Costing Climate Change Impacts on Human Health across Canada

Final Report

December 1, 2020

CANADIAN INSTITUTE FOR CLIMATE CHOICES

Prepared for the Canadian Institute for Climate Choices

ESSA

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Cover Photo: Construction work during a heatwave in Ottawa, J. Eyzaguirre

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1. Introduction

The Canadian Institute for Climate Choices (the Institute) is undertaking a project to explore the economic costs of climate change impacts in Canada. The first phase of the project, which includes this study, is developing monetary estimates of some of the most significant direct damages and losses expected to be caused by climate change. The second phase of the project will integrate direct costs of damages and losses into a macro-economic modelling framework to explore the secondary and multiplier effects of climate change on the broader Canadian economy.

The objectives of the overall project are as follows:

- Improve knowledge of the scale and distribution of the economic consequences of climate change by mid and end of the century;
- Inform the ability of governments and Canadians to prioritize adaptations; and,
- Increase understanding of the economic implications of different global emissions futures for Canada.

As part of the first phase of the project, the Institute is working with ESSA Technologies Ltd. (ESSA), Industrial Economics Inc. and other experts to quantify the physical impacts of climate change and monetize these impacts at a national level, for two future eras and two global greenhouse gas (GHG) concentration scenarios for the following themes:

- Homes, buildings, and real estate
- Transportation infrastructure
- Canada’s North
- Electricity and energy
- Human health
- Business interruption

This report describes the approaches ESSA took to examine the economic consequences of climate change on human health and labour supply, as well as the results of applying these approaches. Impacts on labour supply may be interpreted as part of business interruption.

This report starts with a brief overview of the thematic areas of focus. Section 2 provides information on the specific scope of the study for each of the thematic areas of focus. Section 3 describes our analytical framework for estimating the economic costs of climate change-driven impacts on human health and labour supply, both conceptually and operationally. Section 4 outlines the principal input data that we used to complete the analysis. Section 5 describes our approach to the quantification of physical climate change impacts (i.e., health and labour outcomes), specifying how we derived exposure-response functions (ERFs) and how we applied them. Exposure-response functions provide the quantitative link between climate data and, in this case, health and labour supply outcomes. Section 6 describes our approach to economic valuation. Section 7 presents key results of the analysis on the economic “costs of inaction”. Section 8 outlines how we addressed proactive adaptation in our analysis and presents results of the application of three national-level adaptation scenarios focusing on increased temperatures and labour. Section 9 provides a brief discussion of the results, including study limitations.

1.1 Human Health

Climate change presents risks to the health of Canadians. Important climate change pathways that will impact health include temperature, precipitation, humidity, climate-sensitive vectors for disease and pathogen transmission and exposure to air pollution (Figure 1-1).[1] Direct effects, such as those related to heat, are most frequently examined in the literature.[2] Ecosystem-mediated effects of climate change include risks of vector-borne infectious diseases, as climate change may affect the geographic distribution and biological factors related to the vectors themselves, or the development and prevalence of the infectious agent.[3] Climate change may lead to changes in ambient and household air pollution exposure from ground level ozone, wildfires, mold, and pollen/spores, resulting in exacerbations of existing respiratory conditions, allergies, increased risk of cardiovascular disease, and premature mortality.[4] Risks may be further complicated by urban and rural characteristics such as urban-heat island effects or the reduced availability of adaptation resources in rural areas.[5]

Critically, the impacts of climate change are not equitably distributed. For example, Northern populations are already experiencing food-security challenges related to access, availability and quality of traditional food resources.[6] Food insecurity can be further exacerbated by socioeconomic stressors in these regions.[7] The pathways by which climate change may affect food systems are complex, ranging from direct effects (e.g. changes in precipitation affecting crop production) to indirect effects (e.g. changes in food prices).[8] In cases where living conditions are severely compromised by the combined effect of climate change and other stressors, temporary or permanent migration can be a response.

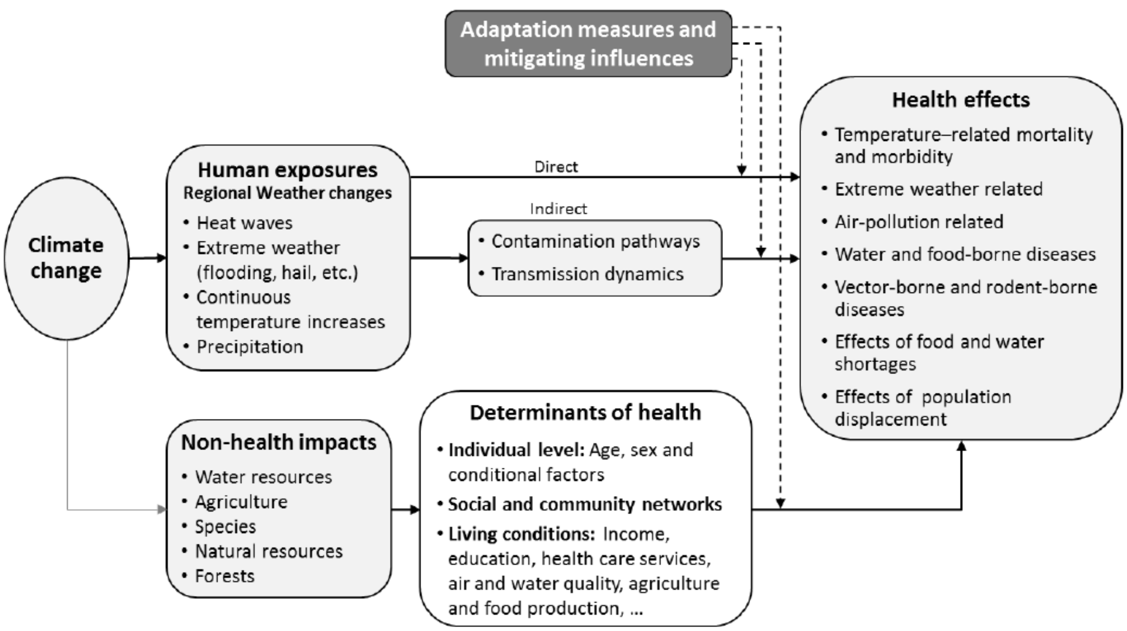

Figure 1-1: Pathways through which climate change may affect human health (Source: Haas et al. 2016)

Human health has received moderate attention in global[9], continental[10] and national[11] climate change costing studies; Canadian economic assessments of the health impacts of climate change are limited.[12] Integration of health impacts into climate assessments relies on the construction of exposure-response functions, which use statistical techniques to correlate climate data with health outcomes derived from epidemiological and other studies. Most studies do not undertake original health impact modelling but rely on published exposure-response functions.

Key gaps and needs in the economic assessment of health impacts of climate change overall include the following[13]:

- Economic valuation studies covering tick-borne diseases (coverage of mosquito-borne diseases is more prevalent, in comparison);

- Economic valuation studies covering air quality, nutrition-related health outcomes and allergies;
- Economic valuation studies covering physical and mental morbidity and mortality from extreme events beyond temperature extremes;
- Improvements in the economic valuation of the impacts of climate change on health services and social care.

1.2 Labour Supply

An emerging field of research on the macro-economic consequences of climate change examines the impact of temperature and heat stress on the productivity of workers across different economic sectors[14]. There is an observable relationship between workplace temperatures and performance; beyond a certain temperature the hourly productivity of workers or the time spent working declines[15]. A growing body of evidence is finding that losses can be substantial under different climate futures—especially for "high-risk" sectors[16] with a largely outdoor workforce (e.g., agriculture, forestry, construction, mining, transportation, utilities). For example, the United States Environmental Protection Agency [USEPA] (2017) found that about 1.9 billion labour-hours in high-risk sectors will be lost annually in the United States by 2090 under a high GHG concentration scenario due to workplace exposure to temperature extremes (i.e., mean daily maximum temperatures above 80°F). This equates to about $160 billion (2015 US dollars) in forgone wages per year by 2090, which represents just under one-third of the total estimated annual damages under the high GHG concentration scenario across all impact categories analyzed. The projected impact on labour productivity was the most economically significant impact category for the United States. Estimates of the impact of climate change on occupational heat stress and associated labour decisions, labour productivity, and economic output for Canada are currently only available from large-scale, highly aggregate global studies.[17]

2. Study Scope

The health and labour supply impacts in Table 2-1 were quantified and monetized in this study.[1] The analysis was conducted at the Census Division level, unless stated otherwise. We evaluated health and labour supply outcomes and associated economics costs for a baseline and two future eras: 30-year periods centered on the 2050s (2041-2070) and 2080s (2071-2100). The climate baseline for the study was defined as the period 1971 to 2000. The socioeconomic baseline was a three-year average centered on 2016 with all economic costs expressed in 2015 constant dollars.

Table 2-1: Study Scope

Climate stressors	Health / labour supply outcome	Spatial and socio-demographic disaggregation	Economic metrics
Hot weather • Daily mean temperature > minimum mortality temperature	• Heat-related mortality (# of deaths)	Census Divisions All ages, all sexes	• Value of Statistical Life (VSL) ($) • Value of Statistical Life Year Lost (VSLY) ($) • Human capital cost ($)
Hot weather • Daily mean temperature > minimum morbidity temperature	• Heat-related hospital admissions (# due to coronary heart disease, stroke, diabetes, and hypertensive diseases)	Census Divisions All ages, all sexes	• Direct resource costs (costs of hospital stays) ($) • Indirect (opportunity) costs associated with stay in hospital ($)
Air quality (ground-level ozone) • Daily maximum temperature and daily maximum seasonal temperature (averaged over May-Sept)	• # acute exposure mortality • # chronic exposure respiratory mortality	Census Divisions All sexes, age groups differ by health outcome	• Value of Statistical Life (VSL) ($) • Human capital cost ($)
• Daily maximum temperature (averaged over May-Sept)	• # of acute respiratory symptom days • # of asthma symptom days • # respiratory emergency room visits		• Welfare losses ($) (willingness to pay to avoid morbidity health outcomes)
Lyme disease • Mean annual temperature	• # of new incident cases	Census Divisions, excluding areas west of the Rocky Mountains and at elevations above 500m. Focused on provinces where the tick vector has been established. All ages, all sexes	• Expected direct costs + indirect costs + welfare losses over lifecycle of disease ($)
Labour Supply • Daily maximum temperature	• # of lost work hours	Census Division Labour force (15-64 years old) in Agriculture, Forestry, Fishing, and Hunting; Mining, Quarrying, and Oil and Gas Extraction; Utilities; Construction; Transportation and Warehousing	• Payroll compensation ($) • Labour productivity ($ GDP)

[1] The scope of work originally included cold-related health outcomes. However, given concerns in the literature over the robustness of evidence relating cold exposures to mortality and morbidities, cold-related impacts were subsequently dropped from the analysis (this is explained further in Section **Erreur! Source du renvoi introuvable.**).

3. Analytical Framework for Estimating the Costs of Human Health Impacts of Climate Change

In this section we explain the overarching analytical framework and model structure.

3.1 Conceptual Framework

Our modelling approach uses a bottom-up impact pathway methodology similar to the health impact analyses in PESETA I and II[18,19] and ClimateCost[20]: three research studies that quantified and monetized the impacts of future climate change on European climate-sensitive sectors, including public health. The structure of our approach is outlined in Figure 3-1.

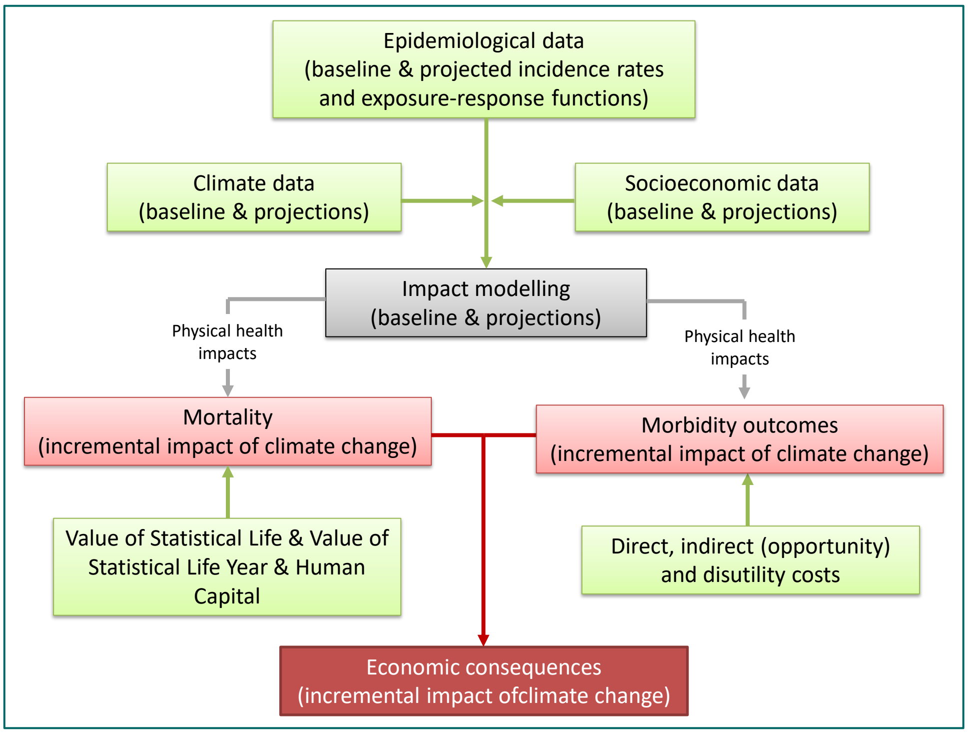

Figure 3-1: Structure of our analytical approach

The core of our approach consists of a set of exposure-response functions (ERFs), some of which we derived from a systematic review of epidemiological studies in the literature (the systematic review can be provided upon request). These functions are coupled with socioeconomic data (population and economic metrics such as gross domestic product), illness/disease incidence/prevalence rates, assumptions about autonomous adaptation (e.g., acclimatization), and climate data, to calculate climate change-related mortality, morbidity and labour outcomes for the 2050s and 2080s. Projected physical health and labour supply outcomes are compared with a reference scenario, typically constructed by applying baseline epidemiological data to projections of future exposed populations. The difference between these two sets of projections provides a measure of the additional mortality, morbidity, and labour supply outcomes attributable to climate change alone. As such, we use a comparative risk assessment approach, in which estimated health or business interruption outcomes are measured as the annual average *excess* cost attributable to climate change compared to a socioeconomic/demographic future without climate change.

Figure 3-2 illustrates this process, as well as how the benefits of proactive adaptation are assessed (also see Section 8.1).

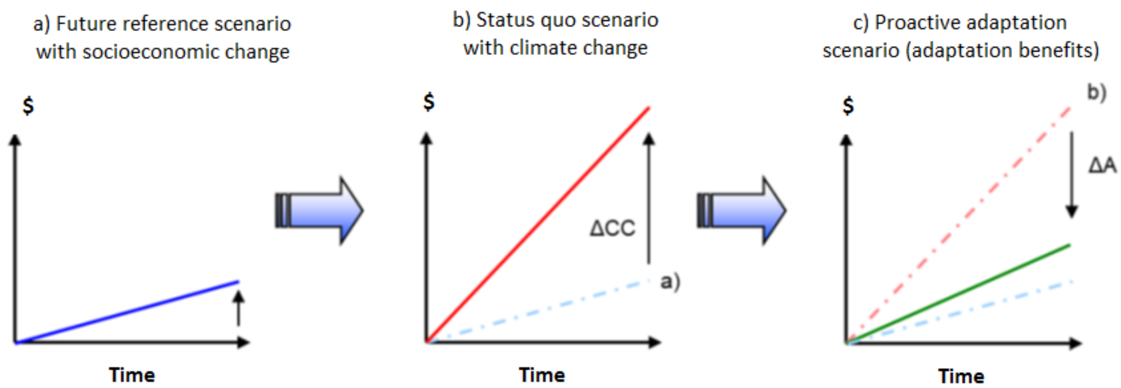

Figure 3-2: Stylized process for calculating costs of climate change and benefits of adaptation (Boyd and Hunt, 2006)

Estimated additional health outcomes are converted into dollars using standard economic valuation methods and values. Finally, interval analysis is conducted on the main sources of uncertainty along the impact chain (climate→ socioeconomic change → ERF→ economic value). Consistent with other bottom-up costing studies, we treat population and socioeconomic change exogenously—i.e., it is assumed to follow a predefined path, unaffected by estimated climate-induced mortality.

3.2 Modeling Framework

We developed a custom modeling framework to handle data integration and automation for this project. The framework consists of a series of modules in the R statistical software environment and leverages cloud computing resources to minimize computation times. We selected the Microsoft Azure Cloud Computing Services as our cloud computing environment due to its efficient integration with R, primarily through the R packages rAzureBatch and AzureStor.

To use climate data and population and other socioeconomic data together, they need to use the same spatial unit. By default, the climate data uses a roughly 10x10km grid, and the census data (the source of the population and socioeconomic data) reports data in 293 Census Divisions. "Census divisions are intermediate geographic areas between the province/territory level and the municipality."[2] Climate data were assigned to a Census Division using an average value of all cells within the spatial extent of the Census Division. Cells that are only partially inside the Census Division were weighted based on the area inside the Census Division relative to the area outside.

Human health and labour impact and related costs were calculated from climate, population, socioeconomic, mortality, morbidity, and labour activity data using a set of ERFs and economic values (see Sections 5 and 6). The input data is divided into 12,306 distinct datasets based on 7 Global Climate Models (GCMs), two emission concentration scenarios, three time-series and 293 Census Divisions. The framework iterates through each of the different datasets, applies the ERFs to derive the human health / labour supply impacts and calculates the associated cost of climate change using a set of monetization functions.

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[2] https://www150.statcan.gc.ca/n1/pub/92-195-x/2011001/geo/cd-dr/def-eng.htm

4. Input Data

The analysis uses different sources of input data to explore climate change-driven projections of human health and labour supply outcomes. These input data fall into three main categories:

- Climate
- Population and other socioeconomic factors
- Mortality and morbidity

4.1 Climate

The primary driver of our analysis is projections of future climate from a set of Global Climate Models (GCMs), each using two trajectories of global greenhouse (GHG) emissions concentrations. The GCMs produce time-series of minimum and maximum temperature and cumulative precipitation on a daily timeframe. The spatial resolution of the data required is a 10x10km grid covering all of Canada. Climate projections were provided by the Canadian Centre for Climate Services (CCCS) and developed by the Pacific Climate Impacts Consortium, which has generated statistically downscaled and bias-corrected scenarios for a range of GCMs and Representative Concentration Pathways (RCPs), or emissions concentration scenarios. Following the United States Environmental Protection Agency's approach to model selection for their Climate Impact and Risk Analysis, the Institute examined the average annual temperature and average annual precipitation changes projected by 24 GCMs in Canada, selecting 7 GCMs that reflected the outer convex hull of possible futures.

Our study evaluates the economic cost of the human health and labour impacts of climate change under two different RCPs, defined by the Intergovernmental Panel on Climate Change (IPCC) in their Fifth Assessment Report: RCP4.5 and RCP8.5. In RCP4.5, global GHG concentrations (represented in carbon dioxide equivalents) peak around 2040, then decline, yielding a stabilization of CO_2-equivalent concentrations by the end of the 21st century (Figure 4-1). In RCP8.5, in contrast, emissions concentrations continue to rise throughout the 21st century.

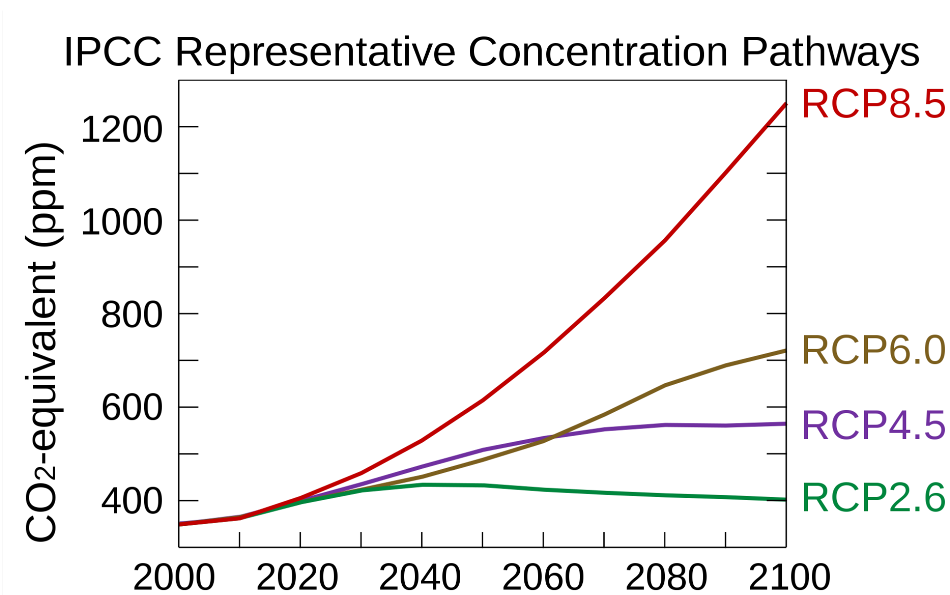


Figure 4-1: IPCC Representative Concentration Pathways. This study uses RCP4.5 and RCP8.5 to evaluate the cost of the human health impact of climate change. (Source: https://en.wikipedia.org/wiki/Representative_Concentration_Pathway)

Estimates of physical impacts are based on outputs of 7 GCMs (Table 4-1). The data received from the CCCS for each GCM included daily time series of minimum and maximum temperature and cumulative precipitation for three time periods: 1971 to 2000, 2040 to 2069, and 2070 to 2100.

Table 4-1: Selected GCMs for this study. The GCMs were selected to best represent the combined certainty out of a multi-model ensemble of 25 GCMs. Source: Environment Canada 2016

Model Name	Place of Origin	Institution
CCSM4	USA	National Centre for Atmospheric Research
GFDL-CM3 GFDL-ESM2M	USA	NOAA Geophysical Fluid Dynamics Laboratory
HadGEM2-AO HadGEM2-ES	UK	UK Met Office Hadley Centre
MIROC-ESM-CHEM	Japan	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MRI-CGCM3	Japan	Meteorological Research Institute

The spatial resolution of the climate data is a nation-wide 10x10km grid. Each grid cell has a time-series of the three variables available from each GCM under each of the two RCPs. For consistency with population and other socioeconomic data, daily time-series of climate data were assigned to each of the 293 Canadian Census Divisions, based on the spatial overlap.

