5–20% | 5–20% |
| Prüss-Üstün and Corvalán, 2006 | 10–30% | 44% (26–53%) |
| Shuler et al., 2006 | — | 30% (10–35%) |

Table 2
The environmental burden of respiratory disease in Canada

| COPD | Number | EAF | EBD range |
|---|---|---|---|
| Hospitalizations | 256,461 | 10–30% | 25,646–76,938 |
| Days in hospital | 1,706,106 | 10–30% | 170,611–511,832 |
| Deaths | 9773 | 10–30% | 977–2932 |
| *Asthma* | | | |
| Restricted activity days | 3,591,000 | 26–53% | 933,660–1,903,230 |
| Hospitalizations | 31,000 | 26–53% | 8060–16,430 |
| Days in hospital | 109,414 | 26–53% | 28,448–57,989 |
| Deaths | 288 | 26–53% | 75–153 |

### 3.2. Cardiovascular disease

Cardiovascular disease continues to be a major cause of morbidity and mortality in Canada. Recent Canadian health-care data indicate that 72,743 deaths, 447,218 hospitalizations, and 3,885,588 patient days in hospital occur each year as a result of cardiovascular illness (Canadian Institute for Health Information, 2002b; Statistics Canada, 2007).

Major risk factors for cardiovascular disease include smoking, high cholesterol, high blood pressure, obesity, and physical inactivity. Short- and long-term exposures to ambient particulate matter are also significant determinants of cardiovascular disease (Pope III et al., 2004). Air pollution can contribute to angina, myocardial infarction, arrhythmias, and congestive heart failure (Cohen et al., 2005). The pathophysiology linking particulate exposure to death includes pulmonary inflammation, accelerated atherosclerosis, and cardiac dysfunction (Pope III et al., 2004). Lead and noise exposures are relatively minor risk factors but can also contribute to cardiovascular disease (Concha-Barrientos et al., 2004; Prüss-Üstün et al., 2004).

Estimates of the EAF for cardiovascular disease are fairly similar (Table 3). The WHO's 2006 study established a best estimate of the EAF for cardiovascular disease of 16% (range 7–23%) in North America (Prüss-Üstün and Corvalán, 2006). The OECD estimate was 5%–15% (Melse and de Hollander, 2001). The EBD study done in Washington State used an EAF of 7.5% (5–10%) for cardiovascular disease (Davies and Hauge, 2005). The WHO figure is higher than the OECD and Washington state estimates because the WHO study incorporates occupational factors, including stress. We use a more conservative EAF of 7.5–15%, similar to the OECD and Washington State studies, to be consistent with our narrower definition of "environmental".

Our estimate of the burden of cardiovascular disease in Canada attributable to adverse environmental factors includes: 5500–11,000 deaths; 33,000–67,000 hospitalizations; and 291,000–583,000 patient-days spent in hospital. (Table 4).

Table 3
Environmentally attributable fractions for cardiovascular disease

| EBD Study | Cardiovascular disease EAF |
|---|---|
| Davies and Hauge, 2005 | 7.5% (5–10%) |
| Melse and de Hollander, 2001 | 5–15% |
| Prüss-Üstün and Corvalán, 2006 | 16% (7–23%) |

Table 4
The environmental burden of cardiovascular disease in Canada

| CVS disease | Number | EAF | EBD range |
|---|---|---|---|
| Hospitalizations | 447,218 | 7.5–15% | 33,541–67,083 |
| Days in hospital | 3,885,588 | 7.5–15% | 291,419–582,838 |
| Deaths | 72,743 | 7.5–15% | 5456–10,911 |

### 3.3. Cancer

Cancer is a leading cause of sickness and death in Canada. Canadian health-care data indicate that about 68,322 deaths, 215,493 hospitalizations, and 2,078,966 patient days in hospital result from cancer-related illness annually (Canadian Institute for Health Information, 2002b; Statistics Canada, 2007). Approximately 159,900 new cases of cancer are diagnosed each year (Canadian Cancer Society and National Cancer Institute of Canada, 2007).