Section 5 of this report describes the use of climate data, including specific variables employed, in estimating human health and labour supply impacts.

4.2 Population and Other Socioeconomic Data

Estimating the human health and labour supply impacts of climate change involves determining Canadians' current and future exposure and sensitivity to climate stressors and their direct and indirect impacts. Our analytical framework accounts for some of the most tractable factors that shape populations' climate change vulnerability. These are:

- The number of people and their geographical location
- The age structure of the population
- Labour participation in "high-risk" occupations (i.e., occupations that expose workers to extreme heat and other climate-related sources of risk of injury or illness)

Other socioeconomic aspects that shape vulnerability to climate change at the individual (e.g., sex, race and cultural heritage, preferences for outdoor activity), household (e.g., wealth, access to health services) and societal (e.g., technological and medical advances, education, workplace norms, land-use changes) levels are not explicitly modeled using quantitative indicators in the socioeconomic scenarios.

Baseline population data and population projections by Census Divisions, for both urban and rural settings, and by province and territory come from Statistics Canada, including the *2016 Census* and *Population Projections for Canada (2018 to 2068), Provinces and Territories (2018 to 2043)*. The Institute provided population data from 2018-2100, broken down by 5-year age groups. The Institute also provided employment projections by province / territory and National Industrial Classification Code (NAICs), for the following sectors:

- NAICS 11: Agriculture, forestry, fishing and hunting
- NAICS 21: Mining, quarrying, and oil and gas extraction
- NAICS 22: Utilities
- NAICS 23: Construction
- NAICS 48-49: Transportation and warehousing
- NAICS 31-33: Manufacturing

Sources of data for the purpose of economic valuation include the following:

- Exchange rates and Purchasing Power Parities (PPP) from the Organization for Economic Cooperation and Development (OECD)[21];
- Market-based and welfare-based (willingness to pay) unit values embedded in Health Canada's Air Quality Benefits Assessment Tool (AQBAT) version 3; and
- Base year and projections of the labour force by province and territory, provided by Institute.

Sections 5 and 6 of this report describe our use of socioeconomic data in estimating and monetizing human health and labour supply impacts.

4.3 Morbidity and Mortality Data

Our physical impact quantification relies on primary studies and existing models. For human health impacts, the formulation of ERFs determines data needs with regards to baseline mortality and morbidity.

Hot temperatures

For heat-related mortality, we used the ERF models for Canadian cities found in Gasparrini et al. (2015). Application of these models required baseline daily all-cause mortality rates (deaths per 100,000 population), which were derived for each province and territory from Statistics Canada Table 13-10-0708-01 (for each province and territory we used a 3-year average centered on 2016); these mortality rates were assumed not to change over time (see Section 5.1.1 below).

For heat-related morbidity, we used the ERF models from Bai et al. (2016 and 2017) for coronary heart disease, stroke, hypertensive diseases and diabetes (see Table 4-2). These morbidities were found to have the most significant relationships with temperature. Application of these models required disease-specific daily hospitalization rates (hospitalizations per 100,000 population), which were extrapolated to each province and territory from the Ontario-specific rates in Bai et al.

Illness	ICD-9	ICD-10
Coronary heart disease	410-414	I20-I25
Stroke	430-438	I21
Hypertension	401-405	I10-13
Diabetes	250	E10-E14

Table 4-2: Data requirements related to baseline temperature-related morbidities

Air quality

Our analysis of air quality impacts driven by temperature rise and related changes in concentrations of ground level ozone relied on the use of Health Canada's Air Quality Benefits Assessment Tool (AQBAT) version 3.[22] AQBAT integrates baseline mortality and hospitalization data at the Census Division (CD) level. Modellers obtained mortality data directly from the Canadian Vital Statistics database and hospital discharge data from CIHI; values are estimated for small population CDs and Quebec. AQBAT includes six health endpoints associated with ground level ozone (O_3). We relied on the baseline rates of incidence embedded in AQBAT to assess the mortality and morbidity impacts of changes in O_3 across Census Divisions and modeling periods. These health outcomes of interest are:

- Acute exposure mortality
- Chronic exposure respiratory mortality
- Acute respiratory symptom days
- Asthma symptom days
- Respiratory emergency room visits

See Judek et al. (2019) and Health Canada (2019) for more information on baseline levels of morbidity and mortality.

Lyme disease

The methods underlying our analysis of climate-driven changes in incidence of Lyme disease do not require baseline incidence rates since the ERFs are derived from a US study and are applied to population data not health outcomes. Nevertheless, where we refer to reported incidence rates of Lyme disease in Canada, we draw from the Public Health Agency of Canada, Public Health Ontario and Institut national de santé publique du Québec. Incidence rates of Lyme disease are trending upward in Ontario and are higher than national average rates (Table 4-3). As a point of comparison, the incidence rate in Quebec in 2019 was 4.4/100,000 people.

Table 4-3: Lyme disease incidence rates for all ages, for all sexes, in Ontario and Canada (Sources: Public Health Ontario, Public Health Agency of Canada)

Period average	Ontario-All ages-all sexes Incidence Rate (cases /100,000 / year)	Canada-All ages-all sexes Incidence Rate (case/100,000 / year)
2005-2009	0.52	
2010-2014	1.44	1.12
2015-2018	4.38	

5. Exposure-Response Functions

This section describes the exposure response functions (ERFs) we used, making special effort to be as transparent as possible so that methods are replicable. A systematic review of epidemiological studies undertaken at the outset of the project informed the selection of key primary studies on which to base the ERFs and approaches described here.

5.1 Temperature stress

Evidence of an association between ambient temperature and mortality or morbidity outcomes has been documented in many studies.[23] As the systematic literature search conducted for this study showed, high and low temperatures have been investigated in relation to natural mortality, to certain specific causes of death (e.g., respiratory, cardiovascular diseases), and to other health outcomes, like hospitalization. Time-series studies of the effects of temperature on mortality have been conducted for many regions and cities globally—for example: see Anderson and Bell (2009) for the United States; Michelozzi et al. (2007), Analitis et al. (2008) and Baccini et al. (2008) for Europe; Martin, et al. (2012) for Canada; and Gasparrini et al. (2015), Guo et al. (2017) and Vicedo-Cabrera et al. (2018) for multi-country, multi-city studies. The association between temperature and mortality has often been shown as a non-linear J-, U- or V-shaped function, with the lowest mortality rates at moderate temperatures and rising as temperatures increase or decrease from the temperature at which minimum mortality occurs. Fewer studies have examined the effect of high and low temperatures on morbidity.[24] These studies similarly show non-linear relationships between temperature and morbidity outcomes.

In this study, we investigated the projected impact of climate change on mortality and hospitalizations attributable to heat exposures. When people are exposed to heat, they can suffer from well-described heat-related clinical syndromes such as heat cramps, heat syncope, heat exhaustion and heat stroke. Exposure to heat can elevate heart rate, increase blood pressure, viscosity and coagulability, and weaken regulation of core temperatures (Nawrot et al., 2005). The cause of death most easily attributable to heat is heat stroke, which has a relatively high case fatality ratio and a rapid onset (Kovats and Koppe, 2005). Other causes of death have been observed to increase following exposure to heat, with little doubt as to causality; in particular, deaths from cardiovascular and respiratory disease (Basu and Samet, 2002; Campbell-Lendrum et al., 2003; Anderson and Bell, 2009). As heat events increase with climate change, the risk of heat-related deaths and illness is also expected to increase (Zhang et al., 2019 and Sarofim et al., 2016).

Although there is robust evidence that hot weather is associated with short-term increases in mortality and morbidities, the extent to which observed excess mortality in winter months[3] is directly attributable to cold weather exposures remains unclear and is currently being debated in the literature (Astrom et al., 2013; Kinney et al., 2012; Ebi and Mills, 2013; Barnett et al., 2012; and Staddon et al., 2014). For instance, in a study of 26 U.S. and 3 French cities, Kinney et al. (2012) concluded that excess winter mortality is not largely driven by cold temperature, but rather is driven by other seasonal factors, such as influenza. Based on an extensive literature review considering the role of temperature in the etiology of specific cold-related health outcomes and in mortality patterns during winter months, Ebi and Mills (2013) concluded that the association between temperature and higher rates of mortality in the winter is relatively weak. Additionally,

[3] It is well documented that more deaths occur in the winter months (typically, the 3-4 coldest months of the year) than other seasons (see, for example, Analitis et al., 2008).

the impact of cold spells on mortality has been found to be negligible (Barnett et al., 2012); cold spells are also only a marginal contributor to excess winter deaths (Ebi and Mills, 2013). In light of the conclusions of this literature, we have omitted consideration of cold-related mortality and morbidity from this study. For similar reasons, PESETA II[25] and ClimateCost[26]–two other national-level studies of the economic costs of climate change for human health—likewise omitted cold-related mortality and morbidity from their analyses.

5.1.1 Mortality

To quantify mortality impacts attributable to high temperatures under projected climate change scenarios we used exposure-response function (ERF) coefficients obtained from Gasparrini et al. (2015), who estimated excess deaths attributable to either cold or heat for 384 locations globally, including for 21 Canadian cities.[4] Excess deaths were defined as deaths attributable to mean daily temperatures above (heat) or below (cold) the "optimum temperature" (i.e., the mean daily temperature between the 2.5th and 97.5th percentiles that corresponded to the minimum daily mortality rate). For Canada, Gasparrini et al. analyzed deaths (all-cause) between 1986 and 2009. The city-specific models included 21 days of lag to catch cumulative risk (including any mortality displacement effects) after the initial short-term exposure to high or low daily temperatures; splines of time were also included to account for seasonality. Fitting long distributed lags (e.g., 21 days) is common practice in studies of cold-related mortality (e.g., Analitis et al., 2008; Anderson and Bell, 2009; Martin et al., 2012; and Guo et al., 2012), as the lag between exposure to ambient temperature and mortality is typically 2-3 weeks. However, the lag for heat is much shorter—several days. Sensitivity tests performed by Gasparrini et al. show that the ERF for heat-related mortality actually increases by about 14% as the modelled lag is shortened from 21 days to 14 days. Heat-related ERFs for Canadian cities are only available for the "main model" estimated by Gasparrini et al., which includes a 21 day lag. Because of these limitations in the ERFs reported in the source study, use of the ERFs will lead us to underestimate heat-related mortality, all else being equal.

Some national-level economic studies of heat-related mortality incorporate acclimatization to projected temperatures to reflect physiological, behavioural and cultural changes that can take place over decades. For example, Dessai (2003), Kovats et al. (2011) and Daci (2014) assumed people would acclimatize to, respectively, +1.0°C, +0.5°C and +0.75°C of warming every 30 years. Due to the computational requirements of incorporating acclimatization into the ERFs of Gasparrini et al., we only include it as a sensitivity test for selected cities.

Estimates of the attributable mortality fractions due to heat exposures for all 21 Canadian cities, along with the average for Canada presented in Table 5-1. Taking Vancouver, for example, 0.31% of daily (all-cause) mortality was attributed to mean daily temperatures above the optimum temperature for the City of 16.7°C.

[4] Founded on the survey of epidemiology literature conducted for this study, we identified two approaches to model heat-related mortality; one based on the ERFs in Gasparrini et al. (2015) and the other based on ERFs derived from Martin et al. (2012). We opted not to use the latter primarily because it would not have allowed us to calculate baseline impacts and costs and consequently separate the influence of socioeconomic change from climate change on total risk (as per the analytical framework we adopted in Figure 5-1). The methods in Gasparrini et al. (2015) are also similar to those in Bai et al. (2016 and 2017), which we used as the basis for modelling heat-related hospitalizations. Furthermore, the required ERFs would have to be calculated from the results of Martin et al., introducing an additional layer of uncertainty into our analysis. Nonetheless, in a further section we present limited results for select cities using ERFs derived from Martin et al. as a sensitivity test.

Table 5-1: Attributable mortality fraction for heat- exposures above the minimum mortality temperature (Source: Gasparrini et al. (2015))

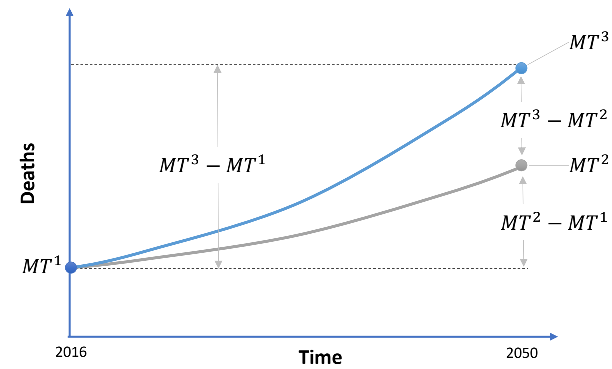
	Minimum mortality temperature (1986-2009) (degrees C)	**Minimum mortality percentile** (centile)	**Fraction of all-cause mortality attributable to HEAT** (%)
Abbotsford	16.4	79	0.21
Calgary	14.7	82	0.21
Edmonton	15.6	81	0.46
Halifax	16.4	80	0.43
Hamilton	18.2	79	0.52
Kingston	18.0	79	0.56
Kitchener-Waterloo	18.1	82	0.57
London	18.5	80	0.60
Montreal	18.9	81	0.68
Ottawa	18.3	80	0.62
Regina	16.6	82	0.49
Sudbury	16.7	81	0.59
Saint John (NB)	15.6	83	0.28
St. Johns (NFLD)	16.5	90	0.48
Saskatoon	16.1	82	0.53
Thunder Bay	15.4	82	0.57
Toronto	18.9	80	0.72
Victoria	15.7	82	0.18
Vancouver	16.7	82	0.31
Windor	20.2	78	0.55
Winnipeg	17.2	81	0.54
Canada	**17.6**	**81**	**0.54**

Note: the 95% confidence intervals for Canada are 0.39% to 0.66% for mortality attributable to heat. These values are used to generate lower and upper bound estimates of projected temperature-related mortality.

The analytical framework underpinning the calculation of excess mortality impacts adopted in our study is illustrated in Figure 5-1.

Figure 5-1: Analytical framework for calculating excess mortality impacts for 2050

Mortality	Climate: Baseline f_{2016}	Climate: Future f_{2050}
Base year MT_{2016}	MT^1	
Future MT_{2050}	MT^2	MT^3



$MT^1 =$ Excess heat-related mortality in base year under baseline climate scenario

$MT^2 =$ Excess heat-related mortality in future under baseline climate scenario

$MT^3 =$ Excess heat-related mortality in future under projected future climate scenario

$\Delta MT^{SC} = MT^2 - MT^1 =$ Excess deaths due to socioeconomic change (SC); no climate change

$\Delta MT^{TR} = MT^3 - MT^1 =$ Excess deaths due to socioeconomic and climate change (change in total risk, TR)

$\Delta MT^{CC} = MT^3 - MT^2 =$ Excess deaths due to climate change (CC)

Excess heat-related mortality is calculated for three separate scenarios (MT^1, MT^2 and MT^3) as shown in Figure 5-1 as follows (using *heat stress* and the period *2041-70* as an example):

$$MT^1_{d(j),T(h),2016} = Pop_{d(j),2016} \times \frac{1}{100{,}000} \times DM_{d(j),2016} \times AF_{d(j),T(h)} \times f^{T(h)}_{1970-00} \times 365$$

$$MT^2_{d(j),T(h),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} Pop_{d(j),t} \times \frac{1}{100{,}000} \times DM_{d(j),2016} \times AF_{d(j),T(h)} \times f^{T(h)}_{1970-00} \times 365 \right]$$

$$MT^3_{d(j),T(h),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} Pop_{d(j),t} \times \frac{1}{100{,}000} \times DM_{d(j),2016} \times AF_{d(j),T(h)} \times f^{T(h)}_{t} \times 365 \right]$$

Where MT is 30-year annual average projected excess heat-related mortality [number of deaths] under each scenario denoted by the super scripts 1, 2 and 3 (see Figure 5-1), Pop is the urban population in census division (d) in province or territory j, DM is the baseline daily all-cause mortality rate applicable to $d(j)$ [deaths per 100,000 population per day], AF is the relevant attributable fraction from Table 5-1 applied in $d(j)$ [% of daily deaths], T denotes the temperature bin with a projected daily mean temperature > the minimum mortality temperature h, f is the frequency (%) of total days in a year falling in daily mean temperature bin T, and t is the year [the base year for the socioeconomic data is a 3-year average centered on t = 2016]. The fraction (1/30) converts a thirty year total to an annual average. DM is derived from Statistics Canada Table 13-10-0708-01 (3-year average centered on 2016) and assumed not to change over time. The meteorological baseline (or climate norm) is the 30-year period 1971-2000. The average AF coefficients for Canada in Table 5-1 are applied to all census divisions, with no allowance made for the relative proportions of rural vis-à-vis urban populations in our central estimates. As a sensitivity test, however, we perform the analysis for urban populations only, based on provincial and territorial level data for 2016 provided by the Institute.[5]

With this approach, estimated deaths attributable to heat stress are also provided for each future year of interest for the scenarios MT^2 and MT^3. This is necessary to enable cost-benefit analysis of adaptation options and the calculation of cumulative (undiscounted) impacts (and costs) over time.

We also distinguish between displaced deaths and advanced (premature) deaths. Displaced deaths refer to deaths that occur during or immediately following exposure to the heat episode, which usually involve individuals near the end of their life who would likely have died soon irrespective of the exposure. As such, heat exposure is a contributing, but not the main, cause of death. Premature deaths, in contrast, refer to deaths in otherwise healthy individuals, who die prematurely because of exposure to the heat episode. **The average loss of life (in terms of remaining life expectancy) is different in both cases, which has implications for monetary valuation**. To account for the distinction between displaced and premature deaths, we modify the above equation as follows:

$$MT^{1,D}_{d(j),T(h),2016} = MT^{1}_{d(j),T(h),2016} \times DR$$
$$MT^{1,P}_{d(j),T(h),2016} = MT^{1}_{d(j),T(h),2016} \times (1 - DR)$$
$$MT^{1,A}_{d(j),T(h),2016} = MT^{1,D}_{d(j),T(h),2016} + MT^{1,P}_{d(j),T(h),2016}$$

And

$$MT^{2,D}_{d(j),T(h),2041-70} = MT^{2}_{d(j),T(h),2041-70} \times DR$$
$$MT^{2,P}_{d(j),T(h),2041-70} = MT^{2}_{d(j),T(h),2041-70} \times (1 - DR)$$
$$MT^{2,A}_{d(j),T(h),2041-70} = MT^{2,D}_{d(j),T(h),2041-70} + MT^{2,P}_{d(j),T(h),2041-70}$$

And

$$MT^{3,D}_{d(j),T(h),2041-70} = MT^{3}_{d(j),T(h),2041-70} \times DR$$
$$MT^{3,P}_{d(j),T(h),2041-70} = MT^{3}_{d(j),T(h),2041-70} \times (1 - DR)$$
$$MT^{3,A}_{d(j),T(h),2041-70} = MT^{3,D}_{d(j),T(h),2041-70} + MT^{3,P}_{d(j),T(h),2041-70}$$

[5] The estimated urban population of each province and territory in 2016 is: Alberta 83.6%; British Columbia 86.4%; Manitoba 73.2%; New Brunswick 49.0%; Newfoundland and Labrador 58.1%; Northwest Territories 64.1%; Nova Scotia 57.4%; Nunavut 49.0%; Ontario 86.2%; Prince Edward Island 45.1%; Quebec 80.5%; Saskatchewan 66.8%; and Yukon 60.6%.

Where DR is the displaced mortality ratio and superscripts A, D and P denote total, displaced and premature mortality, respectively. DR lies between 35%-75%.[27] We used the mid-point (55%) for our central estimates and assume the ratio does not change over time.

The above equation generates projections of the number of excess deaths. For the purpose of valuation, we also needed to generate estimates of projected life years lost. The above equations are thus further modified as follow:

$$YLL^{1,D}_{d(j),T(h),2016} = MT^{1,D}_{d(j),T(h),2016} \times Y^D$$
$$YLL^{1,P}_{d(j),T(h),2016} = MT^{1,P}_{d(j),T(h),2016} \times Y^P$$
$$YLL^{1,A}_{d(j),T(h),2016} = YLL^{1,D}_{d(j),T(h),2016} + YLL^{1,P}_{d(j),T(h),2016}$$

And

$$YLL^{2,D}_{d(j),T(h),2041-70} = MT^{2,D}_{d(j),T(h),2041-70} \times Y^D$$
$$YLL^{2,P}_{d(j),T(h),2041-70} = MT^{2,P}_{d(j),T(h),2041-70} \times Y^P$$
$$YLL^{2,A}_{d(j),T(h),2041-70} = YLL^{2,D}_{d(j),T(h),2041-70} + YLL^{2,P}_{d(j),T(h),2041-70}$$

And

$$YLL^{3,D}_{d(j),T(h),2041-70} = MT^{3,D}_{d(j),T(h),2041-70} \times Y^D$$
$$YLL^{3,P}_{d(j),T(h),2041-70} = MT^{3,P}_{d(j),T(h),2041-70} \times Y^P$$
$$YLL^{3,A}_{d(j),T(h),2041-70} = YLL^{3,D}_{d(j),T(h),2041-70} + YLL^{3,P}_{d(j),T(h),2041-70}$$

Where YLL is the years of life lost from displaced death (D), premature deaths (P), and total excess deaths (A). The loss of life for displaced deaths (Y^D) is assumed to equal 0.5 months (or 0.42 years).[28] For premature deaths (Y^P), the assumed loss of life is 3.5 years, which is the average loss of life years in Canada in 2010-12 for circulatory diseases [I00-I99], cerebrovascular diseases [I60-I69] and respiratory diseases (excluding infectious and parasitic diseases) [J00-J99]. Both Y^D and Y^P are assumed not to change over time.

Calculating life years lost in this manner allows us to employ three valuation scenarios for a future time period (t) (using scenario 2 for the period 2041-70 as an example):

Option:	Displaced mortality
1	$MT^{2,D}_{d(j),T(h),2041-70} \times VSL_{2041-70}$
2	$YLL^{2,D}_{d(j),T(h),2041-70} \times VSLY_{2041-70}$

3 $MT^{2,D}_{d(j),T(h),2041-70} \times HC_{2041-70}$

Where VSL is the value of a statistical life, $VSLY$ is the value of a statistical life year and HC is the value of human capital. The valuation steps are discussed in Section 6.

The final step in quantifying excess temperature-related deaths in physical terms is to calculate the incremental impact (deaths per year) of socioeconomic change (denoted by the superscript SC), climate change (denoted by the superscript CC), and both (denoted by the superscript TR for total risk), as follows (the period 2041-70 as an example):

For deaths:

$$\Delta MT^{SC}_{d(j),T(h),2041-70} = MT^{2,A}_{d(j),T(h),2041-70} - MT^{1,A}_{d(j),T(h),2016}$$
$$\Delta MT^{CC}_{d(j),T(h),2041-70} = MT^{3,A}_{d(j),T(h),2041-70} - MT^{2,A}_{d(j),T(h),2041-70}$$
$$\Delta MT^{TR}_{d(j),T(h),2041-70} = MT^{3,A}_{d(j),T(h),2041-70} - MT^{1,A}_{d(j),T(h),2016}$$

For years of life lost:

$$\Delta YLL^{SC}_{d(j),T(h),2041-70} = YLL^{2,A}_{d(j),T(h),2041-70} - YLL^{1,A}_{d(j),T(h),2016}$$
$$\Delta YLL^{CC}_{d(j),T(h),2041-70} = YLL^{3,A}_{d(j),T(h),2041-70} - YLL^{2,A}_{d(j),T(h),2041-70}$$
$$\Delta YLL^{TR}_{d(j),T(h),2041-70} = YLL^{3,A}_{d(j),T(h),2041-70} - YLL^{1,A}_{d(j),T(h),2016}$$

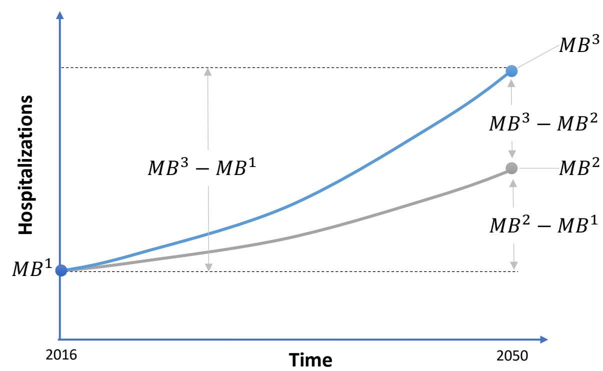
5.1.2 Morbidity impacts

Bai et al. (2016 and 2017) investigated the relationship between ambient air temperatures and hospitalizations for coronary heart disease, acute myocardial infarction, hemorrhagic stroke, ischaemic stroke, hypertensive diseases, diabetes, and arrhythmia in Ontario between 1996 and 2013. For each disease, a non-linear model was estimated to measure the cumulative effect of temperatures on hospitalizations over a 21 day lag period. The approach is like that used by Gasparrini et al. (2015). Excess hospitalizations were defined as admissions attributable to mean daily temperatures above (heat) or below (cold) the "optimum temperature" (i.e., the mean daily temperature between the 2.5th and 97.5th percentiles that corresponded to the minimum daily hospitalization rate). The total burden of hospitalizations attributable to heat was also allocated to "mild" and "extreme" temperatures; mild heat was defined as temperatures between the optimum temperature and the 2.5th (97.5th) percentile and extreme heat was defined as temperatures below the 2.5th (higher than the 97.5th) percentile. The most robust models were estimated for coronary heart disease, stroke, hypertensive diseases, and diabetes.

In this study, we investigated the impact of climate change on hospitalizations for these four diseases, using the results from Bai et al. (2016 and 2017), which are summarized in Table 5-2. The analytical framework underpinning the calculation of excess hospitalizations is illustrated in Figure 5-2.

Figure 5-2: Analytical framework for calculating excess morbidity (hospitalizations) impacts for 2050

Morbidities		Climate: Baseline f_{2016}	Climate: Future f_{2050}
	Base year MB_{2016}	MB^1	
	Future MB_{2050}	MB^2	MB^3



$MB^1 =$ Excess heat-related morbidities in base year under baseline climate scenario

$MB^2 =$ Excess heat-related morbidities in future under baseline climate scenario

$MB^3 =$ Excess heat-related morbidities in future under projected future climate scenario

$\Delta MB^{SC} = MB^2 - MB^1 =$ Excess hospitalizations due to socioeconomic change (SC); no climate change

$\Delta MB^{TR} = MB^3 - MB^1 =$ Excess hospitalizations due to socioeconomic and climate change (change in total risk, TR)

$\Delta MB^{CC} = MB^3 - MB^2 =$ Excess hospitalizations due to climate change (CC)

Excess heat-related hospitalizations are first calculated for three separate scenarios (MB^1, MB^2 and MB^3) as shown in Figure 5-2 as follows (using the period *2041-70* as an example):

$$MB^1_{k,d(j),T(h),2016} = Pop_{d(j),2016} \times \frac{1}{100{,}000} \times HP_{k,d(j),2016} \times AF_{k,d(j),T(h)} \times f^{T(h)}_{1970-00} \times 365$$

$$MB^2_{k,d(j),T(h),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} Pop_{d(j),t} \times \frac{1}{100{,}000} \times HP_{k,d(j),2016} \times AF_{k,d(j),T(h)} \times f^{T(h)}_{1970-00} \times 365 \right]$$

$$MB^3_{k,d(j),T(h),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} Pop_{d(j),t} \times \frac{1}{100{,}000} \times HP_{k,d(j),2016} \times AF_{k,d(j),T(h)} \times f^{T(h)}_{t} \times 365 \right]$$

Where MB is 30-year annual average projected excess heat-related hospitalizations [number] under each scenario denoted by the super scripts 1, 2, and 3 (see Figure 5-2) for disease k (coronary heart disease, stroke, hypertensive diseases, or diabetes), HP is the baseline daily hospitalization rate applicable to $d(j)$ [hospitalizations per 100,000 population per day], AF is the relevant attributable fraction from Table 5-2 applied in $d(j)$ [% of daily hospitalizations], T denotes the temperature bin with a projected daily mean temperature > the minimum morbidity temperature h. All other variables are as defined above. In the absence of other data, the daily hospitalization rates for Ontario shown in Table 5-2 were extrapolated to each province and territory.[6] The AF coefficients in Table 5-2 are applied nationally to all census divisions. No allowance was made for the relative proportions of rural vis-à-vis urban populations in our central estimates. In contrast to the heat-related mortality AF coefficients, which are almost exclusively representative of urban centres, the heat-related morbidity AF coefficients derived by Bai et al. (2016 and 2017) are representative of both rural and urban populations across Ontario.

With this approach, estimated hospitalizations attributable to temperature stress are also provided for each future year of interest for the scenarios MB^2 and MB^3. As noted above, this is necessary to enable cost-benefit analysis of adaptation options and the calculation of cumulative (undiscounted) impacts (and costs) over time.

The incremental impact (hospitalizations, on average, per year) of socioeconomic change (denoted by the superscript SC), climate change (denoted by the superscript CC), and both (denoted by the superscript TR for total risk), are calculated as follows (using the period 2041-70 as an example):

$$\Delta MB^{SC}_{k,d(j),T(h),2041-70} = MB^{2,A}_{k,d(j),T(h),2041-70} - MB^{1,A}_{k,d(j),T(h),2016}$$
$$\Delta MB^{CC}_{k,d(j),T(h),2041-70} = MB^{3,A}_{k,d(j),T(h),2041-70} - MB^{2,A}_{k,d(j),T(h),2041-70}$$
$$\Delta MB^{TR}_{k,d(j),T(h),2041-70} = MB^{3,A}_{k,d(j),T(h),2041-70} - MB^{1,A}_{k,d(j),T(h),2016}$$

With reference to Table 5-2, the above described calculations are performed for “total heat” effects only, and not individually for moderate and extreme heat. Separate projections of excess hospitalizations are generated for each disease (k) since their respective costs are different.

[6] Within the timeframe available for this study is was not possible to obtain daily hospitalization data for each health authority in Canada from the Canadian Institute for Health Information.

Table 5-2: Minimum morbidity temperatures, attributable fractions, and attributable numbers for heat effects on hospitalizations for four diseases in Ontario, 1996-2013 (Sources: Bai et al. (2016 and 2017))

	Coronary heart disease			Stroke			Diabetes			Hypertension diseases		
ICD-10 Codes	I20-I25			I60-I68			E10-E14			I10-I13, I15		
Baseline hospitalizations, 1996-2013	1,389,057			355,837			324,034			50,798		
Average annual hospitalization rate (per 100,000), 1996-2013	1.81			0.46			0.42			0.07		
Minimum morbidity temperature & percentile												
Mean daily temperature, degrees C	18.0			16.6			-6.4			18.6		
Mean daily temperature, percentile	79			74			11			81		
HEAT: attributable fraction (%)												
Mild heat (median, 95% CI)	1.04	0.07	1.86	1.63	-0.06	3.09	10.55	7.05	13.36	1.12	-1.03	2.79
Extreme heat (median, 95% CI)	0.16	0.09	0.22	0.19	0.11	0.26	0.57	0.36	0.70	0.31	0.13	0.44
Total heat (median, 95% CI)	1.20	0.22	2.13	1.82	0.06	3.20	11.12	7.47	14.20	1.43	-1.01	3.20
HEAT: attributable number (hospitalizations)												
Mild heat (median, 95% CI)	14,472	929	25,823	5,795	-204	10,986	34,200	22,840	43,290	569	-524	1,417
Extreme heat (median, 95% CI)	2,176	1,216	3,093	680	401	921	1,860	1,164	2,271	158	65	226
Total heat (median, 95% CI)	16,628	3,040	29,559	6,469	223	11,378	36,045	24,209	46,024	726	-514	1,625
Temperature definitions (mean daily)												
Extreme heat (degrees C)	temp > 24.8			temp > 24.8			temp > 24.8			temp > 24.8		
Mild heat (degrees C)	24.8 ≥ temp > 18.0			24.8 ≥ temp > 16.6			24.8 ≥ temp > -6.4			24.8 ≥ temp > 18.6		
Total heat (degrees C)	temp > 18.0			temp > 16.6			temp > -6.4			temp > 18.6		

Note: Projections of heat-related morbidities in this study are based on the “total heat” attributable fractions.

5.2 Air Quality (Ground-Level Ozone)

Air pollution has long been recognized as a health threat to Canadians[29] and is a leading cause of premature death globally.[30] Particulate matter, ozone, and nitrous oxide are of particular concern. Short-term and long-term exposure to these pollutants causes premature deaths from heart disease, stroke and lung cancer, as well as increased hospital admissions due to aggravated asthma among other effects. Despite marked improvements in air quality across Canada since the 1970s and relatively low levels of air contaminants (see Box 1), air pollution is still responsible for tens of thousands of premature deaths (14,600), millions of asthma and acute respiratory symptom days, among other impacts of illness, and costs Canada $114 billion per year (2015$).[31] Children, the elderly, individuals sensitive to respiratory irritants, and those active outdoors are most sensitive to succumb to adverse effects of air quality episodes.[32]

In assessing the costs of climate change impacts from health, the Institute identified impacts from ground-level ozone ("smog") as a priority.[7] This pollutant is a colourless and odorless gas, and is a bi-product of the chemical interaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight.[33] Ozone's formation and transport depends on prevailing weather conditions and concentrations of precursor emissions. Numerous studies have documented a strong positive correlation between ozone concentration and changes in temperature[34] (also see Figure 5-3), with four environmental factors influencing this relationship[35]: emissions controls[36], the rural / urban divide[37], difference in weekend / weekday conditions[38] and the extent of organic nitrate recycling.[39]

Box 1: Ozone pollution and Canadians air quality standards

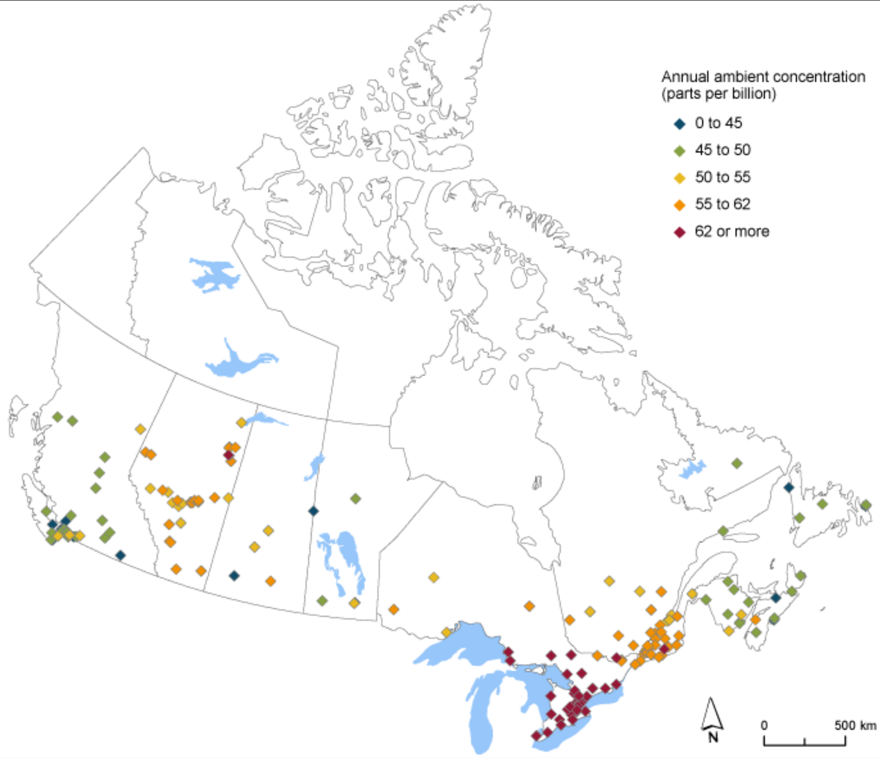
The Canadian Council of Ministers of the Environment (CCME) developed Canadian Ambient Air Quality Standards (CAAQS), including for ozone (O_3), to support air quality management across the country. Multi-stakeholder consultations guide the review of these standards every five years to ensure they are sufficient to meet environmental and human health objectives. The CAAQS for ozone (shown below) are currently under review.

Pollutant	Averaging time	2015	2020	2025	Statistical form
Ozone (O_3)	8-hour	63 ppb	62 ppb	60 ppb	The 3-year average of the annual 4th highest of the daily maximum 8-hour average ozone concentrations

Source: http://airquality-qualitedelair.ccme.ca/en/

The National Air Pollution Surveillance program measures concentrations of ground-level ozone and other air pollutants at stations across the country and published for public outreach through the Canadian Environmental Sustainability Indicators initiative. The map below shows the values for "annual 4th-highest of the daily maximum 8-hour average concentrations of ozone in parts per billion" at monitoring stations across Canada. The highest concentrations of peak ozone in Canada occur in southern Ontario.

[7] This decision was largely based on the science basis linking ground level ozone concentrations to temperature and availability of a straightforward method to simulate the health impact and economic consequences of climate change on ozone concentrations.



Source: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/air-quality.html#O3-peak

Air quality modelling studies integrating climate change projections suggest that warmer temperatures under climate change may worsen ozone air pollution. Canadian studies are few[40] but U.S. studies show the potential for future temperatures to increase future concentrations of ground-level ozone.[41] They also suggest that both natural and anthropogenic sources of ozone-precursor emissions could increase with temperature.[42] Although these studies point to temperature as the main meteorological driver of ozone concentrations, local conditions such as those driving the long-range transport of ozone precursor emissions also influence ozone concentrations and their spatial distribution.[43]

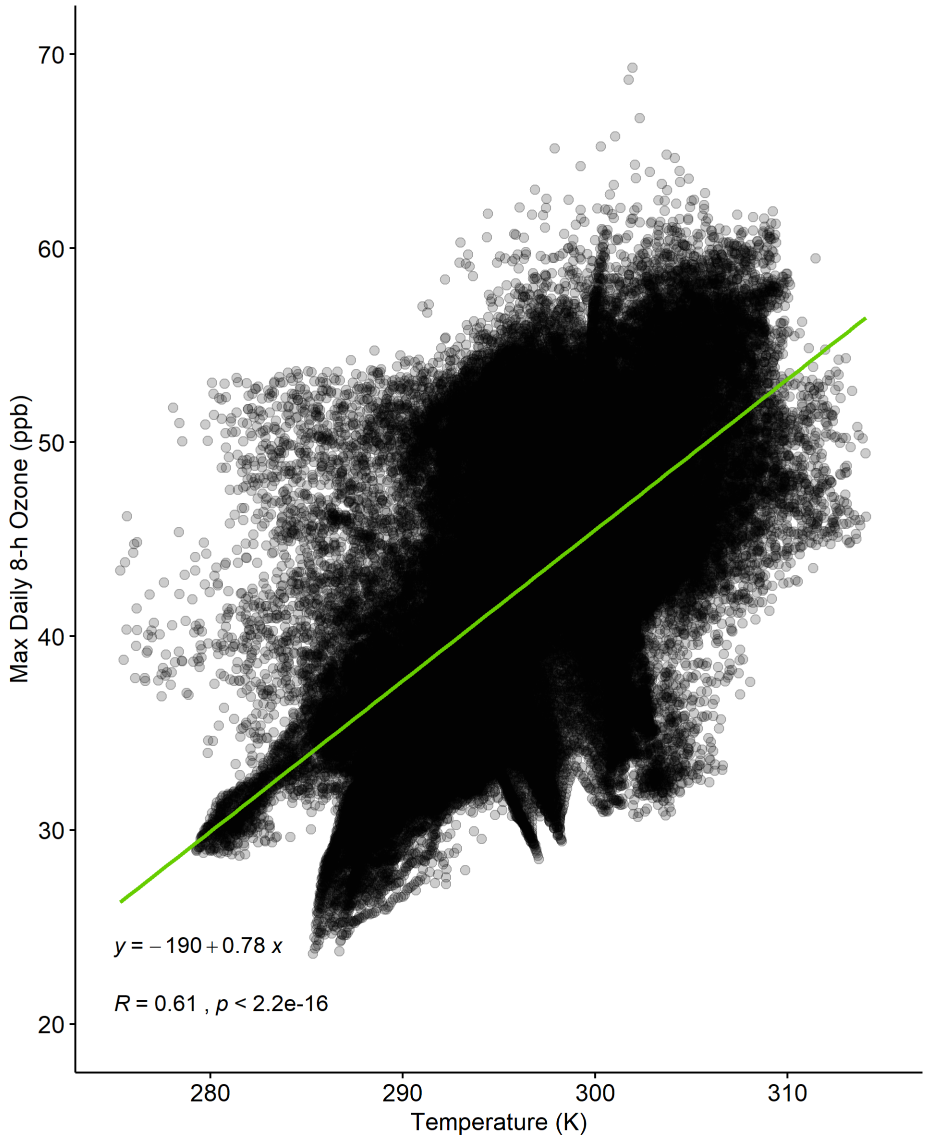


Figure 5-3: Correlation between temperature and ozone concentrations in the United States. Data from EPA (2017) were provided to ESSA Technologies Ltd. (CG Nolte, personal communication, 2020). The data consist of records of gridded maximum daily 8-h ozone levels, and daily maximum temperature, averaged over 1 May through 30 September for each modeled year (1995-2005 and 2025-2035).

Canadian epidemiological studies assessing the health impacts of weather and climate-influenced air pollution are limited. One Quebec-based study examined the relationship between ozone exposure, including the effect of meteorological parameters, and respiratory system diseases between 2003 and 2010; it did not find any significant associations.[44] Two linked studies examined historical and projected levels of air pollution combined with climate using a synoptic weather-typing approach for four cities: Montreal, Toronto, Ottawa, and Windsor.[45] Analyzing data from 1954 to 2000, the first study found elevated mortality counts attributable to extreme temperatures plus acute air pollution exposure for the four cities. The second study incorporated these estimates into projections of percent changes in heat-related and air pollution-related mortality in 2050s and 2080s relative to 1954-2000. Air pollution-related mortality increased in Montreal and Toronto by 15 to 55%, largely driven by ozone-related mortality.[46]

Studies exploring the costs of health impacts from climate-change induced ozone air pollution are scarce. Internationally, only the U.S. has integrated air pollution as part of their national climate costing studies.[47]

The National Round Table on the Environment and Economy (NRTEE) included ozone air pollution in "Paying the Price", with results based on a study commissioned to Marbek.[48] This study covered temperature-related mortality and morbidity due to ozone air pollution in Toronto, Montreal, Calgary, and Vancouver in 2020s, 2050s and 2080s. The cumulative present value of these health impacts (2008$, 3% discount rate) from 2010-2100 totaled $162 million under combined high emissions and high population / GDP growth scenarios.