Cancer is a multi-factorial disease with long latency periods, making it difficult to establish causation in many cases. Researchers are concerned, however, by increasing rates of certain cancers associated with exposure to environmental contaminants, such as thyroid cancer and non-Hodgkin's lymphoma (Cancer Care Ontario, 2005). Individuals exposed to substantial quantities of pesticides face triple the risk of non-Hodgkins lymphoma compared to unexposed individuals (Fritschi et al., 2005). In-utero exposure to industrial chemicals, particularly those produced by fossil fuel combustion, is linked to the development of childhood cancer (Knox, 2005).

A peer-reviewed report published by the Ontario Division of the Canadian Cancer Society found evidence correlating environmental exposures of arsenic to lung, skin, and bladder cancers; particulate air pollution and polycyclic aromatic hydrocarbons (PAHs) to lung cancer; asbestos to mesothelioma and lung cancer; ultraviolet (UV) radiation to skin cancer; drinking water disinfection byproducts to bladder cancer; and extremely low-frequency electromagnetic fields to childhood leukemia (Cancer Care Ontario, 2005). There is also evidence linking environmental contaminants with carcinoma of many organs and tissues including bladder, bone, brain, breast, esophagus, larynx, kidney, pancreas, liver, scrotum, skin, and salivary glands, as well as to leukemia, angiosarcoma, multiple myeloma, and Hodgkins lymphoma (Coyle, 2004; Janssen et al., 2004).

Table 5
Environmentally attributable fractions for cancer

| EBD study | Cancer EAF |
|---|---|
| Davies and Hauge, 2005 | 5% (2–10%) |
| Landrigan et al., 2002 | 5–90%[a] |
| Melse and de Hollander, 2001 | 1–5%[b] |
| Massey and Ackerman, 2003 | 5–90%[a] |
| Mathews and Parry, 2005 | 5% (5–90%)[a] |
| Prüss-Üstün and Corvalán, 2006 | 19–29% |
| Shuler et al., 2006 | 5% (2–10%) |

[a]Estimate includes only childhood cancers
[b]Estimate does not include occupational exposures

The precise proportion of cancer cases attributable to environmental exposures remains the subject of ongoing discussion (Table 5). A number of experts estimate that environmental exposures (including pollution, UV radiation, occupational exposures, and consumer products) cause between 2% and 10% of cancer deaths (Doll and Peto, 1981; Thomas and Hrudey, 1997). The OECD used an EAF of 1–5% for cancer (Melse and de Hollander, 2001). Other health experts view these estimates as too low. Health Canada, for example, estimates that 10–15% of cancers are linked to the environment (Health Canada, 1999). The WHO estimated that 19% of cancers (12–29%) throughout the world are due to environmental causes (Prüss-Üstün and Corvalán, 2006). More specifically, in developed countries like Canada 30% (6–55%) of lung cancers and 15% (10–34% for men and 10–23% for women) of all other cancers are linked to environmental causes (Prüss-Üstün and Corvalán, 2006).

Recent evidence about the environmental burden of specific types of cancer in Canada (e.g., lung cancer caused by radon, environmental tobacco smoke, asbestos, and air pollution, and mesothelioma caused by asbestos) suggests that the lower EAF estimates for cancer are excessively conservative. A summary of this evidence is presented below.

#### 3.3.1. Radon

As a recognized determinant of lung cancer, exposure to radon is believed to be responsible for at least 10% of lung cancer deaths worldwide (Darby et al., 2005; Krewski et al., 2005). Estimates suggest that 1700–2900 deaths annually in Canada are caused by lung cancer associated with exposure to radon (Boyd, 2006).

#### 3.3.2. Environmental tobacco smoke

Exposure to environmental tobacco smoke (second-hand smoke) is associated with both cancer and cardiovascular disease. More than 1000 Canadians die annually because of lung cancer and heart disease caused by exposure to second-hand smoke (de Groh and Morrison 2002).