5.2.1 Approach

Our approach follows that of Marbek (2011). We use the Health Canada Air Quality Benefits Assessment Tool (AQBAT) version 3 to estimate the mortality and morbidity impacts associated with changes in ozone concentration for various climate scenarios. AQBAT is an Excel-based *"computer simulation application designed to estimate the human health and welfare benefits or damages associated with changes in Canada's ambient air quality."*[49]

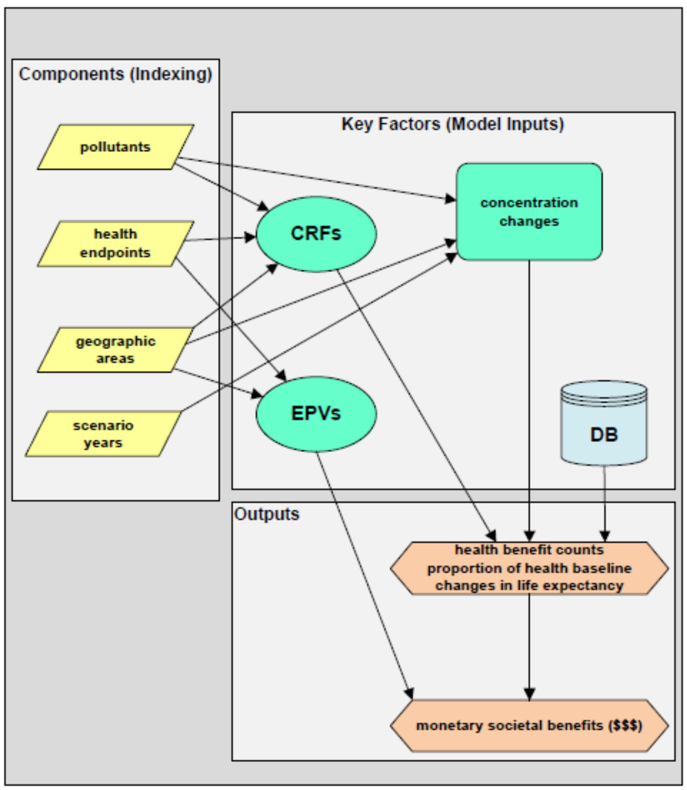


Figure 5-4: Conceptual diagram of the AQBAT simulation model. Model inputs, including CRFs (concentration response functions) and EPVs (endpoint valuations) are linked to four key components (pollutants, health endpoints or outcomes, spatial and temporal coverage) to generate physical counts and monetary values (Source: Judek et al. 2019)

Ozone is one of the air pollutants modelled by AQBAT; the model has the capability of quantifying the health and monetary impact of a change in pollutant concentration from baseline levels. It relies on Health Canada-endorsed Concentration Response Functions and monetary values (i.e., Endpoint Valuation in Figure 5-4) from published literature. AQBAT allows users to specify the pollutant, health outcomes, geographic disaggregation (including Census Divisions), population, and scenario years.

We used AQBAT to simulate the impact of climate change by comparing baseline rates of incidence of morbidity and mortality due to ozone air pollution to incidence rates as a result of temperature-related changes in ozone concentrations. AQBAT allows users to select how the input reduction value is to be interpreted, including a relative concentration change (e.g., an input value of 10% results in a concentration of 45 parts per billion or ppb O_3, which is 90% of the reference concentration of 50 ppb O_3). Therefore, our climate data needs included daily maximum annual and seasonal temperatures (averaged over May-September) corresponding to the range of eras modeled and for each of the Census Divisions across Canada. As well, we required a simple, yet credible relationship of changes in ozone concentrations per degree ˚C change in temperature. We discuss this below. AQBAT is capable of generating welfare impacts of changes in deaths and illness from ozone air pollution so we used the economic values embedded in the model, adjusted for consistency with the study as a whole.

Analytical framework

The analytical framework underpinning the calculation of excess mortality and morbidity impacts from climate change-induced ozone air pollution is illustrated in Figure 5-5.

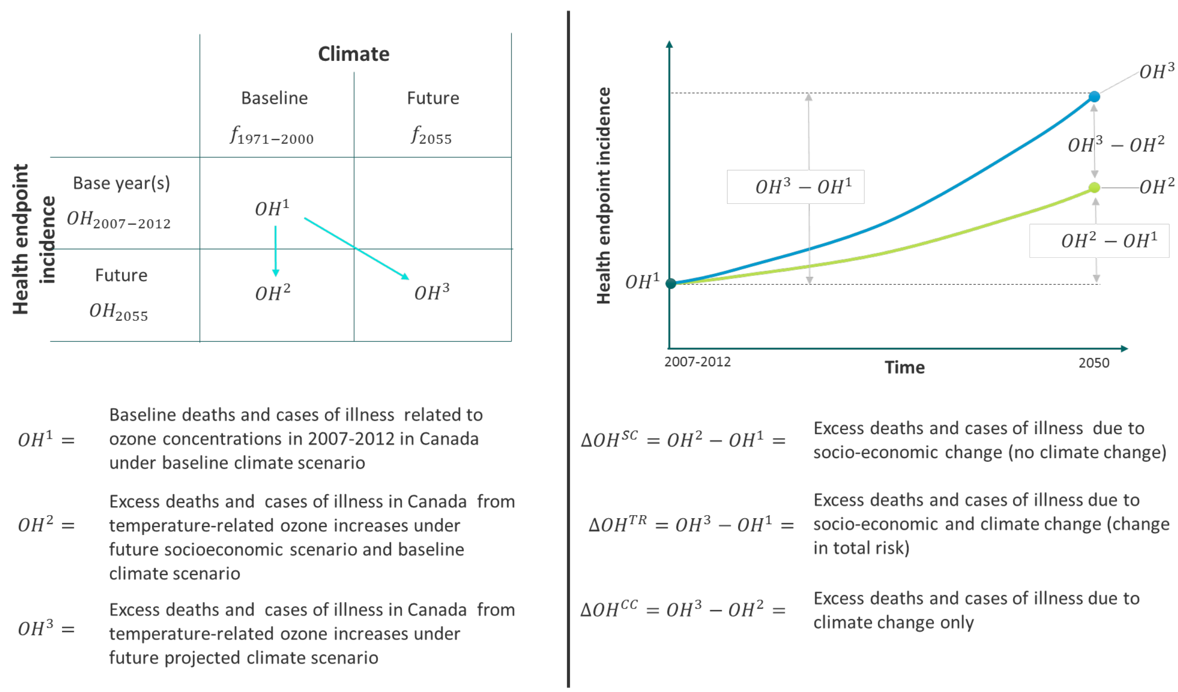


Figure 5-5: Analytical framework for calculating excess deaths and cases of illness due to ozone air pollution for 2050 (OH = health impacts from ozone air pollution; health endpoint base years reflect data on baseline occurrence rates embedded in AQBAT version 3)

Health endpoints

A range of health endpoints (related to acute or chronic exposure), their associated concentration response functions (CRFs) and the population groups to which they apply are pre-defined in AQBAT, with values endorsed by Health Canada. The health endpoints related to ozone included in AQBAT appear in Table 5-3. We included a subset of these in this study (in boldface in Table 5-3), considering the potential for overlap among certain health endpoints (e.g., Minor Restricted Activity Days and Acute Respiratory Symptom Days). AQBAT allows users to specify threshold concentrations for certain endpoints (i.e., effects differ at different levels of exposure to pollutant concentrations). Our analysis does not assume threshold effects, which is an assumption also adopted by Health Canada in their studies on the health impacts of air pollution in Canada. Detailed information on each CRF and the underlying studies and data sources to derive them appears in the AQBAT User Guide.[50]

Table 5-3: Health endpoints related to ozone embedded in AQBAT version 3 (Source: Judek et al. 2019). Those used in this study are in **boldface.**

Health endpoint	Applicable population	Comments on netting [b]
1. *Acute Exposure Mortality [a]	100% of the total population (all ages)	
2. Chronic Exposure Respiratory Mortality (May-Sept)	100% of the population 30 and over	
3. *Acute Respiratory Symptom Days (May-Sept)	100% of all adults (20 and over) and 85.7% (non-asthmatic) of children aged 5 to 19	
4. *Asthma Symptom Days (May-Sept)	14.3% (asthmatic) of children aged 5 to 19	
5. *Minor Restricted Activity Days (May- Sept) [b]	100% of all adults (20 and over) and 85.7% (non-asthmatic) of children aged 5 to 19)	Netted with endpoint #3
6. *Respiratory Emergency Room Visits (May-Sept)	100% of the total population (all ages)	
7. Respiratory Hospital Admissions (May-Sept) [b]	100% of the total population (all ages)	Netted with endpoint #6

a The CRF between acute exposure mortality and gaseous pollutants is from a multi-pollutant model so it may not precisely reflect the true attribution of risk to ozone (Health Canada, 2019). b To avoid overestimation of endpoints that are distinct but overlapping, AQBAT applies a netting process prior to economic valuation (see pg 48 in Judek et al., 2019). * Denotes that these health endpoints were monetized in the study by Marbek (2011).

Health baseline

The baseline scenario to generate counts of health endpoints per Census Division relies on values and time series embedded in AQBAT. Available historical population data may not coincide with the last year of available ozone concentration data. As well there are inconsistencies among provinces and territories in the years for which baseline mortality and hospital admission count data are available (to estimate baseline incidence rates) (see pg. 154 in the AQBAT version 3.0 User Guide).

For *mortality* the following three baseline year sets are used in AQBAT:

- Years 2010-2012 for NL, PE, NS, NB, MB, SK, BC and YT,
- Years 2009, 2010, 2012 for ON and Northwest Territories,
- Years 2008, 2009, 2012 for AB
- Years 2007-2009 for Nunavut
- Years 2008, 2009 and 2012 for QC

For *hospital admissions* (morbidity or cases of illness), the model uses 2010-2012 as basis years for all non-Quebec CDs, and 2008-2010 for Quebec CDs.

Therefore, provinces / territories will have a range of three-year basis years.

Base occurrence rates (of mortality of morbidity) in AQBAT vary over time to reflect changes in both mortalities/morbidities and age structure. In most cases, the future base occurrence rates increase over time, as an aging population has higher mortalities and morbidities. This effect offsets any decrease in overall rates over time due to an expected longer life span.

We extended the AQBAT time-series of base occurrence rates to 2100 using a combination of linear equations and standard means. First, we tried to fit a linear equation to the last 25 years of the time series for each population projection and census division. We then checked the resulting p-values to see if there was support for a linear model. We extended the time series using a linear equation if the p-value was less than 0.05 and using the mean of the last 25 years if the p-value was above this threshold.

To apply baseline values in our analysis we had to isolate excess mortality (or morbidity) for ozone levels above background ambient levels. Health Canada (2019) uses 26 ppb (annual) and 28 ppb (May-September) for O_3 as background ambient levels, which are the numbers we have adopted in our analysis.

For example, for the 2016 baseline, the Canada-wide population is 34,342,780, and the baseline occurrence rate for Acute Exposure Mortality to ozone is 6,730 events annually per one million people. This yields a baseline of 231,127. To calculate the portion of mortality attributable to increased air pollution we have to find the ozone increase due to anthropogenic sources. Health Canada (2019) uses 39 ppb O_3 as the ambient level Canada-wide, so the anthropogenic contribution to O_3 is 13 ppb (39 minus 26 ppb). That yields excess mortality of 1.1%, which amounts to 2,535. For the 2050 baseline, we have a Canada-wide population of 45,720,970 (a 33% increase), and the baseline occurrence rate for Acute Exposure Mortality from ozone is 10,400 (a 55% increase) events annually per one million people. This yields a baseline of 5,230. The increase due to socioeconomic factors is 2,695.

Future population

To ensure consistency across the study, instead of using future population estimates embedded in AQBAT we used the projections provided by the Institute. We also calculated the future affected populations for health endpoints that do not apply to the entire population (Chronic Exposure Respiratory Mortality, Acute Respiratory Symptom Days, Acute Respiratory Symptom Days, and Asthma Symptom Days). The future affected population is calculated assuming that the proportion of the total population is the same as the 2016 proportion specified in AQBAT. Changes in the age structure over time are accounted for internally in AQBAT by using changed base occurrence rates.

Climate data needs

For the health outcomes of interest, AQBAT looks at daily Maximum 1-Hour O_3 concentrations in ppb volume averaged over the period of interest. The period of interest is year-round for Acute Exposure Mortality and 1 May through 30 September for all other health endpoints. To simulate changes in O_3 concentrations due to climate change as a "shock" to AQBAT, we will **use daily maximum temperature data, averaged over the period of interest, and over each modeled epoch** (2041-2070 and 2071-2100).

To simulate future ozone concentrations, we used correlations between temperature (^oC) and ozone concentration (parts per billion by volume, ppbv) found in the literature. Table 5-4 summarizes the values we compiled.

Values for daily maximum 1-Hour O_3 found in the literature were as follows. Taking the average of the values from geographic locations of most relevance to Canada and in metrics needed to introduce into AQBAT (shaded in beige in Table 5-4) we proposed to use a relationship of **2.9 ppb(v) in 1-hr ozone concentrations per ˚C increase in summertime temperatures (defined as May to September). To undertake sensitivity analysis we used the following relationships:**

- 0.12 ppb(v) in 1-hr ozone concentrations per ˚C increase in summertime temperatures (Avise et al. 2012)
- 6.512 ppb(v) in 1-hr ozone concentrations per ˚C increase in summertime temperatures (Rasmussen et al. 2012)

Table 5-4: Correlations between ambient temperature and ozone concentrations found in the literature

m_{O_3-T} (adjusted)[a]	m_{O_3-T}	In-Text Citation	Reference	Geography	Metric (Ozone)	Metric (Temperature)	Time Period
	2.1 ppb(v) K^{-1}	Figure 3	(Bloomer et al. 2009)	Great Lakes	Average Hourly $[O_3]$ (May to September)	Average Hourly T (C)	May – September
	2.4 ppb(v) K^{-1}	Figure 3	(Bloomer et al. 2009)	Northeastern USA	Average Hourly $[O_3]$ (May to September)	Average Hourly T (C)	May – September
	14% Increase (0.14 ppb K^{-1})	Moreover, an emission and climate change study focusing on London, England has estimated that a 1ºC rise in summer air temperature is associated with a 14% increase in surface ozone concentration (Lee, 1993).	(Leung 2015)	London England			
	2.049 ppb K^{-1}	Figure 3 “Climate and ozone concentrations for June, July, and August in the 2050s were simulated with the linked models. Projected future ozone concentrations were compared to those of the 1990s, holding constant all other human contributions to ozone pollution. Average summertime temperatures for the eastern US were projected to rise by 1.6 to 3.2 °C for these 50 cities from the 1990s to the 2050s.” page 64	(Bell et al. 2007)	50 Eastern USA Cities (See Fig. 1)	Daily Average $[O_3]$	Average Summertime Temperature (JJA)	June – August
	2.940 ppb K^{-1}				Avg Max 1hr Avg $[O_3]$		
3.09 ppb K^{-1}	2.969 ppb K^{-1}				Avg Max 8hr Avg $[O_3]$		
0.121 ppb K^{-1}	0.34 ppb K^{-1}	“The simulation- and domain- averaged daily maximum 8h average ozone concentration increased linearly by 0.34 ppbK^{-1}.”	(Dawson et al. 2007) p 1499	The modeling domain was the eastern half of the US	Avg Max 8hr Avg $[O_3]$	Simulated ΔT across model.	
	4.7 ppb K^{-1}	“Additionally, the peak hourly concentration at any point in the domain for the entire simulation increased by an average of 4.7 ppb K^{-1}	(Dawson et al. 2007) p 1499	The modeling domain was the eastern half of the US	Peak Hourly $[O_3]$	Simulated ΔT across model.	
	3.2–3.5 ppb K^{-1}	“Peak ozone concentrations at 460 Easting and 3805 Northing increased by 7 ppb and 16 ppb for the +2 K and +5 K perturbation scenarios respectively.”	(Aw and Kleeman 2003)	Los Angeles, USA	Peak Hourly $[O_3]$	Hourly Average T	One Day
	2.8 ppb K^{-1}	“For instance, temperature changes peak ozone by 10.1 ppb/◦C and the ozone concentrations in Milan by 2.8 ppb/◦C.” In Milan a slope of 2.8 ppb/◦C is found. The strongest gradient is found in the ozone plume with 10.1 ppb/◦C.	(Bärtsch-Ritter et al. 2004)	Milan, Italy	Hourly $[O_3]$	Hourly Average T	One Day
	10.1 ppb K-1		(Bärtsch-Ritter et al. 2004)	Ozone Plume over Milan, Italy	Hourly $[O_3]$	Hourly Average T	One Day
	6 ppb K^{-1}	In summary, the ozone concentrations in Verzago in the late afternoon typically increase by about 6 ppb ozone per 1°C daily maximum temperature.	(Neftel et al. 2002)	Milan Basin (Verzago)	[O3] at 17:30 (pm)	Daily Maximum Temperature	Summer
3.125-6.512 ppb K^{-1}	3-6 ppb K^{-1}	We first produce a monthly climatology for each site over all available years, defined as the slope of the best-fit line (mO3-T) between monthly average values of maximum daily 8-hour average (MDA8) O3 and monthly average values of daily maximum surface temperature (Tmax). Applying two distinct statistical approaches to aggregate the site- specific	(Rasmussen et al. 2012)	Northeast USA	maximum daily 8-hour average O3	monthly average values of daily maximum surface temperature	Summer
3.125-4.254 ppb K^{-1}	3-4 ppb K^{-1}		(Rasmussen et al. 2012)	Great Lakes, USA	maximum daily 8-hour average O3	monthly average values of daily	Summer

m_{O_3-T} (adjusted)[a]	m_{O_3-T}	In-Text Citation	Reference	Geography	Metric (Ozone)	Metric (Temperature)	Time Period
		measurements to the regional scale, we find that summer time mO3-T is 3-6 ppb K^{-1} (r¼ 0.5 e0.8) over the Northeast, 3-4 ppb K^{-1} (r¼ 0.5e0.9) over the Great Lakes, and 3-6 ppb K^{-1} over the Mid-Atlantic.				maximum surface temperature	
2.312; 3.734; 2.605; 2.662; 1.679 ppb K^{-1}	2.28; 3.54; 2.54; 2.59; 1.72 ppb K^{-1}	See Table 4	(Brown-Steiner et al. 2015)	Northeastern USA	fourth highest Daily-Maximum 8-Hour [O3]	Daily Maximum Temperature	JJA
	2.47 ppb K^{-1}		(Steiner et al. 2010)	Various locations, California, USA	daily 1 hour maximum [O3]	Tmax from	June 1 Oct 31
	0.12–2.65 ppb K^{-1}	Figure 5	(Avise et al. 2012)	Various locations across lower 48 states	daily 1 hour maximum O3	Daily maximum temperature	June-August
1.25 ppb K^{-1}	1.34 ppb K^{-1}		(Zhao et al. 2013)	United States and Canada	daily maximum 8 h average 03	Unclear?	July – September
	2.4 ppb K^{-1}	Table 2	(Sillman and Samson 1995)	Rural	Peak O3	Daily Maximum Temperature	Apr 1 – September 30 Empirical
	5.4 ppb K^{-1}			Urban			
	0.5 – 9 ppb K^{-1}		(Pusede et al. 2015)	Aggregate Results	Aggregate Results	Aggregate Results	Aggregate Results
0.618 ppb K^{-1}	0.78 ppb K^{-1}		(EPA 2017)	USA	average maximum daily 8-hour	Daily Maximum Temperature	1 May through 30 September
3. 915 ppb K^{-1}	~0 - ~3.7 ppb K^{-1}	Fig 10 / 11	(Otero et al. 2018)	Continental Europe	maximum daily 8 h mean ozone	Daily Maximum Temperature	JAS

[a] This column includes values adjusted from Maximum Daily 8h Average Ozone (MDA8) to Maximum Daily 1h Average Ozone (MDA1), using the formula presented in EPA (1999) (and, solving for MDA8):

$$MDA8 = 0.8857(MDA1) + 0.2325$$

$$MDA1 = \frac{MDA8 - 0.2325}{0.8857}$$

($R^2 = 0.9548$)

5.3 Lyme Disease

5.3.1 Impacts of Lyme disease

Lyme disease is a public health concern in Canada.[51] It is the most commonly-reported vector-borne disease in North America[52]; with surveillance in Canada pointing to the expansion of populations of black-legged ticks (*I. scapularis*) into eastern and central Canada.[53] Reported cases of Lyme disease in Canada date back to the early 2000s.[54] Official, nation-wide tracking and management of the disease through the public health system began in 2009.[55] Between 2009 and 2015 the number of Canadian municipalities registering Lyme disease cases increased more than five-fold and the number of Lyme disease cases in Canada increased six-fold.[56] Over this period the national incidence rate of Lyme disease went from 0.4 to 2.6 cases per 100,000 population.[57] Incidence of the disease was slightly higher among male Canadians (56% of cases versus 44%) and among adults aged 45–74 years and children aged 5–9 years. Incidence of Lyme disease is highest in Ontario, Quebec, and Nova Scotia. In western Canada, incidence rates are very low in comparison. This is because the tick species endemic to those areas do not carry the *B. burgdorferi* bacterium or are less capable carriers. In the case of British Columbia, bacterial infection of western black-legged ticks is far lower than in black-legged ticks found in central and eastern Canada (*I. scapularis*).

Lyme disease is climate-sensitive and a warming climate is one driver of the spread of *I. scapularis* and the *B. burgdorferi* bacterium into Central and Eastern Canada from northeastern United States.[58] For example, climate influences the survival of tick populations, as well as ticks' rates of growth and reproduction[59], with temperature (accumulated degree days > 0˚C) as one key indicator of whether habitats are suitable for tick populations to become established.[60] Temperatures required for black-legged tick populations to survive are 2,800 to 3,100 cumulative annual degree days >0˚C. .[61]

However, exposure of humans to disease-carrying ticks is a function of several factors and, therefore, predicting future Lyme disease risk is complex. A range of factors shape i) human or host exposure to infected ticks and ii) the risk of humans contracting Lyme disease or ticks becoming infected by *B. burgdorferi*.[62] Table 5-5 summarizes risk factors documented across 545 public health studies from Canadian and international sources.

Table 5-5: Examples of risk factors related to Lyme disease summarized from a systematic literature review with a global scope (Source: Greig et al. 2018).

Risk factor category	Human (n=262 studies)	Vertebrate hosts (n=202 studies)	Arthropod vector (ticks) (n=297 studies)
1. Demographic factors			
Age of cases / life stage	111	66	14
Gender	99	46	7
Other	28[a]	44[b]	
2. Human behaviours			
Occupational risk	108		
Outdoor recreation	65		
Pet ownership	54		
History / number of tick bites	34		
Gardening or yard work	18		
Walking or jogging in woods	16		
Clearing brush in yard during spring and summer	10		
Other	37[c]		
3. Geography			

Risk factor category	Human (n=262 studies)	Vertebrate hosts (n=202 studies)	Arthropod vector (ticks) (n=297 studies)
Region	83	98	102
Urban, suburban or rural setting	33	15	18
Living in a single family home with yard	14		
4.Month of the year	60	97	99
5. Climate			
Temperature	22	28	64
Precipitation	14	26	35
Relative humidity	5	4	26
Other	5 [d]	6 [e]	9 [f]
6. Landscape features			
Woodland type	28	34	94
Elevation / slope of land	11	22	50
Deer on properties	15	4	10
Other	39 [g]	31 [h]	75 [i]

[a] Includes household income, race, education and duration of residency

[b] Includes specificity for a Borellia sp., species, body size and breed

[c] Includes travel history to tick-endemic areas, contact with animals, co-morbidities/infections, blood transfusions and engagement in at-risk behaviors for tick bites

[d] Includes type of climate, air pressure and wind speed, monthly soil moisture and growing days

[e] Includes growing days and snow depth

[f] Includes saturation deficit, snow cover, Mediterranean climate, wind conditions, solar insolation, North Atlantic Oscillation indices, light intensity, cool moist winters and warm dry summers

[g] Includes forest cover, proximity to woods, vegetation type, patch size, weeds in yard, vegetable garden, fencing, presence of lizards, beaches or dunes

[h] Includes vegetation type, soil characteristics, maturity of trees, land use, impact of sudden oak death, vegetation index, presence of lizards and patch size

[i] Includes habitat type, forest fragmentation, vegetation index, maturity of trees, land use, patch size, soil characteristics, proximity to forest, impact of sudden oak death, downed wood, beaches or dunes, forestry, density of trees, plant biomass, property size

As climate change intensifies, scientists expect the incidence of Lyme disease to increase, with the continued range expansion and establishment of black-legged tick populations and extended seasons of disease transmission.[63] Climate-driven changes in the infection of mobile hosts can also increase the risk of disease spread.[64] At a local level, however, the geographic spread of disease-carrying black-legged ticks may be uneven, in response to environmental drivers beyond temperature and lags between tick establishment and prevalence of *B. burgdorferi* infection.[65]

Several quantitative modelling studies have examined the possible range expansion of *I. scapularis* and *B. burgdorferi* in Canada, some including the effect of climate change. Leighton et al. (2012) projected a tick range expansion of around 46 km / year. At this rate of tick establishment, the proportion of eastern Canadians exposed to black-legged ticks would increase from 18% in 2010 to over 80% by 2020. In a local study focused on southeast Quebec, Simon et al. (2014) projected a northward expansion of the *B. burgdorferi* bacterium at a rate of 3.5 to 11 km per year (or 250 to 500 km by 2050). Ogden et al. (2005) developed a mechanistic *I. scapularis* population model to simulate seasonal and spatial dynamics of this tick. Modelling capabilities were subsequently expanded to predict the "basic reproduction number" or R_0 – a measure of transmissions potential of a disease that describes the propensity of a pathogen to survive and be propagated – of *I. scapularis* (Wu et al. 2013). Ogden et al. (2014) and McPherson et al. (2017) took this research further by evaluating the effect of future climate change on R_0 values of *I. scapularis*, using a range of GHG concentration scenarios. Results indicate that increases in R_0 values of *I. scapularis* and the northward expansion of this tick could well occur even under the emissions scenarios consistent with Paris climate goals (RCP 2.6), altering the distribution and severity of Lyme disease risk across the country.[66] In the absence of information on the abundance of infected ticks, one study asserts that temperature (degree days greater than zero) is the best measure of overall risk.[67] In contrast, the US National Climate Assessment[68] deems the effect of climate change on the future distribution and magnitude of Lyme disease incidence as uncertain because of the weak ability of meteorological variables to predict the density of ticks nymphs infected with Lyme disease bacteria. The difference between the US and Canada is that Canada is at the northern edge of the range of *I. scapularis* where climate and climate change have a large effect on occurrence of the tick. Variations in occurrence of the tick in the US are more associated with climate-independent factors because most of the range of the tick in the US is well within the tick's climate-suitability envelope.

Compared to the volume of detailed studies examining the climate response of Lyme disease vectors, quantitative modelling studies directly examining the climate link to human cases of Lyme disease – let alone economic impacts –in Canada are far fewer. Our systematic literature review yielded only one study on human health outcomes, comparing 2017 Lyme disease incidence rates to average rates from the previous five years in Ontario.[69] Findings indicate an increase in the incidence of Lyme disease (6.7/100,000 persons) compared to the previous five-year (2012-2016) average incidence (2.28/100,000 persons). Focusing on Quebec, Larrivée et al. (2015) estimated the public sector and societal costs of Lyme disease under climate change. The study applied economic values to estimated incidence rates for 2020 (18.1/100,000 people) and 2050 (22.2/100,000.) Future incidence rates were derived from linear extrapolation of published annual Canada-wide incidence of Lyme disease. Discounted social costs of Lyme disease incidence from 2015 to 2065 amounted to C$805 million ($2012) in present value costs (using a 4% discount rate).

5.3.2 Approach

Because of the paucity of Canadian studies directly linking Lyme disease incidence in human populations to climate, we turned to a US study (Dumic and Severnini 2018) that examined the incidence (per 100,000 people) of Lyme disease with reference to different average temperature ranges and precipitation levels in the 15 states that contribute the majority (over 95%) of reported cases. Appendix II provides a qualitative assessment of potential biases in this study. We moved forward with this approach after consulting with experts (part of the Canadian Lyme Disease Research Network) and making efforts to develop an alternate approach within the scope of this Institute study that more directly built on Canadian data and research. Appendix III provides a brief account of the steps we took.

Using pooled annual data from the US Centers for Disease Control and Prevention (CDC) for 468 counties for the period between 2000 and 2016, Dumic and Severnini (2018) examined the relationship between annual Lyme disease incidence rates in northern US "high incidence" states[8],, annual average temperatures across seven bins (below 5, 5–7, 7–9, 9–11, 11–13, 13–15, and above 15°C) and annual total precipitation across six bins (below 70, 70–120, 120–170, 170–220, 220–270 and above 270 cm). The epidemiological data pool comprised states with at least 10 confirmed cases per 100,000 in the previous reporting years. This included northeast and upper Midwest regions of the US (Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia and Wisconsin). Using a panel regression model, Dumic and Severnini (2018) found an inverted U-shape response of Lyme disease incidence to temperature (Figure 5-6). According to authors, this inverted U-shaped modelled response is in line with patterns of black-legged tick survival and host-seeking behavior. In the model with most explanatory power, temperature explained over 70% of the variability of Lyme disease incidence but precipitation showed no statistical significance.

[8] This study does not use low incidence hot southern states, which some studies do erroneously. In these southern states most cases are travel related (N. Ogden, pers. comm., November 2020).

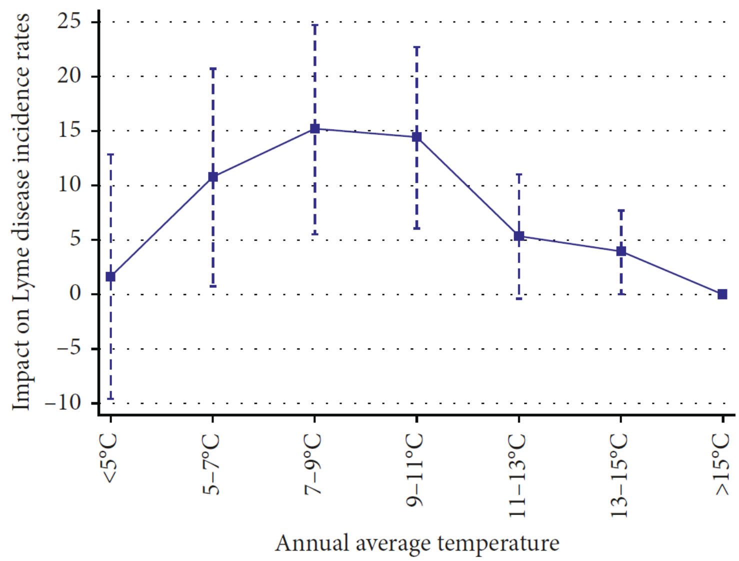


Figure 5-6: The impact of temperature on the incidence of Lyme disease (cases per 100,000 people). Point estimates are blue squares, with vertical dashed lines representing the 95% confidence interval. The zero value at >15˚C does not mean that Lyme disease risk is 0; >15˚C is the reference temperature. (Reproduced from Dumic and Severnini 2018)

Our study adopts the point estimates of the response of Lyme disease incidence to annual average temperature in 2°C bins to estimate the incremental incidence of Lyme disease in Canada under future climate and socioeconomic scenarios. The applicable ERFs characterizing the relationship between annual average temperatures and Lyme disease incidence by temperature bin are shown in Table 5-6. We assessed the sensitivity of Lyme disease incidence as a function of annual average temperatures using the lower and upper 95% confidence intervals of the point estimates in Table 5-6.

Table 5-6: Incidence of Lyme disease in the US with exposure to different temperatures (Source: Table 2 in Dumic and Severnini 2018)

Reference	Dates	Location	Health effect	Description of exposure [a]	Effect estimates [b] (standard error)
Dumic and Severnini 2018	2000-2016	United States (468 in 15 north-eastern and mid-western states)	Incidence of Lyme disease/100,000 population / year	Average temperature: < 5°C	1.6156 (5.7073)
				Average temperature: 5–7°C	10.7294** (5.0919)
				Average temperature: 7–9°C	15.1306*** (4.8862)
				Average temperature: 9–11°C	14.4033*** (4.2444)
				Average temperature: 11–13°C	5.3232* (2.9025)
				Average temperature: 13–15°C	3.8847** (1.9730)
				Reference: above 15°C	0

[a] Reference temperature >15°C; [b] Adjusted for observed and unobserved time-varying factors, observed and unobserved changes in state variables and including quadratic terms; [c] Annual average temperature; ∗∗∗Significance at 1%; ∗∗significance at 5%; ∗significance at 10%.

Determining the Affected Canadian Population

Following the approach in McPherson et al. (2017), we exclude (mask) populations in geographic locations west of the Rocky Mountains and at elevations greater than 500m above sea-level. This is because the analysis in Dumic and Severnini (2018) focuses on Lyme disease carried by *I. scapularis.* As well, work by Diuk-Wasser et al. (2012) evaluating the geographic pattern of human risk for infection from *B. burgdorferi* focusing on the tick life stage that has a significant role in disease transmission (nymph stage) highlighted the importance of accounting for elevation. In their field-based work no infected tick vectors were found above 510 metres. To determine the census divisions in scope we took the following steps:

- We imported spatial data layers for Census Divisions[70], lakes[71] and elevation[72] into QGIS.
- In QGIS we used the "Difference" tool to 'subtract' lakes from the Census Divisions layer so that calculations of average elevation are not skewed down by the large area of lakes.
- We used the adjusted Census Divisions layer as a "Zones" layer in the QGIS "Zonal Statistics" tool (input = Digital Elevation Model). This outputs desired statistics inside the "difference" shapefile (the output Census Divisions), with the prefix "Zonal_".
- This file was exported to CSV and imported to Excel where we used vlookup to match Census Divisions to their mean, minimum, and maximum elevation. We retained Census Divisions with a mean elevation of less than 500 metres above sea level.
- Further, we identified Census Divisions east of the Rocky Mountains. Since there is no precise line defining the Rocky Mountains we consider Census Divisions as East of the Rockies as any Census Division that has some portion of land that is east of the Rocky Mountains.

For each Census Division in scope (220), we use population data from the 2016 Census and related population projections provided by the Institute. We do not differentiate the population by age class.

Finally, because the U.S. model is based on Lyme disease cases in states with established tick populations we report results for Manitoba, Ontario, Quebec and Atlantic provinces only.[73]

Climate Data Needs

Estimating Lyme disease incidence in response to temperature at the Census Division level using Dumic and Severnini's ERF point values requires annual observed and projected average temperature data. The data are processed as follows:

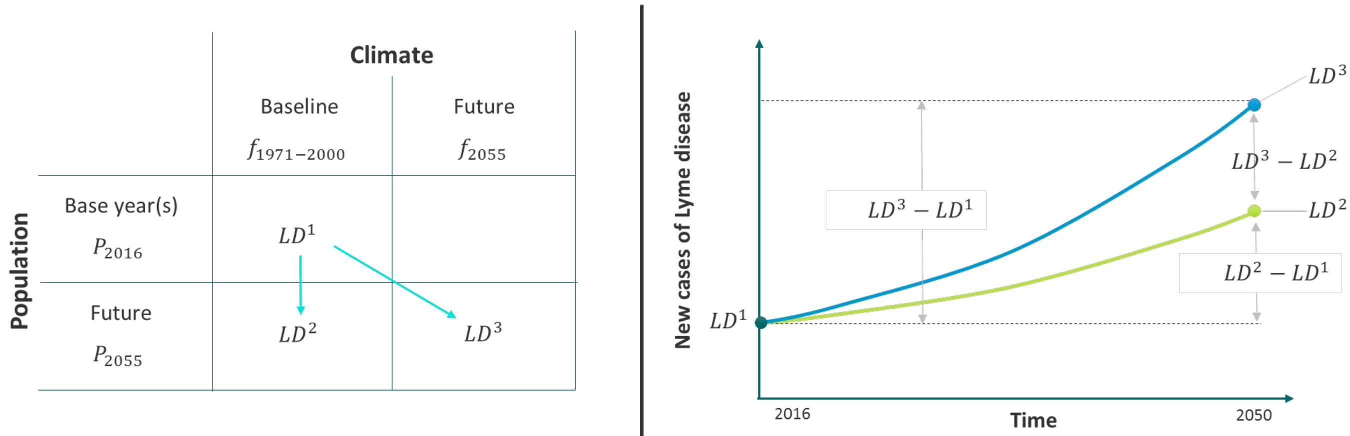
1. Develop a frequency distribution of annual average temperatures by taking the arithmetic average of daily maximum and minimum temperatures from *observed* data over the assumed climate baseline of 1971-2000. Bin widths should match those used by Dumic and Severnini (see Figure 5-6). This defines baseline climate conditions.

2. Develop a frequency distribution of projected annual average temperatures by taking the arithmetic average of daily maximum and minimum temperatures from *modelled* data for each future epoch (2041-2070 and 2071-2100) and climate scenario (RCP 4.5 and RCP 8.5) of interest (same bin widths). This defines future climate conditions.

Calculations of physical impacts

Estimated changes in new incidence cases of Lyme disease (measured in cases / year) are derived by combining the frequency distributions developed in step 1 (no climate change) and step 2 (projected climate change) above with population projections at the census division level (excluding masked areas) expressed per 100,000 persons and the ERFs in Table 5-6. The analytical framework underpinning the calculation of physical impacts is depicted in Figure 5-7.

Figure 5-7: Analytical framework for calculating cases of Lyme disease in 2050



$LD^1 =$ Cases of Lyme disease in base year population under baseline climate scenario

$LD^2 =$ Cases of Lyme disease in future population under baseline climate scenario

$LD^3 =$ Cases of Lyme disease in future population under projected future climate scenario

$\Delta LD^{SC} = LD^2 - LD^1 =$ Case of Lyme disease due to population growth (no climate change)

$\Delta LD^{TR} = LD^3 - LD^1 =$ Case of Lyme disease due to population growth and climate change (change in total risk)

$\Delta LD^{CC} = LD^3 - LD^2 =$ Case of Lyme disease due to climate change only

Taking the first future epoch of interest as an example, the change in Lyme disease cases is calculated as follows:

First, future Lyme disease new incidence cases are calculated under baseline (B) climate conditions (i.e., no climate change):

$$LD^B_{d(j),2041-70} = \sum_{T=1}^{7} \hat{P}_{d(j),2041-70} \times f^B_T \times 30 \text{ [years]} \times ER_T$$

And

$$\hat{P}_{d(j),2041-70} = \left(\sum_{t=2041}^{2070} P_{d(j),t} \right) \times \frac{1}{100{,}000} \times \frac{1}{30}$$

Where LD is the number of cases of Lyme disease over the period 2041-2070 (30 years), f is the frequency (%) of total years falling in annual average temperature bin T (of which there are 7 bins), ER is the exposure response point estimate (cases per 100,000 people per year) for temperature bin T. $\hat{P}$ is the 30-year average population exposed to Lyme disease risk (all-age class population expressed in 100,000 people), P is the population in year t and $d(j)$ is the census division in province or territory j.

Second, the future Lyme disease new incidence cases are calculated under projected (CC) climate conditions with climate change:

$$LD^{CC}_{d(j),2041-70} = \sum_{T=1}^{7} \hat{P}_{d(j),2041-70} \times f^{CC}_{T} \times 30 \text{ [years]} \times ER_T$$

Finally, incremental new incidence cases (number) of Lyme disease attributable to climate change over the epoch is calculated as:

$$\Delta LD_{d(j),2041-70} = LD^{CC}_{d(j),2041-70} - LD^{B}_{d(j),2041-70}$$

We discuss our approach to monetizing changes in the incidence of Lyme disease in Canada in Section 6. Our quantification of Lyme disease incidence assumes projected impacts reflect past adaptations and behaviours, and no new planned adaptations. The Government of Canada's framework for Lyme disease outlines three pillars for evidence-based management of this public health concern: i) surveillance, ii) guidelines and best practices and iii) education and awareness. Information on the effectiveness of investments to date in avoiding or reducing exposure to Lyme disease vectors and increasing capacity to lessen the disease burden is not yet available. According to departmental plans for 2020-2021, the Public Health Agency of Canada measures its performance in relation to capacity for accurate diagnosis.[9] Since Lyme disease remains an emerging issue in Canada the assumption of no additional adaptations or behaviours in the projected baseline is reasonable and results in a potential upper bound for future Lyme disease cases.

5.4 Labour Supply

5.4.1 Impacts of temperature stress on workers

There is an observable relationship between workplace temperatures and performance; beyond a certain temperature the hourly productivity of workers declines.[74] When the body performs strenuous physical work, heat is generated by the body. The risk of overheating increases with the level of physical exertion required to perform a given task, the duration of the task, the experience of the work in performing the task, and the ambient temperature of the work environment.[75] Heat generated needs to be transferred to the external environment to avoid increases in the body's temperature. If the body is unable to dissipate the heat—perhaps because of prolonged exposure or dehydration—it begins to cause dizziness, muscle cramps and fever. In the extreme, exposure to hot temperatures can cause acute cardiovascular, respiratory, and cerebrovascular distress, which can be life threatening.

At lower temperatures in the workplace, before these serious health effects occur, workers can experience diminished "work ability".[76] Temperature stress may affect workers in two ways:[77]:

- It may cause direct physical or psychological discomfort.
- It may reduce task productivity, altering the increment of effort exerted within any given hour or the marginal return of that effort.

[9] https://www.canada.ca/en/public-health/corporate/transparency/corporate-management-reporting/reports-plans-priorities/2020-2021-departmental-plan.html#a3.2

In turn, these two direct effects may adversely affect labour supply (hours) or labour productivity (output per hour worked).[78] For example, Vanos et al. (2019) found that labourers at an outdoor industrial site in Ontario lost, on average, 22 hours each summer (equivalent to about 1% of annual work hours) as a result of taking breaks or stopping work due to heat stress.

The links between workplace temperatures, performance, economic outcomes, and health generally, are illustrated in Figure 5-8. The mechanisms considered in this study (and, therefore, in the subsequent macroeconomic analysis by the Institute) are shown in orange boxes.

As mentioned, a growing literature has investigated the economic consequences of temperature stress on labour supply decisions and labour productivity under different climate futures; select examples are provided in Box 2, two of which provide results for Canada. These studies not only demonstrate the economic importance of investigating the impact of climate change on the workforce, they also provide a range of methodologies for consideration in this study.

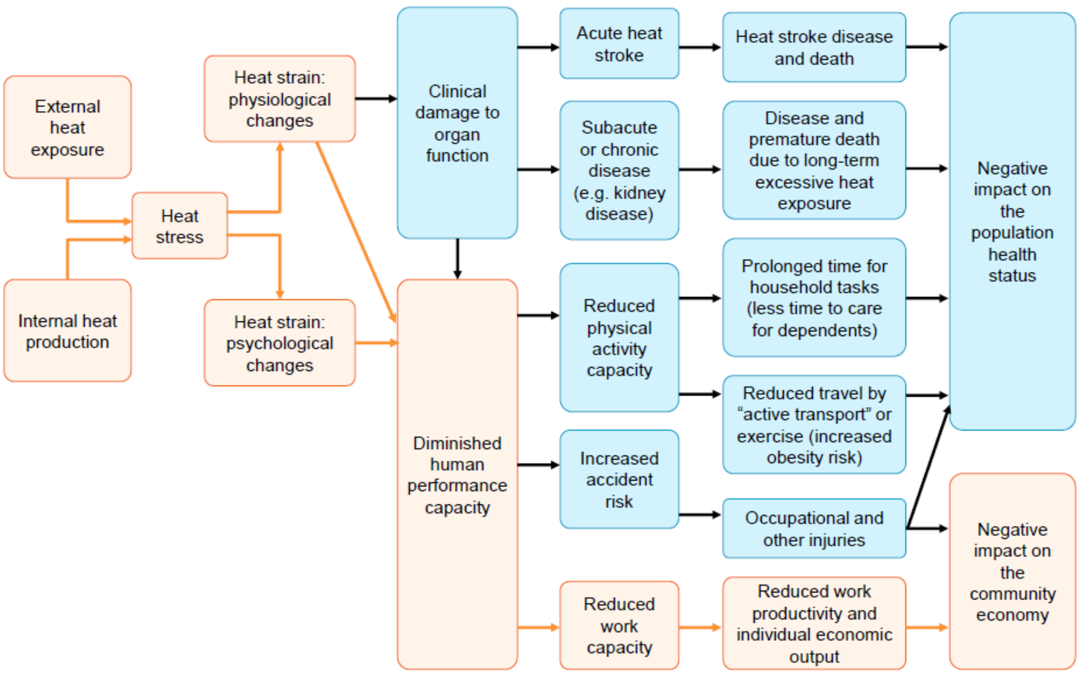


Figure 5-8: Effects of heat stress on workers, including impacts on labour productivity. Pathways considered in this study and expected in subsequent macro-economic modelling are shaded in orange (Sources: Vivid Economics (2017), based on Kjellstrom et al. (2016))

Box 2: Examples of existing estimates of the economic impact of climate change on labour productivity

- Deryugina and Hsiang (2014) found that daily labour productivity in the USA declines by 1.7% for every 1°C rise in daily average temperature above 15°C, based on an examination of daily temperature changes over 40 years.
- Behrer and Park (2017) found that an additional day with daily maximum temperatures above 36°C results in a contemporaneous 0.22% reduction in the level of per capita payroll in exposed sectors, as a result of reductions in labor supply, effort, and productivity.
- Gosling et al. (2018) found that the productivity of outdoor labour in Europe could decline by 2-4% (northern Europe) and 10-15% (southern Europe) relative to the present day by the end of the century under RCP 8.5.
- Kovats et al. (2011) found that working days lost to heat would increase by 0.76% in southern Europe and 0.5% in eastern Europe, relative to current levels, by the 2080s under SRES A1B. These productivity losses are valued at €300-€740 million, with the range in losses reflecting assumptions about the future structure of the labour market.
- Hsiang et al. (2017) found that total hours of labor supplied declines by about 0.11% for every 1°C rise in global mean surface temperature for low-risk workers in the USA, who are mostly not exposed to outdoor temperatures, and 0.53% per degree C for high-risk workers who are exposed to outdoor temperatures (workers in construction, mining, agriculture, and manufacturing).
- Rhodium Group (2014) found, under RCP 8.5, that labour supply in high-risk occupations declines by 0.8%-2.4% by late century (2080-2099); labour supply in low-risk occupations is projected to fall by 0.1%-0.5% by late-century. Nationally, this equates to annual value added losses of $42-$150 (2011 US dollars) billion.
- US EPA (2015) found that by 2100 under RCP 8.5 over 1.8 [1.2-2.4] billion labour hours across the US workforce are projected to be lost due to unsuitable working conditions. These lost hours equate to over $170 [$110-$220] (2014 US dollars) billion in lost wages.
- US EPA (2017) found that about 1.9 [1.0-2.7] billion labour hours (in high-risk occupations) will be lost annually in the US by 2090 under RCP 8.5 due to extreme heat. This equates to about $160 [$87-$120] (2015 US dollars) billion in lost wages per year by 2090.
- ILO (2019) found that projected economic losses globally due to heat stress at work could amount to US$2,400 billion (Purchasing Power Parity) in 2030. Based on a global temperature rise of 1.3°C by 2030, 2.2% of total working hours worldwide could be lost to high temperatures; a productivity loss equivalent to 80 million full-time jobs.
- Kahn et al. (2019) found that an increase in average global temperature of 0.04°C per year (corresponding to RCP 8.5) will reduce the world's real GDP per capita by 7.2% by 2100, through the impacts of temperature on labour productivity. Projected reductions in real GDP per capita in **Canada** in 2030, 2050 and 2100 are estimated at, respectively, 1.4%, 4.4% and 13.1%.
- Chavaillaz et al. (2019) found that, for every teratonne of carbon emitted, annual labour productivity losses will increase by 3.6% [±1.77%] of global GDP under RCP 8.5. This represents an annual economic loss reaching $4,359 billion (international 2011 PPP dollars) when cumulative emissions under RCP 8.5 reach one teratonne of carbon. Annual productivity losses in **Canada** are projected to be less than 0.1% for every teratonne of carbon emitted globally.