#### 3.3.3. Asbestos

As well as increasing the risk of lung carcinoma, asbestos exposure causes a rare form of cancer called mesothelioma. There are approximately 400 new cases of mesothelioma and 340 deaths from mesothelioma annually in Canada (Canadian Cancer Society and National Cancer Institute of Canada, 2007).

#### 3.3.4. Drinking water

Cancer may be caused by certain contaminants not infrequently found in Canadian drinking water including arsenic and disinfection by-products, i.e., chemicals such as trihalomethanes created when chlorine added to water as a disinfectant combines with naturally occurring organic materials (Cantor et al., 1998; International Agency for Research on Cancer, 2004.).

#### 3.3.5. Air pollution

Air pollution causes cancer of the lungs, trachea and bronchus (Cohen et al., 2005). The primary cause is believed to be fine particulate matter, although benzene and other chemicals may also be responsible.

Based on the evidence linking various malignancies to adverse environmental exposures, we use an EAF of 5–15% for cancer. This is higher than the 1–5% range used by the OECD and the 2–10% range used by other researchers because known cases of environmentally linked cancer represent at least 5% of cancer deaths in Canada. However, our range is lower than the WHO's global EAF of 19–29%. The WHO's estimates of the EAF for cancer in developed countries are lower than estimates for developing nations, meaning that the WHO's global range is too high for Canada. In addition, as noted earlier, we use a narrower definition of environmental risk factor than the WHO.

Our estimate of the mortality and morbidity in Canada caused by cancer attributable to adverse environmental factors includes: 3400–10,200 deaths; 8000–24,000 new cases of cancer diagnosed; 11,000–32,000 hospitalizations; and 104,000–312,000 patient-days spent in hospital (Table 6).

### 3.4. In-utero exposure and congenital affliction

According to recent health-care data, the annual burden of congenital morbidity and mortality in Canada includes 1700 infant deaths, 25,000 cases of low birth weight infants, 1900 stillbirths and 6400–9600 serious congenital anomalies. The most common birth defects in Canada are musculoskeletal anomalies, heart defects, and central nervous system anomalies including neural tube defects (Canadian Institute for Health Information, 2005a; Federal, Provincial and and Territorial Advisory Committee on Population Health, 1999; Health Canada, 2003). According to survey data collected in 1994: 26% of children living in Canada aged 6–11 years old have at least one identifiable learning or behavioral problem;

Table 6
The environmental burden of cancer in Canada

| Cancer | Number | EAF | EBD range |
|---|---|---|---|
| New cases | 159,900 | 5–15% | 7995–23,985 |
| Hospitalizations | 215,493 | 5–15% | 10,775–32,324 |
| Days in hospital | 2,078,966 | 5–15% | 103,948–311,845 |
| Deaths | 68,322 | 5–15% | 3416–10,248 |

14–16% of children living in Canada had cognitive deficits; and another 17–22% had "behavioral problems" defined as hyperactivity and Attention Deficit Hyperactivity Disorder (Statistics Canada, 1997). Unfortunately, there is no current, comprehensive and reliable national data on the prevalence of neurodevelopmental disorders amongst Canadian children, so we have not attempted to estimate the EBD of this category of illness.

The human fetus is routinely exposed to myriad chemical contaminants as a result of acute as well as accumulated maternal exposure (Genuis, 2006a). A recent study of the umbilical cord blood of newborn infants revealed the presence of an average of 200 industrial chemicals per sample, including flame retardants, plasticizers, and heavy metals (Houlihan et al., 2005). Residues from banned pesticides continue to be detected in the meconium of newborns (Enrique et al., 2002). Congenital anomalies have been linked to a wide range of contaminants (Genuis, 2006b) including lead, chlorination byproducts and nitrates in drinking water, environmental tobacco smoke, solvents, phthalates, pesticides, and ethanol.