5.4.2 Approach

Two generic forms of exposure response function (ERF) are used in the studies listed in Box 2 to quantify the labour response to temperature stress:

- Absolute [$] or relative [%] change in labour productivity = $f(WBGT)$ [e.g., Kovats et al. 2011; Gosling et al. 2018; Chavaillaz et al. 2019 and ILO 2019].

- Absolute [hours] or relative [%] change in labour supply = $f(T_X)$ [e.g., Rhodium Group 2014; US EPA 2015 and 2017 and Hsiang et al. 2017].[10]

$WBGT$ is the Wet Bulb Globe Temperature and T_X is the daily maximum temperature. The former is a well-established heat index for workplace applications, frequently used to set quantitative standards to protect workers from heat stress. For example, the U.S. National Institute of Occupational Safety and Health (NIOSH) standard stipulates a $WBGT$ level above which no worker should be expected to carry out ongoing tasks. It also underpins the recommendations set out in the ESDC "Thermal Stress in the Workplace" Guideline. Calculating $WBGT$ is not straightforward, however, and not all the required variables are routinely generated by climate models. For example, the specification of outdoor $WBGT_{OD}$ used by Gosling et al. (2018), shown below, requires projections of T_X and the psychrometric wet bulb temperature, T_W; the latter is not usually generated by climate models and must therefore be approximated from projections of daily maximum relative humidity (RH_X).

$$WBGT_{OD} = 0.67 \times T_W + 0.33 \times T_X + 3.0$$

Where T_W is given by:

$$T_X\ atan\left[0.151977(RH_X + 8.313659)^{\frac{1}{2}}\right] + atan[T_X + RH_X] - atan[RH_X - 1.676331] \\ + 0.00391838(RH_X)^{\frac{3}{2}} \times atan[0.023101 \times RH_X] - 4.686035$$

Furthermore, as the above equation implies, $WBGT$ must typically be calculated for both indoor (typically, lower-risk occupations) and outdoor (typically, high-risk occupations) conditions. In contrast, daily maximum temperature is a standard output of climate models and its application in impact models requires no secondary calculations. Consequently, for practical reasons, we will adopt the (daily maximum) temperature-labour impact model used by Rhodium Group (2014) and US EPA (2015 and 2017), based on the ERFs generated by Graff Zivin and Neidell (2014).

Using a panel data set created from the American Time-Use Survey, Graff Zivin and Neidell (2014) examined the response of labour to daily maximum temperature across 5°F (≈2.8°C) bins, from >25°F (-3.9°C) to 105°F (40.6°C). They found that days with extreme temperatures are associated with significant changes in the time allocated to labour by individuals. On days when maximum temperatures exceeded 37.8°C (100°F), workers in industries with relatively high exposure to weather reduced time allocated to labour by nearly one hour compared to temperatures in the 24.4-26.7°C range, which represents a 14% reduction in labour supply for the day.[11] However, they found no statistically significant temperature-labour supply effects in other industries that are less exposed to weather (e.g., non-manufacturing, indoor occupations).

For the purpose of this study, we used Graff Zivin and Neidell's point estimates of the response of labour supply to daily maximum temperatures in each 5°F (≈2.8°C) bin to calculate incremental labour impacts

[10] Kahn et al. (2019) use mean daily temperature as the dependent variable in their impact model.

[11] High-exposure industries are industries where the work is performed primarily outdoors, as well as manufacturing, where facilities are sometimes not climate controlled and the production processes often generate considerable heat.

under future climate and socioeconomic scenarios. The applicable ERFs characterizing the relationship between daily maximum temperature and time allocated to labour by temperature bin are shown in Table 5-7. The sensitivity of the labour response to projected future daily maximum temperatures was assessed using the lower and upper 95% confidence intervals of the point estimates in Table 5-7 and Figure 5-10.

Determining the affected labour pool

Due to the lack of statistically detectable effects on low-exposure industries, we only include industries with high-risk occupations in the analysis. High-risk industries are: (NAICS 11) Agriculture, Forestry, Fishing, and Hunting; (NAICS 21) Mining, Quarrying, and Oil and Gas Extraction; (NAICS 22) Utilities; (NAICS 23) Construction; (NAICS 31-33) Manufacturing; and (NAICS 48-49) Transportation and Warehousing. Given potential ambiguities regarding the degree of heat exposure within the manufacturing sector, like Graff Zivin and Neidell, we will treat manufacturing as a low-risk industry (excluding the sector from aggregated results) as a sensitivity test.

For each census division, we use labour force data for each 2-digit NAICS industry from the 2016 Census to determine the base year labour force (i.e., the population aged 15 years and over) employed in each of our high-risk industries—denoted:

$$LF_{i,d(j),t} \text{ [workers]}$$

Where i is the 2-digit NAICS industry, LF is the labour force, $d(j)$ is the census division in province or territory j and t is the year; the base year for the analysis is t = 2016. The starting point for calculating the future labour force exposed to temperature stress is projections of employment by industry and province / territory provided by the Institute; these projections cover the period 2015-2050. These projections were used to construct a growth index for employment (denoted EI) for each province or territory, with 2016 = 100. Values for years after 2050 were generated using the linear forecasting function in Excel (including 95% confidence intervals), using the data for the period 2031-2050. The future labour force in year t in each of the high-risk industries, by census district, is then calculated as:

$$LF_{i,d(j),t}\text{[workers]} = LF_{i,d(j),2016}\text{[workers]} \times EI_{i,j,t} \text{ [index number]}$$

This represents the number of workers in high-risk industries exposed to temperature stress in each future year of interest.

Climate data needs

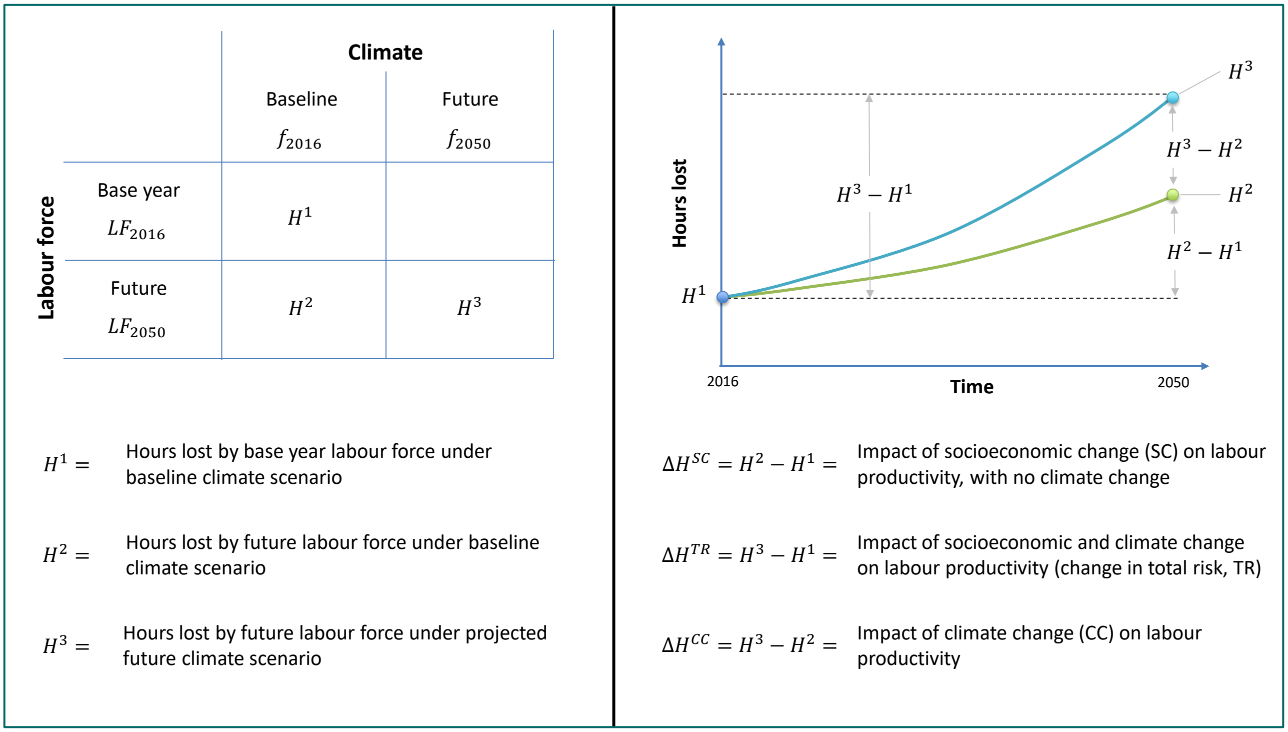
Determination of the labour response to temperature stress at the census division level using Graff Zivin and Neidell's ERF point estimates requires daily observed and projected maximum temperature data. The data is processed as follows:

1. Develop a frequency distribution of daily maximum temperature from *observed* data over the assumed climate baseline of 1971-2000. Bin widths should match those used by Graff Zivin and Neidell (see Table 5-7). This defines baseline climate conditions.
2. Develop a frequency distribution of projected daily maximum temperature from *modelled* data for each future epoch (2041-2070 and 2071-2100) and climate scenario (RCP 4.5 and RCP 8.5) of interest (same bin widths). This defines future climate conditions.

Calculation of physical impacts

Estimated changes in labour supply (measured in hours) are derived by combining the frequency distributions developed in step 1 (baseline case with no climate change) and step 2 (projected climate change scenarios) above with base year and projected numbers of workers employed in high-risk industries and the ERFs in Table 5-7. The analytical framework underpinning the calculation of physical impacts described below is depicted in Figure 5-9.

Figure 5-9: Analytical framework for calculating physical impacts on labour productivity for 2050



First, the future labour supply response is calculated for three separate scenarios (H^1, H^2 and H^3) as shown in Figure 5-7 (using the period 2041-70 as an example):

$$H^1_{i,d(j),2016} = \sum_{T=1}^{16} \frac{1}{60} \times LF_{i,d(j),2016} \times f^T_{1970-00} \times (365 \times h_{i,j,2016}) \times ER^T$$

$$H^2_{i,d(j),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} \sum_{T=1}^{16} \frac{1}{60} \times LF_{i,d(j),t} \times f^T_{1970-00} \times (365 \times h_{i,j,2016}) \times ER^T \right]$$

$$H^3_{i,d(j),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} \sum_{T=1}^{16} \frac{1}{60} \times LF_{i,d(j),t} \times f^T_t \times (365 \times h_{i,j,2016}) \times ER^T \right]$$

Where H is the annual average number of hours lost under each scenario defined by the super scripts 1, 2 and 3 (see Figure 5-7), f is the frequency (%) of total days falling in daily maximum temperature bin T (of which there are 16 bins), ER is the exposure response point estimate (minutes per worker per day) for temperature bin T, and h is the fraction of the year (365 days) that people work. All other variables and subscripts are as defined above. The two fractions convert minutes to hours (1/60) and a thirty year total to an annual average (1/30).

With this approach, estimated physical impacts are also provided for each future year of interest for H^2 and H^3. This is necessary to enable cost-benefit analysis of adaptation options and the calculation of cumulative (undiscounted) impacts (and costs) over time.

Second, the incremental impact (hours lost, on average, per year) of socioeconomic change (denoted by the superscript SC), climate change (denoted by the superscript CC), and both (denoted by the superscript TR) is estimated:

$$\Delta H^{SC}_{i,d(j),2041-70} = H^{2}_{i,d(j),2041-70} - H^{1}_{i,d(j),2016}$$

$$\Delta H^{CC}_{i,d(j),2041-70} = H^{3}_{i,d(j),2041-70} - H^{2}_{i,d(j),2041-70}$$

$$\Delta H^{TR}_{i,d(j),2041-70} = H^{3}_{i,d(j),2041-70} - H^{1}_{i,d(j),2016}$$

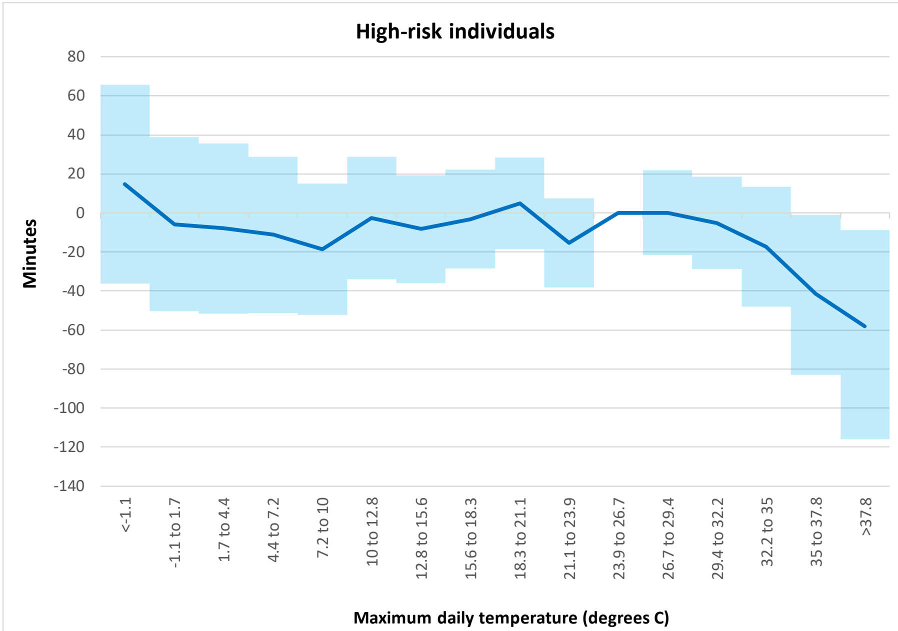
Monetization of these results is discussed in the next chapter. Note that we are assuming that workplace conditions do not vary from current conditions over the entire study period. Further, we assume that workers do not gradually acclimatize to hotter work environments.

Table 5-7: Exposure response functions for relationship between maximum daily temperature and time allocation (change in minutes allocated to labour at each temperature bin relative to 24.4°C - 26.7°C)

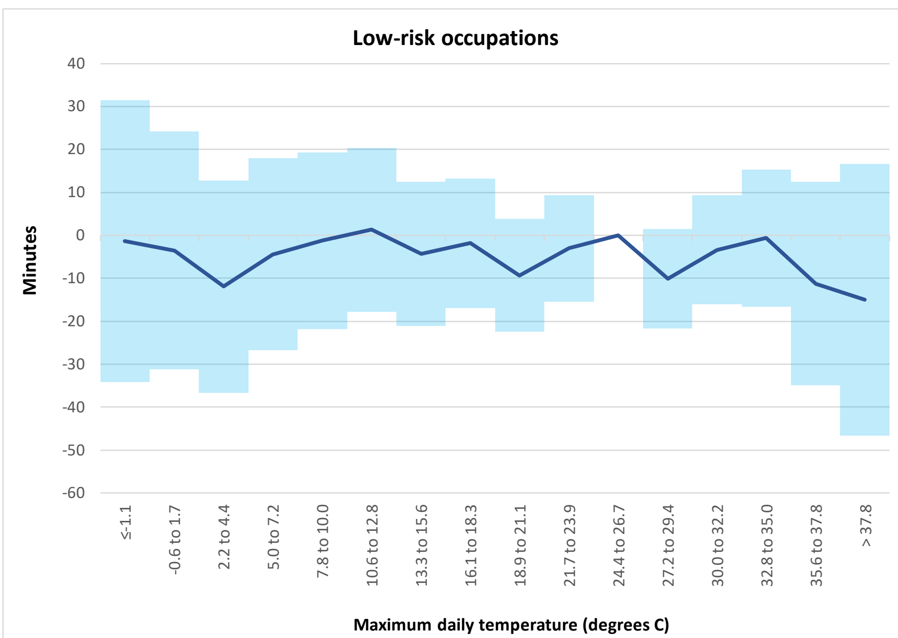
Max daily temperature (degrees C)	All individuals (mins / worker / day)	High-risk occupations (mins / worker / day)	Low-risk occupations (mins / worker / day)
≤-1.1	+6.423	+14.653	-1.324
>-1.1 to 1.7	-6.976	-5.808	-3.494
>1.7 to 4.4	-0.885	-7.981	-11.951
>4.4 to 7.2	-2.892	-11.226	-4.382
>7.2 to 10.0	-5.605	-18.642	-1.253
>10.0 to 12.8	-3.983	-2.729	+1.310
>12.8 to 15.6	-3.357	-8.180	-4.317
>15.6 to 18.3	-1.029	-3.092	-1.851
>18.3 to 21.1	-4.682	+4.807	-9.338
>21.1 to 23.9	-3.453	-15.397	-3.029
>23.9 to 26.7	---	---	---
>26.7 to 29.4	-3.769	+0.148	-10.061
>29.4 to 32.2	-4.642	-5.053	-3.364
>32.2 to 35.0	-6.621	-17.400	-0.633
>35.0 to 37.8	-13.876	-41.417	-11.256
> 37.8	-18.327	-58.032	-14.951

Source: Graff Zivin and Neidell (2014, Table A1)

(a) High-risk occupations



(b) Low-risk occupations



Source: Graff Zivin and Neidell (2014, Figures 3 and 4). The light blue shaded area is the 95% confidence interval; the solid blue line shows the labour supply-temperature response point estimates.

Figure 5-10: Relationship between daily maximum temperature and time allocated to labour

6. Economic Valuation

6.1 Health Outcomes

Consistent with other bottom-up costing studies of climate-related health impacts[79] projected physical health outcomes are converted to economic costs by multiplying the projected health outcome by an appropriate projected "unit value":

Economic cost in future year *t*

=

projected health outcome (physical units) in year *t*

times

projected "unit value" ($ per physical unit) of the health outcome in year *t*

In the context of this study, health outcomes describe the clinical symptoms (consequences) of disease or illness for an affected individual, group or population, or the changes in health status that result from specific planned interventions (adaptations). For the purpose of monetization, morbidity health outcomes (the condition of being diseased or ill) are treated separately from mortality outcomes (the condition of being dead). Morbidities may present slowly or suddenly and improve or worsen after onset and may lead to mortality. This gives rise to a key methodological choice in health costing studies—i.e., whether to adopt an incidence-based or prevalence-based approach.

Cost analyses in health economics can be conducted from a variety of perspectives. These perspectives may estimate costs to individuals and their families, government, businesses, the health care system, or society.[80] Depending on the perspective adopted, different cost items are included in the analysis, leading to a wide range of estimated costs for the same illness or disease. The societal perspective is the most comprehensive because it includes all direct, indirect, and disutility costs regardless of who incurs those costs. We have adopted a societal perspective. As such, as a rule we excluded transfer payments from cost estimates, as they do not represent the consumption of real resources, but rather money just changing hands. Income maintenance payments from government or social insurance to support individuals unable to work due to ill-heath are an example of a transfer payment.[81] In practice, we did not need to take deliberate action to exclude transfer payments; none of the data we worked with included them in the end.

6.1.1 Incidence versus prevalence-based approaches

Many diseases or illnesses (such as Lyme disease) can give rise to persistent or increasing costs for years after first diagnosis or onset. The true total cost of a disease or illness should ideally account for all the costs incurred attributable to the disease or illness from the time of diagnosis to the time of cure or the death of the afflicted individual—i.e., the appropriate metric is the lifetime stream of incremental[12] costs associated with the disease or illness.

The **incidence-based approach** estimates the total lifetime cost of a disease from the year in which the disease is first diagnosed, over its natural course. The total cost of the disease is equal to the sum of the

[12] By incremental we mean the cost of the disease or illness beyond those expected to be incurred by the same individual in the absence of the disease or illness.

present value costs of disease-related events over the lifetime of everyone with the disease. Moreover, for each year post-diagnosis, costs are only incurred if the individual survives to that year, and the number of years of survival post-diagnosis will vary from one individual to another. It is thus the expected, or average, incremental lifetime stream of costs that is of interest, as opposed to simply the incremental annual costs. To estimate this expected value requires longitudinal data over the history of a disease and life of the patient, such as disease incidence, survival probabilities, and the natural course of the disease and associated disease-related events, as well as the impact of the disease on lifetime employment. Collecting this type of data is, of course, very resource intensive. To assess lifetime costs without longitudinal data taken over a disease's lifetime, it is necessary to model a synthetic cohort of individuals with the illness over time, which requires strong assumptions.

The **prevalence-based approach** estimates the total costs of a disease (like diabetes) incurred during a given time period, typically a year. All disease-related events experienced by individuals with the disease in that period are costed, regardless of when the first diagnosis of the disease occurred (which may have been many years earlier). At the same time, all disease-related events experienced by afflicted individuals in subsequent years are not captured when taking a snapshot of costs attributable to the prevalence of a disease in the current year. In other words, prevalence-based estimates provide a cross-sectional view of the costs attributable to a disease or illness. This approach is less data intensive than the incidence-based approach and is therefore the more commonly applied approach for economic burden of disease studies.

However, in contrast to the incidence-based approach, the prevalence-based approach does not provide a baseline against which planned interventions (adaptations) can be evaluated.[82] It is therefore not as useful as the incidence-based approach for evaluating the cost-effectiveness, cost-utility or cost-benefits of potential adaptation options in this study. Consequently, we applied an incidence-based approach to the monetization of projected health outcomes associated with Lyme disease.

6.1.2 Monetization of temperature and ozone-related morbidities

Ill-health can contribute to losses in individual utility or welfare directly (because people prefer to be more healthy than less healthy) and indirectly (e.g., by reducing satisfaction from the consumption of goods and services not related to health, by reducing earning potential and income that allows people to consume goods and services and by reducing capabilities to engage with cultural, spiritual and heritage activities and practices). Our interest lies with determining the impact of climate induced ill-health on overall social welfare. The valuation of the full welfare impact of ill-health on individuals, including the value of reduced health itself, requires the application of willingness-to-pay (WTP) metrics.[83] [13] WTP to avoid ill-health comprises three components:[84]

- Direct (resource) costs, which arise from the consumption of medical (primary and secondary care expenditures, drug purchases and formal home care costs) and non-medical resources (e.g., payments for transportation to access health care);
- Indirect (opportunity) costs, which arise from foregone leisure opportunities or lost production (from absenteeism or presenteeism) due to ill-health, premature mortality or informal caregiving; and,

[13] Strictly speaking there are four monetary measures used to value changes in health states: the value of a negatively viewed change can be measured by the individual's WTP to avoid ill-health (increased health risk) or willingness-to-accept compensation (WTA) to tolerate ill-health (increased health risk); and the value of a positively viewed change can be measured by the individual's WTP for improved health (reduced health risk) or WTA to forgo the improvement in health (reduction in health risk) (Hammitt, 2017).

- Disutility (human or quality of life) costs, which refers to the value individuals attribute to the emotional distress, pain, and suffering that they, family and friends experience as a result of ill-health or loss of life.

Where available, we used WTP-based unit values to monetize projected morbidities, but this was not possible for all morbidities of interest—specifically, hospitalizations attributable to heat stress.

WTP-based unit values for the health outcomes resulting from ground-level ozone exposures included in this study are already embedded in AQBAT—specifically for, acute respiratory symptom days (ARSD), asthma symptom days (ASD), and respiratory emergency room visits (ERV). These unit values were converted to 2015 Canadian dollars following best practices.[85] This involves adjusting values for growth in real income and monetary inflation (see the discussion of mortality valuation below for the formula). Projected future values over the period 2016-2100 are adjusted for anticipated growth in real incomes, but not expected changes in general price levels. Economic unit values used for analyses of baseline impacts in 2016 and projected impacts in the 2050s and 2080s are shown in Table 6-1; these values were applied nationally.

Table 6-1: Projected economic unit values for valuation of morbidities resulting from ground-level ozone exposures

Morbidity endpoint	Central	Low	High
	($ 2015 per episode)	($ 2015 per episode)	($ 2015 per episode)
Acute Respiratory Symptom Days (ARSD)			
2016	22	0	45
2050s	24	0	53
2080s	28	0	64
Asthma Symptom Days (ASD)			
2016	47	12	200
2050s	52	12	239
2080s	60	14	286
Respiratory Emergency Room Visits (ERV)			
2016	3,336	2,649	4,022
2050s	3,726	2,763	4,799
2080s	4,320	3,118	5,753

Note: the economic unit values for the 2050s and 2080s are 30-year annual averages for the periods 2041-70 and 2071-2100, respectively, centered on 2055 and 2085.

Economic unit values for projected hospitalizations attributable to heat exposures comprise two components: (1) the Cost of a Standard Hospital Stay (CSHS) for each disease of interest (diabetes, hypertensive diseases, coronary heart disease and stroke); and (2) the opportunity costs (forgone productivity) associated with time spent in hospital. Region-specific CSHSs for each disease (in 2015 dollars) were generated from the CIHI Patient Cost Estimator and CIHI Functional Area Resource Intensity Proportions by Case Mix Groups for 2016. Future CSHS values were derived by inflating the baseline estimates for projected real growth in the hourly wage rate of "health occupations" over the period 2016-2100; growth in wages is the most notable driver of health-care price inflation (CIHI, 2011).[14] Regarding (2),

[14] CIHI (2011). Health Care Cost Drivers: The Facts. Canadian Institute for Health Information (CIHI), Ottawa, ON., p 33.

the average Length of Stay (LOS) in hospital, in days, were generated from the CIHI Patient Cost Estimator for each disease of interest for 2016; the LOS estimates were assumed to remain constant over time. Estimated LOS values for 2016 were adjusted to account for the proportion of the population employed in each province / territory in 2016 and multiplied by daily payroll compensation costs for all industries (in 2015 dollars) to derive disease- and region-specific unit values for baseline opportunity costs attributable to hospitalization. Future unit values were derived by inflating the baseline estimates for real growth in payroll compensation costs over the period 2016-2100 (see the discussion of labour supply unit values below). The total unit values used in the analyses of projected hospitalizations attributable to heat stress are shown in Table 6-2; region-specific values were applied to all relevant census divisions in each province and territory.

It was not possible to source or derive disutility costs for hospitalizations for the diseases of interest. Projected costs reported below will therefore understate the true social cost of hospitalizations attributable to heat stress.

Table 6-2: Projected economic unit values for valuation of morbidities resulting from hospitalizations attributable to heat stress

		2016	2050s	2080s		2016	2050s	2080s
		($ 2015 per hospitalization)				($ 2015 per hospitalization)		
Diabetes	Newfoundland and Labrador	14,210	20,040	26,110	Coronary heart disease	14,580	20,530	26,710
	Prince Edward Island	13,780	17,980	22,140		13,910	18,000	22,050
	Nova Scotia	13,560	17,580	21,460		14,020	18,110	22,070
	New Brunswick	12,480	15,750	18,850		13,150	16,560	19,790
	Quebec	14,150	16,760	19,100		14,300	16,950	19,330
	Ontario	13,750	16,080	18,130		13,970	16,370	18,500
	Manitoba	14,100	18,970	23,830		14,230	19,140	24,040
	Saskatchewan	15,240	22,080	29,390		15,560	22,490	29,900
	Alberta	18,010	24,310	30,620		18,710	25,190	31,680
	British Columbia	13,320	14,860	16,170		13,800	15,400	16,760
	Northwest Territories	18,700	22,780	26,530		19,630	23,800	27,640
	Yukon	17,100	21,120	24,850		16,820	20,850	24,610
	Nunavut	17,930	21,820	25,390		18,660	22,600	26,220
Hypertensive diseases	Newfoundland and Labrador	11,450	16,170	21,070	Stoke	20,630	29,060	37,830
	Prince Edward Island	11,760	15,260	18,740		15,810	20,720	25,570
	Nova Scotia	11,660	15,100	18,420		19,610	25,390	30,980
	New Brunswick	14,350	18,090	21,620		15,860	19,990	23,880
	Quebec	16,290	19,310	22,000		18,690	22,160	25,260
	Ontario	16,150	18,890	21,330		19,660	23,010	25,970
	Manitoba	11,750	15,810	19,880		21,100	28,370	35,620
	Saskatchewan	13,740	19,890	26,460		18,990	27,490	36,590
	Alberta	16,810	22,670	28,550		24,100	32,500	40,930
	British Columbia	16,020	17,880	19,450		18,490	20,630	22,450
	Northwest Territories	14,900	18,090	21,020		22,550	27,400	31,860
	Yukon	15,330	18,960	22,340		20,840	25,770	30,350
	Nunavut	15,110	18,330	21,290		21,600	26,220	30,460

6.1.3 Monetization of temperature and ozone-related mortality

Two metrics are typically used to monetize displaced or premature mortality in health costing studies[86]: the value of a statistical life (VSL) and the value of a statistical life year (VSLY).[15] An individual's VSL reflects his/her marginal rate of substitution between small changes in their own mortality risk and own spending on non-health goods and services in a defined time period; it is not the value an individual, government, or society places on life. For example, if an individual is WTP $900 for a 1/10,000 annual change in the risk of death, then their VSL is equal to $9 million (i.e., $900 ÷ 1/10,000). Similarly, over a population of 10,000, if the average WTP for a 1/10,000 annual reduction in the risk of death is $900, then the number of statistical deaths avoided in the population is one (i.e., 10,000 x 1/10,000) and the VSL is $9 million (i.e., $900 x 10,000). The VSLY values a change in mortality risk in proportion to the corresponding change in life expectancy and thus provides a more precise measure of disutility costs for mortality at different ages. With the VSLY, changing an individual's risk of dying today produces a gain equal to the increase in the chance of surviving the current year multiplied by the individual's life expectancy in years (conditional on surviving the year). The monetary value of this gain is given by the expected number of life-years saved times the VSLY. The VSLY thus provides a proxy means of accounting for differing lengths of life-expectancy at death than making direct adjustment to the VSL for age or future life-years lost.[16]

In theory, the VSLY could be estimated directly; in practice, it is typically derived from the VSL.[87] For example, in the simplest case of a zero discount rate and a constant VSLY, the VSLY is calculated by dividing the VSL by the number of life years lost (saved) because of an increase (decrease) in mortality risk (calculated from the average remaining life expectancy of the affected population). In practice, remaining life years at death are discounted, such that the VSLY is given by the VSL divided by the present value sum of remaining life years.

For projected deaths resulting from heat stress we will use both metrics (VSL and VSLY) in this study to reflect the potential for both displaced and advanced (premature) deaths. Recall that displaced deaths refer to acute mortality that occurs during or immediately after exposure and concerns individuals at the end of their lives who would likely have died regardless of heat exposure (with low life-expectancy). Premature deaths, on the other hand, refer to excess mortality in otherwise healthy individuals, who die earlier because of heat or ozone exposure. The loss of life years per premature death depends on the expected remaining life of the exposed individual at death and their health status and may range from several months to the remaining life expectancy at age of death. To estimate the costs of deaths due to increased ozone exposure we adopted the default metric used in AQBAT (VSL).

Estimated unit values for the VSL (low, central, and high) were derived from Chestnut and De Civita (2009); their recommended central value is $6.5 million [range of $3.5-$9.5 million, 2007 dollars], which represents the average of the mean estimate from stated preference studies and the mean estimated from revealed preference studies for Canada. These values were converted to 2015 Canadian dollars by adjusting the 2007 dollar values for growth in real income and monetary inflation between 2007 and 2015 using the following formula [88]

$$VSL^{2015} = VSL^{2007} \times \left(\frac{CPI^{2015}}{CPI^{2007}}\right) \times \left(\frac{Y^{2015}}{Y^{2007}}\right)^{\varepsilon}$$

Where:

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[15] The latter is also sometimes referred to as the value of a life year (VOLY) lost.

[16] There is evidence that VSL estimates for children are higher than for the average-aged adult, values for adults of working age increase to middle age, peak and then decline, and that values for older adults may decline (Alberini et al., 2004; Robinson et al. 2018).

CPI^{2015}	=	Consumer Price Index (CPI) level in 2015 for Canada
CPI^{2007}	=	CPI level in 2007 for Canada
Y^{2015}	=	Real income (constant dollar GDP per capita) in 2015 in Canada
Y^{2007}	=	Real income (constant dollar GDP per capita) in 2007 in Canada
ε	=	Income elasticity of the VSL

Based on a recent review of income elasticities for mortality valuation conducted for the US EPA's Office of Air and Radiation and Office of Policy, we adopt a central estimate of 0.7 for ε [reasonable range: 0.3 to 1.4].[17] Projected future VSL values (in constant 2015 dollars) over the period 2016-2100 are adjusted for anticipated growth in real (per capita) incomes only.

Estimated VSL values used to monetize projected temperature- and ozone-related mortality impacts (measured as deaths) are shown in Table 6-3. The sets of values in the low, central and high columns are based on the low ($3.5 million), central ($6.5 million), and high ($9.5 million) VSL estimates found in Chestnut and De Civita (2009). Projected values are shown for all three estimates of the income elasticity of the VSL; however, in the analysis we only use values corresponding to our central estimate of 0.7. Projected VSL values are applied nationally.

Table 6-3: Projected VSLs for valuation of deaths attributable to temperature and ozone exposures

	Value of Statistical Life								
	Low			Central			High		
	ε = 0.3	ε = 0.7	ε = 1.4	ε = 0.3	ε = 0.7	ε = 1.4	ε = 0.3	ε = 0.7	ε = 1.4
	($2015 million)	($2015 million)	($2015 million)	($2015 million)	($2015 million)	($2015 million)	($2015 million)	($2015 million)	($2015 million)
2016	4.02	4.08	4.19	7.46	7.58	7.78	10.91	11.08	11.37
2055	4.30	4.78	5.76	7.99	8.88	10.69	11.68	12.98	15.62
2085	4.53	5.40	7.35	8.42	10.04	13.65	12.31	14.67	19.95

Estimates for the VSLY were derived directly from the projected VSL values (in constant 2015 dollars), accounting for (a) the number of life years foregone, on average, by the population from which the VSL values are derived and (b) an assumed discount rate. Specifically, the VSLY is calculated by dividing the VSL by the present value of life years lost at death (i.e., the remaining life expectancy at death). We assume the age at death is 65 years; this is roughly a mid-point between the average of deaths attributable to extreme extreme heat and air pollution exposures in North America (Deschenes and Moretti, 2007; Lelieveld et al., 2020 and Vaidyanathan et al., 2020). Further, we use a real discount rate of 3% per year, which is the social discount rate recommended by the Treasury Board Secretariat for cost-benefit analysis.

Estimated VSLY values used to monetize projected temperature- and ozone-related mortality impacts (measured as Years of Life Lost, YLL) are shown in Table 6-4. These are derived from the VSL values in Table 6-3. Again, in the analysis we only use values corresponding to our central estimate of 0.7 for the income elasticity of the VSL. Projected VSLY values are applied nationally.

[17] Recommended Income Elasticity and Income Growth Estimates: Technical Memorandum. February 5, 2016. Prepared by staff in EPA's Office of Air and Radiation and Office of Policy, US Environmental Protection Agency (EPA), Washington, DC., p 4.

Table 6-4: Projected VSLYs for valuation of YLL attributable to temperature and ozone exposures

	Value of Statistical Life Year								
	Low			Central			High		
	ε = 0.3 ($2015 million)	ε = 0.7 ($2015 million)	ε = 1.4 ($2015 million)	ε = 0.3 ($2015 million)	ε = 0.7 ($2015 million)	ε = 1.4 ($2015 million)	ε = 0.3 ($2015 million)	ε = 0.7 ($2015 million)	ε = 1.4 ($2015 million)
2016	0.263	0.267	0.274	0.488	0.495	0.508	0.713	0.723	0.743
2055	0.247	0.274	0.330	0.458	0.509	0.612	0.669	0.744	0.895
2085	0.236	0.282	0.383	0.439	0.523	0.712	0.642	0.765	1.040

To allow for the inclusion of projected mortality impacts in the macroeconomic analysis, we also use estimates of human capital in Canada to generate projections of the financial impacts of mortality attributable to heat and ozone exposures. Traditional cost-of-illness studies use estimates of human capital to monetize mortality. Employing a lifetime earnings approach, Gu and Wong (2010) estimate the human capital (i.e., lifetime labour income) value of individuals in Canada. The human capital value of an individual in 2007 was estimated at $661,000 in current dollars or $746,000 in 2015 dollars. Future human capital values were derived by inflating this estimate for projected real growth in labour productivity over the period 2016-2100; labour productivity is a key driver of growth in human capital over time (Gu and Wong, 2010). The human capital values used in the analyses of projected deaths attributable to heat and ozone exposures are shown in Table 6-5; like the VSL and VSLY, these values are applied nationally.

Table 6-5: Projected human capital values for valuation of deaths attributable to temperature and ozone exposures

	Human capital (all individuals)		
	Low	Central	High
	($ 2015 million)	($ 2015 million)	($ 2015 million)
2016	0.75	0.75	0.75
2055	0.85	0.94	1.01
2085	0.94	1.11	1.27

6.1.4 Monetization of Lyme disease

The monetization of projected new incident cases of Lyme disease is more complex than for projected morbidity and mortality outcomes attributable to temperature and ground-level ozone exposures, since each infection can give rise to a range of clinical manifestations. We used a pathogen- and incidence-based approach, that uses outcome trees to link all relevant (acute-early stage and chronic-late-stage) health outcomes to their infectious cause in a particular year.[89] A generic outcome tree is shown in Figure 6-1. It provides a qualitative description of an individual's progression through various stages of infection, disease/illness, full recovery (R) or death (D). Quantitative estimates of the economic burden of an infection are derived by assigning probabilities (sample proportions, P) to the arrows depicting transitions from the various health outcome states, combined with information on the time spent in each state and the associated (present value) direct, indirect and disutility costs. The economic cost per case is thus given by the probability-weighted sum of (discounted or undiscounted) costs across all relevant health outcome states, including death. The projected economic cost per case in future year t is then multiplied by the projected number of new incidence cases in that year to derive a measure of the total future economic burden of new infections attributable to climate change.

A number of studies have employed Cost-of-Illness approaches to estimate the economic burden of Lyme disease from different perspectives (e.g., healthcare payer, societal).[90] We have used these studies as a basis to develop economic unit costs to value projected new incident cases of Lyme disease in Canada, from a societal perspective. These studies typically distinguish between three possible clinical outcomes, as shown in Figure 6-2. The first outcome is the presence of erythema migrans (an enlarging skin lesion at the site of the tick bite), from which people usually fully recover. If not (successfully) treated, the pathogen may disseminate from the site of the bite, leading to more serious outcomes, which may manifest as a multi-symptom disease with skin (secondary migrans), cardiac, musculoskeletal, and neurological symptoms. Individuals with either erythema migrans or disseminated Lyme borreliosis may develop a more chronic form of the disease, with persisting symptoms, such as fatigue, pain and cognitive impairment. However, in the case of these chronic symptoms, there is often no convincing scientific (clinical or laboratory) evidence of a relationship with *B. burgdorferi* infection, objective signs of infection, or a history of exposure to areas where Lyme disease is endemic[91]. Indeed, more than 10% of the general population in the U.S. exhibit symptoms that could be clinically consistent chronic Lyme disease[92]. Given the questionable association between chronic symptoms and persistent infection with *B. burgdorferi*, and in contrast to the other national level costing studies referenced above, we do not include the costs of persisting symptoms in our central case analysis. Appendix IV provides estimated unit costs for Lyme disease inclusive of persisting symptoms for interested readers.

The proportions of people with confirmed infections experiencing each clinical outcome shown in Figure 6-2 are taken from Wijngaard et al. (2015 and 2017). A review of 114 death certificates listing Lyme disease as a cause of death in the U.S. by the CDC found that only one record was consistent with clinical outcomes of Lyme disease.[93] That same study (Kugeler et al., 2011) reported that found that of the 96,068 confirmed cases of Lyme disease over the 1999-2003 period, Lyme disease was the cause of death of 23 individuals, as coded in death records. This equates to a mortality rate of only 0.024% per confirmed case of Lyme disease over the period 1999-2003. We have therefore not included mortality outcomes in our unit cost estimates. Shing et al (2018), likewise, excluded mortality from their cost analysis.

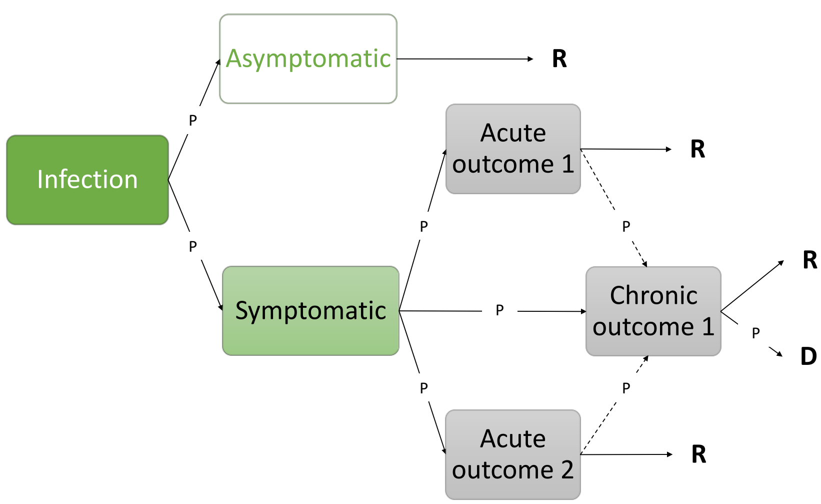


Figure 6-1: Generic outcome tree linking infection and all health outcomes

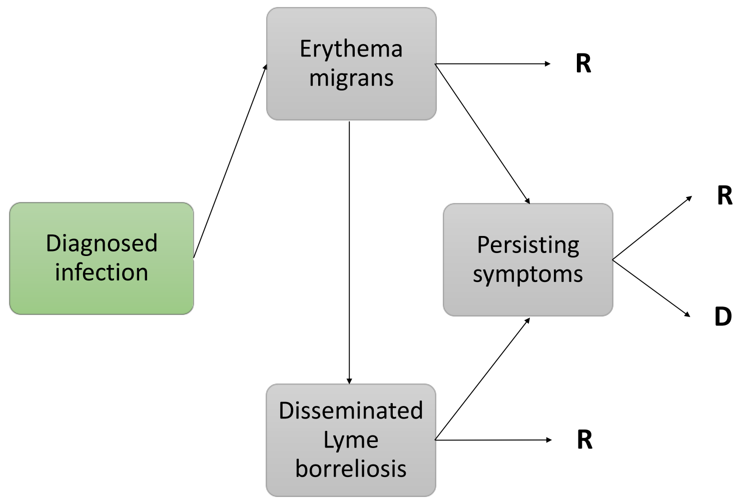


Figure 6-2: Outcome tree for valuation of Lyme disease health outcomes

Note: economic unit costs associated with persisting symptoms are not included in our results.