Exposure to toxic substances in-utero is associated with a wide range of adverse health effects that may manifest prior to birth, at birth, at later stages of development, or even in adulthood. Prenatal exposure to air pollution is associated with adverse birth outcomes such as early fetal loss, preterm delivery, and lower birth weight (Liu et al., 2003; Salam et al., 2005). Prenatal exposure to environmental contaminants is also associated with neurological and behavioral afflictions, including hyperactivity, Attention Deficit Hyperactivity Disorder (ADHD), learning disabilities, mental retardation, and autism spectrum disorder (Fombonne, 2003). In particular, heavy metals such as lead and mercury may cause neurodevelopmental problems ranging from small but perceptible effects on IQ, sensory and motor function to severe and sustained cognitive deficits (Grandjean and Landrigan, 2006; Mendola et al., 2002).

There is considerable uncertainty about the proportion of congenital affliction that is attributable to environmental contaminants. In 2000, an expert committee established by the US National Academy of Sciences estimated that 3% of all congenital defects and developmental disorders in children are directly caused by exposure to environmental contaminants and that another 25% are caused by multi-factorial inheritance, i.e., interactions between environmental factors and genetic susceptibility (National Academy of Sciences Committee on Developmental Toxicology, 2000). Thus, the committee determined that about 28% of congenital disorders could be attributed wholly or partially to environmental contaminants, not including alcohol, tobacco, or illegal drugs. The WHO estimated the EAF at 5% (2–10%) for congenital affliction (Prüss-Üstün and Corvalán, 2006). The OECD used an EAF of 1–5% (Melse and de Hollander, 2001). The EBD study in the UK used a higher EAF of 10% (5–20%) because research in the UK suggests that a higher proportion of pediatric affliction is related to prenatal environmental exposure (Knox, 2005; Mathews and Parry, 2005). The majority of other EBD studies use the 2–10% range as the EAF for congenital affliction (Table 7). We used the EAF range of 2–10% because it is widely used by EBD researchers, including the WHO. The UK and OECD estimates appear to be outliers on the high and low ends of the spectrum, respectively.

Our estimate of the burden of congenital affliction in Canada attributable to adverse environmental factors includes 72–360 deaths; 128–640 serious congenital anomalies; 300–1500 hospitalizations; 2000–10,000 patient-days spent in hospital; and 500–2500 low birth weight babies. (Table 8) These figures do not include developmental disorders.

## 4. Discussion

Although there is increasing evidence of the connection between toxicant exposure and a wide range of chronic health problems, we have focused on respiratory illness, cardiovascular disease, cancer, and congenital affliction. A more comprehensive analysis, detailing the Canadian EBD for the full spectrum of illnesses, is beyond the scope of a single article. Yet despite the limited focus of this study, our estimate indicates that the environmentally attributable proportion of respiratory illness, cardiovascular disease, cancer, and congenital effects in Canada is substantial: 10,000–25,000 deaths; 78,000–194,000 hospitalizations; 600,000–1.5 million days spent in hospital; 1.1–1.8 million restricted activity days for asthma sufferers; 8000–24,000 new cases of cancer; and 500–2500 low birth weight babies (Table 9)

The foregoing estimates are consistent with other Canadian studies about the adverse health effects of specific environmental hazards. For example, experts with Health Canada estimated that air pollution in parts of eight large cities is linked to 5900 premature deaths annually (Judek et al., 2005). Similarly, the Ontario Medical Association estimated that air pollution in the province of Ontario alone is associated with 5900 premature deaths annually (Ontario Medical Association, 2005). In both studies, cardiovascular disease and respiratory illness are the dominant causes of death. The estimates from these studies could be conservatively doubled to cover Canada as a whole, resulting in a national estimate of more than 11,000 premature deaths resulting annually from cardio-

Table 7
Environmentally attributable fractions for congenital affliction

| EBD study | Congenital affliction EAF |
|---|---|
| Davies and Hauge, 2005 | 5% (5–10%) |
| Melse and de Hollander, 2001 | 1–5% |
| Mathews and Parry, 2005 | 20% (1–40%) |
| Prüss-Üstün and Corvalán, 2006 | 5% (2–10%) |
| Shuler et al., 2006 | 5% (5–10%) |
| Smith et al., 1999 | 5–10% |

Table 8
The environmental burden of congenital affliction in Canada

| Congenital affliction | Number | EAF | EBD range |
|---|---|---|---|
| Low birth weight babies | 25,000 | 2–10% | 500–2500 |
| Serious congenital anomalies | 6400 | 2–10% | 128–640 |
| Hospitalizations | 15,580 | 2–10% | 312–1558 |
| Days in hospital | 99,103 | 2–10% | 1982–9910 |
| Deaths | 3600 | 2–10% | 72–360 |

Table 9
A summary of the environmental burden of disease in Canada

| Disease | Deaths | Hospitalizations | Days in hospital |
|---|---|---|---|
| COPD | 977–2932 | 25,646–76,938 | 170,611–511,832 |
| Asthma | 75–153 | 8060–16,430 | 28,448–57,989 |
| Cardiovascular disease | 5456–10,911 | 33,541–67,083 | 291,419–582,838 |
| Cancer | 3416–10,248 | 10,775–32,324 | 103,948–311,845 |
| Congenital affliction | 72–360 | 312–1558 | 1982–9910 |
| Totals | 9996–24,604 | 78,334–194,333 | 596,408–1,474,414 |

vascular and respiratory illnesses linked to air pollution. The results of these air pollution studies suggest that the lower end of our EAF range (1000 deaths from respiratory illnesses and 5500 deaths from cardiovascular disease) may be too conservative. It is difficult to determine whether the EBD in Canada is likely to be at the low, middle, or high end of the range. Canada is widely regarded as a clean and pristine nation but its environmental record does not live up to its reputation, particularly with regard to air pollution (Boyd, 2003).

### 4.1. Economic impact of the EBD in Canada

A preliminary assessment of the economic costs of the EBD in Canada can be made by applying the EAFs determined above to the costs of respiratory disease, cardiovascular disease, cancer, and congenital illness as calculated by Health Canada for 1998 (Health Canada, 2002). Direct costs include the costs of physician care, operating hospitals, and assorted other medical expenses. Indirect costs include lost productivity due to death, illness, or disability, but do not incorporate costs related to pain, suffering or loss of life. The total cost of the EBD for these four categories of disease, in 2006 Canadian dollars, is $3.6–$9.1 billion (Table 10). The 1998 costs reported by Health Canada were adjusted to 2006 dollars to incorporate inflation by using Statistics Canada's Consumer Price Index. This is a conservative approach because Canadian health-care expenses have risen faster than inflation (Canadian Institute for Health Information, 2005b).

### 4.2. Study limitations

As noted earlier, quantifying the EBD in Canada is challenging because of scientific uncertainties and data constraints. Because of these difficulties, our study includes only four categories of disease. We did not evaluate the EBD for gastro-intestinal illness, reproductive problems, auto-immune conditions, neuro-psychiatric disorders, injuries, poisonings, and many other categories of illness. We did not address the health implications of climate change, electromagnetic radiation, endocrine-disrupting chemicals, declines in native biodiversity, or nanotechnology (Choi et al., 2004; Epstein and Mills, 2005; Ezenwa et al., 2006; Hardell et al., 2006; Powell and Kanarek, 2006). As evidence of adverse health effects associated with a wide range of environmental hazards grows stronger, future EBD studies will be able to address a broader spectrum of health outcomes.

We have relied largely on EAFs generated by other studies because uniquely Canadian data are lacking. Unlike nations like the United States and Germany, Canada has never conducted a national biomonitoring program to determine population-level exposures to environmental hazards, although the federal government recently announced plans for such a program (Health Canada and Statistics Canada). Even for lead, a well-established environmental hazard posing a serious risk to children, Canada has not carried a national study of blood-lead levels since 1979 (Tsekrekos and Buka, 2005). Canada also lacks both an environmental health surveillance system and a national environmental health strategy. Finally, Canadian research in the area of environmental health is underfunded relative to other industrialized nations. As a blue ribbon panel of Canadian health experts recently observed, "The area of environmental impacts on health has been seriously neglected in Canada and requires urgent investment" (National Advisory Committee on SARS and Public Health, 2003).

EBD studies to date, including this study, may underestimate the magnitude of adverse health effects caused by environmental hazards. Emerging research suggests that official health statistics (deaths, illnesses, hospitalizations, etc.) represent only a portion of the actual environmental impact on human health. Many adverse health effects (e.g., sub-clinical toxicity, neuropsychiatric disorders, fertility impairment, intellectual impairment, etc.) often escape detection, are not reported, or are attributed to factors other than adverse environmental exposures. Of particular note is the recent finding that some toxicants have the potential to alter gene regulation and expression by

Table 10
The economic costs of the EBD in Canada (all figures in millions of Canadian dollars)

| Disease category | Direct costs | Indirect costs | Total costs | EAF | EBD $1998 | EBD $2006 |
|---|---|---|---|---|---|---|
| Respiratory | $3461.4 | $5069.7 | $8531.1 | 10–30% | $853–2559 | $1025–3075 |
| Cardiovascular | $6818.1 | $11,654.8 | $18,472.9 | 7.5–15% | $1385–2770 | $1664–3328 |
| Cancer | $2462.4 | $11,758.0 | $14,220.4 | 5–15% | $711–2133 | $854–2563 |
| Congenital | $481.6 | $828.6 | $1310.2 | 2–10% | $26–131 | $31–157 |
| Total | | | | | | $3574–9123 |

*Note*: Costs for 1998 were adjusted to 2006 dollars to incorporate inflation by using Statistics Canada's Consumer Price Index. A basket of goods and services that cost $100 in 1998 would cost 120.15 in 2006.

previously unrecognized epigenetic changes, an alteration which may persist through successive generations (Anway et al., 2006; Murray et al., 2007). Recent data on the clinical impact of mold exposure (Genuis, 2007a) and adverse electromagnetic fields (Genuis, 2007b) are also emerging areas of intense research. Finally, in addition to single adverse exposures, multiple environmental exposures may facilitate synergism of toxicity—a reality that is only beginning to be explored (Welshons et al., 2003).

Further research on the EBD in Canada should strive to refine the broad ranges of EAFs that we identified. Future research may also provide greater depth of detail on environmentally attributable morbidity by calculating disability-adjusted life years (DALYs). This would enhance international comparisons and facilitate identification of priorities for public health interventions. Future work on the EBD in Canada could also benefit from a regional or provincial approach (because of wide variations among regions and provinces in the distribution of environmental hazards) and a focus on vulnerable populations (e.g., children, Aboriginal people, and low-income Canadians). As well, because the prevalence of disease varies between males and females, a refined analysis examining the EBD by gender would be useful. For example, morbidity and mortality rates from COPD are falling for Canadian men but rising for Canadian women (Canadian Lung Association and the Canadian Thoracic Society, 2006).

## 5. Conclusion

This study attempts to quantify, for the first time, the magnitude of respiratory disease, cardiovascular disease, cancer, and congenital affliction associated with environmental risk factors in Canada. The results indicate that a significant proportion of mortality, morbidity, and healthcare expenditure in Canada is linked to environmental hazards. While other risk factors including smoking, diet, fitness, and lifestyle still predominate, there is a critical difference between these risk factors and environmental hazards. The former involve personal choices, whereas exposure to many environmental hazards, such as air pollution, is involuntary. This critical distinction places a greater onus on governments to reduce the risks posed by environmental hazards.

Most adverse environmental exposures are preventable through stronger public policy, technological change, and behavioral modification. As evidence about environmental health and disease aetiology continues to accumulate, ongoing EBD assessments should provide a foundation for strategic improvements in environmental legislation, health policy, and public health programs.

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