As discussed above, the societal costs of a disease comprise three components: direct resource costs; opportunity costs (e.g., lost production); and disutility costs. All three components are included in our estimated economic unit costs for Lyme disease cases. Estimated resource costs (inpatient care, outpatient care, drug costs, patient costs) and productivity losses, by clinical outcome, are based on Zhang et al. (2006), Adrion et al. (2015), Wijngaard et al. (2017) and Shing et al (2018). As per Robinson et al. (2018) and Robinson and Hammitt (2018), annual cost estimates from Zhang et al. (2006) and Adrion et al. (2015) are first inflated to 2015 US dollars using the U.S. Medical Care Cost Index (for indirect medical costs), the U.S. All-items Consumer Price Index for All Urban Consumers (for patient costs), and the U.S. Employment Cost Index (for lost production), then converted to 2015 Canadian dollars using PPP exchange rates.[94] Likewise, direct resource cost information from Wijngaard et al. (2017) is first adjusted to 2015 euros using the Consumer Price Index (HICP) for the health sector in the Netherlands, then converted to 2015 Canadian dollars using PPP exchange rates. Canadian healthcare resource cost information from Shing et al. (2015) is inflated to 2015 dollars using the "health care" product group of the Consumer Price Index.

The estimated duration of the different clinical outcomes was taken from Table 2 in van den Wijngaard et al. (2015). The duration of erythema migrans and disseminated Lyme disease is assumed to be, respectively, 35 [26 - 47] days and 158 [111 - 239] days.[18] These estimates of disease duration are used in the calculation of Disability-adjusted life years (DALYs)[95]. To approximate the disutility costs associated with a new incident case of Lyme disease, we have combined estimated Disability-adjusted life years by clinical outcome from van den Wijngaard et al. (2015)[96] with the projected estimates for the Value of a Statistical Life Year (VSLY) discussed above (recall Table 6-4).[97]

The total unit costs used in the calculation of projected Lyme disease costs are shown in Table 6-6; the footnote to the table provides the breakdown of the central estimates between direct resource costs, opportunity costs and disutility costs. The latter account for 96-97% of total costs per new incident case of Lyme disease.

[18] Persistent symptoms are assumed to last for 1,667 [1,430 - 1,910] days. This assumption may be conservative. In a recently published survey of 3,000 individuals diagnosed with chronic Lyme disease, the majority of respondents said they had been experiencing symptoms for 10 of more years.[18]

Table 6-6: Projected expected (undiscounted) life-time costs for valuation of new incident cases of Lyme disease diagnosed in 2016, 2055 and 2085 (excluding chronic effects)

	Low ($ 2015 per case)	Central ($ 2015 per case)	High ($ 2015 per case)
2016	6,880	*26,795	84,315
2050s	7,145	**27,705	87,020
2080s	7,400	***28,610	89,750

Note: * 0.9% are resource costs, 1.9% are opportunity costs and 97.2% are disutility costs; ** 1.1% are resource costs, 2.2% are opportunity costs and 96.7% are disutility costs; *** 1.3% are resource costs, 2.4% are opportunity costs and 96.3% are disutility costs.

6.2 Labour

The direct economic consequences of climate induced changes in labour supply are monetized using two metrics:

- Total payroll compensation per hour worked (or "hourly compensation"). It is calculated as the ratio between total compensation paid all jobs and the number of hours worked in all jobs. Total compensation is a measure of the total payroll costs of domestic producers. It consists of all payments, whether cash or in-kind, to workers for services rendered, including salaries and social contributions paid by employers, plus an imputed labour income for self-employed workers.
- Labour productivity. It is calculated as the ratio between value added generated and hours worked in all jobs. Labour productivity provides a measure of losses to society, differentiating it from the loss of compensation—a measure that more reflects losses for the individual worker. For a specific sector, value added is given by that sector's gross output (mainly sales) less purchases of intermediate goods and services supplied by other sectors. It corresponds to GDP at basic prices.

For each province and territory, the above metrics have been calculated for each 2-digit NAICS industry for the baseline year 2016.[19] By way of example, values for Newfoundland and Labrador and Prince Edward Island are shown in Table 6-7 and Table 6-8, respectively. NAICS industries are organized by "high-risk" and "low-risk" occupations (see the discussion above).

Like US EPA (2015 and 2017), future values for each metric are generated as follows, using hourly compensation (C) as an example:

$$C_{i,j,t} = C_{i,j,2016} \times \frac{GDP_{j,t}/Population_{j,t}}{GDP_{j,2016}/Population_{j,2016}}$$

Where i is the NAICS industry, j is the province or territory and t is the future year of interest. The same industry-specific unit value is assumed to apply across all census divisions within a province or territory. In effect, C is a provincial or territorial average value for industries in future years. A set of central, low, and high projected payroll compensation and labour productivity costs were generated based on central, low, and high projections for GDP and population by region. Table 6-9 shows the base year and projected costs used in the analysis, for the 2050s and 2080s for the central case, for each "high-risk" sector, by province and territory.

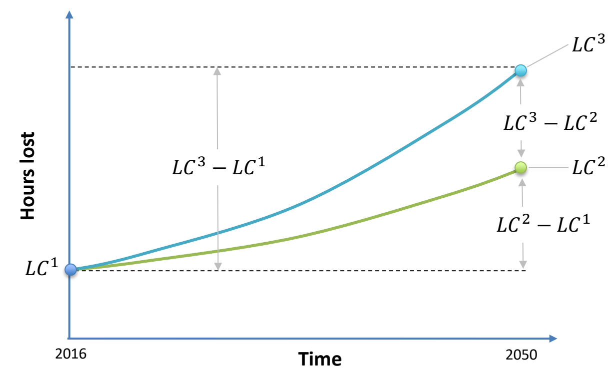
[19] The ratio of labour compensation per hour and labour productivity provides an indicator of unit labour costs (i.e., total payroll costs per unit of GDP).

Calculations of economic costs

The analytical framework underpinning the calculation of economic losses due to temperature-related impacts on labour productivity is depicted in Figure 6-3.

Figure 6-3: Analytical framework for calculating physical impacts on labour productivity for 2050

Labour force	Climate: Baseline f_{2016}	Climate: Future f_{2050}
Base year LF_{2016}	LC^1	
Future LF_{2050}	LC^2	LC^3



$LC^1 =$ Labour supply costs in base year under baseline climate scenario

$LC^2 =$ Labour supply costs in future under baseline climate scenario

$LC^3 =$ Labour supply costs in future under projected future climate scenario

$\Delta LC^{SC} = LC^2 - LC^1 =$ Cost of labour productivity impacts due to socioeconomic change (SC); no climate change

$\Delta LC^{TR} = LC^3 - LC^1 =$ Cost of labour productivity impacts due to socioeconomic and climate change (change in total risk, TR)

$\Delta LC^{CC} = LC^3 - LC^2 =$ Cost of labour productivity impacts due to climate change (CC)

Future labour supply costs (LSC) for the three physical impact scenarios (H^1, H^2 and H^3) shown in Figure 6-3 are calculated as follows, using the period 2041-70 and hourly compensation (C) as an example: [20]

$$LSC^1_{i,d(j),2016} = \sum_{T=1}^{16} C_{i,j,2016} \times \frac{1}{60} \times LF_{i,d(j),2016} \times f^T_{1970-00} \times \left(365 \times h_{i,j,2016}\right) \times ER^T$$

$$LSC^2_{i,d(j),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} \sum_{T=1}^{16} C_{i,j,t} \times \frac{1}{60} \times LF_{i,d(j),t} \times f^T_{1970-00} \times \left(365 \times h_{i,j,2016}\right) \times ER^T \right]$$

$$LSC^3_{i,d(j),2041-70} = \frac{1}{30} \times \left[\sum_{t=2041}^{2070} \sum_{T=1}^{16} C_{i,j,t} \times \frac{1}{60} \times LF_{i,d(j),t} \times f^T_t \times \left(365 \times h_{i,j,2016}\right) \times ER^T \right]$$

[20] Note that the difference between LSC^2 and LSC^3 in this example is that the former is based on current climate conditions measured by the 30-year average climate normal ($f^T_{1970-00}$) whereas the latter is based on projected climate conditions in each year over the period 2041-70 (denoted by f^T_t).

Where LSC is the annual average economic costs of labour hours lost under each scenario defined by the super scripts 1, 2 and 3 (see Figure 6-3). All other variables and subscripts are as defined above.

With this approach, economic costs are also estimated for each future year of interest for LSC^2 and LSC^3. As noted above, this is necessary to enable cost-benefit analysis of adaptation options and the calculation of cumulative (discounted and undiscounted) impacts (and costs) over time.

The incremental economic costs (2015 dollars, on average, per year) of socioeconomic change (denoted by the superscript SC), climate change (denoted by the superscript CC), and both (denoted by the superscript TR) are estimated as follows:

$$\Delta LSC_{i,d(j),2041-70}^{SC} = LCS_{i,d(j),2041-70}^{2} - LSC_{i,d(j),2016}^{1}$$

$$\Delta LSC_{i,d(j),2041-70}^{CC} = LSC_{i,d(j),2041-70}^{3} - LSC_{i,d(j),2041-70}^{2}$$

$$\Delta LSC_{i,d(j),2041-70}^{TR} = LSC_{i,d(j),2041-70}^{3} - LSC_{i,d(j),2016}^{1}$$

Total labour supply costs for all affected industries or individual industries, and/or for individual or all provinces or territories, and/or for individual epochs or all future years are generated by summing across the relevant sets of results.

Table 6-7: Base year (2016) metrics for measuring economic consequences of climate-induced changes in labour supply: Newfoundland and Labrador (Source: Derived from Statistics Canada, Table 36-10-0480-01)

NAICS industry	Canada	Total jobs	Hours worked (all jobs)	Average annual hours	Total compensation (all jobs)	GDP at basic prices	Labour productivity	Hourly Compensation	Unit labour costs
		(jobs)	(thousand hours)	(hours per job)	($ 2015 million)	($ 2015 million)	($ 2015 GDP per hour)	($ 2015 per hour)	($ 2015 per unit of GDP)
	High-risk								
11	Agriculture, forestry, fishing and hunting	3,290	6,606	2,008	150	599	90.7	22.7	0.250
21	Mining and oil and gas extraction	6,325	14,689	2,322	920	5,346	363.9	62.6	0.172
22	Utilities	2,315	4,597	1,986	254	543	118.1	55.2	0.467
23	Construction	29,585	69,816	2,360	2,517	4,099	58.7	36.1	0.614
31-33	Manufacturing	8,160	14,508	1,778	690	1,256	86.5	47.5	0.549
48-49	Transportation and warehousing	8,935	17,799	1,992	640	943	53.0	35.9	0.678
	Sub-total / average	58,610	128,014	2,184	5,170	12,786	99.9	40.4	0.404
	Low-risk								
41	Wholesale trade	6,095	11,256	1,847	415	689	61.2	36.8	0.602
44-45	Retail trade	28,815	46,375	1,609	1,066	1,613	34.8	23.0	0.661
51	Information and cultural industries	2,485	4,215	1,696	201	669	158.6	47.7	0.301
52	Finance and insurance	6,785	11,958	1,762	524	944	79.0	43.8	0.555
53	Real estate, rental and leasing	2,515	4,578	1,820	136	659	143.9	29.7	0.207
54	Professional, scientific and technical services	8,160	15,135	1,855	627	956	63.2	41.4	0.655
55	Holding companies	1,565	2,956	1,889	92	97	32.9	31.2	0.949
56	Administrative and support, waste management and remediation services	6,900	12,087	1,752	344	430	35.6	28.5	0.801
61	Educational services	995	1,368	1,375	23	28	20.5	16.6	0.810
62	Health care and social assistance	9,970	17,061	1,711	490	743	43.6	28.7	0.659
71	Arts, entertainment and recreation	2,165	2,922	1,350	50	71	24.2	17.0	0.704
72	Accommodation and food services	16,060	24,544	1,528	444	569	23.2	18.1	0.780
81	Other private services	7,965	13,698	1,720	297	337	24.6	21.6	0.880
81	Non-profit institutions serving households	7,965	13,698	1,720	297	337	24.6	21.6	0.880
91	Government sector	64,985	110,715	1,704	4,663	6,000	54.2	42.1	0.777
	Sub-total / average	173,425	292,566	1,687	9,668	14,142	48.3	33.0	0.684

Table 6-8: Base year (2016) metrics for measuring economic consequences of climate induced changes in labour supply: Prince Edward Island (Source: Derived from Statistics Canada, Table 36-10-0480-01)

NAICS industry	Canada	Total jobs	Hours worked (all jobs)	Average annual hours	Total compensation (all jobs)	GDP at basic prices	Labour productivity	Hourly Compensation	Unit labour costs
		(jobs)	(thousand hours)	(hours per job)	($ 2015 million)	($ 2015 million)	($ 2015 GDP per hour)	($ 2015 per hour)	($ 2015 per unit of GDP)
	High-risk								
11	Agriculture, forestry, fishing and hunting	4,455	9,979	2,240	151	391	39.2	15.1	0.385
21	Mining and oil and gas extraction	55	105	1,902	3	5	49.8	24.7	0.495
22	Utilities	220	414	1,881	24	73	177.2	58.0	0.327
23	Construction	4,675	9,785	2,093	238	311	31.8	24.3	0.763
31-33	Manufacturing	5,075	9,970	1,964	294	629	63.1	29.5	0.468
48-49	Transportation and warehousing	2,045	4,479	2,190	106	201	44.9	23.6	0.526
	Sub-total / average	16,525	34,731	2,102	815	1,611	46.4	23.5	0.506
	Low-risk								
41	Wholesale trade	1,825	3,046	1,669	97	115	37.7	31.9	0.845
44-45	Retail trade	7,870	12,629	1,605	256	392	31.1	20.3	0.653
51	Information and cultural industries	575	969	1,685	33	161	166.2	33.9	0.204
52	Finance and insurance	2,065	3,674	1,779	137	279	75.9	37.2	0.490
53	Real estate, rental and leasing	930	1,749	1,880	33	152	87.0	18.9	0.217
54	Professional, scientific and technical services	2,360	4,242	1,798	137	172	40.5	32.3	0.798
55	Holding companies	210	358	1,706	11	27	74.3	30.8	0.415
56	Administrative and support, waste management and remediation services	2,520	4,227	1,677	81	116	27.3	19.0	0.697
61	Educational services	520	712	1,370	13	10	14.5	18.1	1.241
62	Health care and social assistance	3,285	5,437	1,655	127	174	32.1	23.3	0.728
71	Arts, entertainment and recreation	1,180	1,900	1,610	22	24	12.6	11.5	0.916
72	Accommodation and food services	5,300	8,415	1,588	123	170	20.2	14.7	0.724
81	Other private services	2,365	4,179	1,767	70	83	20.0	16.7	0.836
81	Non-profit institutions serving households	2,365	4,179	1,767	70	83	20.0	16.7	0.836
91	Government sector	20,665	34,206	1,655	1,286	1,533	44.8	37.6	0.839
	Sub-total / average	54,035	89,921	1,664	2,496	3,493	38.8	27.8	0.715

Table 6-9: Base year and projected payroll compensation costs and labour productivity costs for the 2050s and 2080s, by "high-risk" sector, by province and territory (central case)

	NAICS 11						NAICS 21					
	Payroll compensation ($ 2015 per hour)			Labour productivity ($ 2015 GDP per hour)			Payroll compensation ($ 2015 per hour)			Labour productivity ($ 2015 GDP per hour)		
	2016	2050s	2080s	2016	2050s	2080s	2016	2050s	2080s	2016	2050s	2080s
Newfoundland and Labrador	23	31	39	91	123	155	63	85	107	364	493	622
Prince Edward Island	15	13	12	39	35	32	25	22	20	50	44	40
Nova Scotia	18	22	25	44	52	59	48	57	65	73	87	99
New Brunswick	20	23	26	46	54	61	37	43	48	88	103	115
Quebec	16	19	22	44	54	63	44	53	62	109	133	155
Ontario	14	18	22	31	40	48	53	67	81	118	150	181
Manitoba	13	17	21	42	55	68	46	60	74	191	249	306
Saskatchewan	12	15	17	80	99	117	55	68	80	261	324	383
Alberta	15	19	22	55	67	78	70	85	98	166	201	234
British Columbia	26	29	32	55	62	69	55	62	68	173	195	215
Yukon	16	17	17	23	24	25	53	55	56	182	189	195
Northwest Territories	21	28	35	38	51	63	78	104	129	165	219	272
Nunavut	27	29	30	109	116	122	56	60	63	127	134	141

	NAICS 22						NAICS 23					
	Payroll compensation ($ 2015 per hour)			Labour productivity ($ 2015 GDP per hour)			Payroll compensation ($ 2015 per hour)			Labour productivity ($ 2015 GDP per hour)		
	2016	2050s	2080s	2016	2050s	2080s	2016	2050s	2080s	2016	2050s	2080s
Newfoundland and Labrador	55	75	94	118	160	202	36	49	62	59	80	100
Prince Edward Island	58	51	47	177	157	143	24	22	20	32	28	26
Nova Scotia	57	68	77	189	224	255	28	33	37	37	43	49
New Brunswick	62	72	81	177	207	233	26	31	35	38	45	51
Quebec	62	76	89	253	309	361	37	45	53	52	64	75
Ontario	59	75	90	161	204	246	37	45	53	52	66	80
Manitoba	62	80	98	205	268	328	33	42	52	45	58	72
Saskatchewan	59	73	86	267	332	392	34	42	50	58	71	84
Alberta	71	86	100	141	171	198	41	50	58	59	72	84
British Columbia	63	72	79	293	331	364	35	39	43	51	58	64
Yukon	80	84	86	176	184	189	42	44	45	78	81	83
Northwest Territories	81	107	133	155	205	255	48	64	79	103	136	169
Nunavut	82	88	92	107	113	119	40	43	45	82	87	91

	NAICS 31-33						NAICS 48-49					
	Payroll compensation ($ 2015 per hour)			Labour productivity ($ 2015 GDP per hour)			Payroll compensation ($ 2015 per hour)			Labour productivity ($ 2015 GDP per hour)		
	2016	2050s	2080s	2016	2050s	2080s	2016	2050s	2080s	2016	2050s	2080s
Newfoundland and Labrador	48	64	81	87	117	148	36	49	61	53	72	100
Prince Edward Island	30	26	24	63	56	51	24	21	19	45	40	26
Nova Scotia	33	39	44	47	55	63	27	32	36	38	46	49
New Brunswick	27	31	35	51	59	67	26	30	34	43	50	51
Quebec	37	45	53	59	73	85	28	35	41	45	56	75
Ontario	40	51	61	67	85	102	29	37	44	47	59	80
Manitoba	34	44	54	55	72	88	30	39	47	55	72	72
Saskatchewan	37	46	55	82	102	120	30	37	43	71	88	84
Alberta	42	52	60	104	126	146	37	45	52	74	90	84
British Columbia	39	44	48	59	67	74	35	40	44	59	67	64
Yukon	40	42	43	65	68	70	40	42	43	58	60	83
Northwest Territories	35	46	57	80	106	132	45	59	74	110	146	169
Nunavut	37	40	42	79	84	88	39	41	43	48	51	91

7. “Cost of Inaction” Results

This section presents key results of the analysis as pooled estimates of the seven climate models considered. The outcomes are presented as annual averages over 30-year periods, as national totals, by province/territory and by sector, as relevant.

7.1 Hot Temperatures

Mortality impacts and costs

Projected excess deaths associated with exposure of the general population to mean daily temperatures **above** the “optimum temperature” (recall Section 5.1.1) are summarized in Table 7-1 and Table 7-2 for RCP 4.5 and RCP 8.5, respectively. Thirty-year annual average results are presented for both the 2050s and 2080s. For both future time periods, results are provided for three scenarios: (1) the incremental total effect relative to the baseline (the baseline is a combination of 2016 socioeconomic data and climate data for the 1971-2000 climate normal); (2) the incremental effect attributable to projected socioeconomic change only; and (3) the incremental effect attributable to climate change only (see Figure 5-1 for a graphical representation of what these three scenarios entail). (1) can be interpreted as the change in total risk associated with exposures to heat. Furthermore, **results are shown for a “central case” and an “interval”. The central case combines the mean climate projection across the seven GCMs with central case assumptions across all other input variables (ERFs and socioeconomic data); the interval shows the range of projected results from combining the mean climate projection across the seven GCMs with low and high assumptions for ERFs and socioeconomic data.**[98]

In line with expectations, the results in Table 7-1 and Table 7-2 show that: (a) as the number of people exposed to heat stress grows in the future, excess heat-related deaths likewise increase, even in the absence of further climate change; and (b) as ambient daily temperatures rise because of projected climate change, the number of days with mean daily temperatures above the “optimum temperature” increases relative to the baseline, resulting in an increase in excess heat-related deaths. With respect to heat exposures, both effects are additive. By the 2050s and 2080s under RCP 8.5, projected excess deaths for Canada due to a combination of socioeconomic change and climate change amount to about 535 [315, 770] and 1,040 [575, 1,600] deaths per year. Under RCP 4.5 the corresponding values for Canada are 440 [260, 645] and 730 [390, 1,150] deaths per year.

Looking at the 2080s, approximately 76% of total projected excess deaths from heat are attributable to climate change alone under RCP 8.5. In contrast, deaths attributable to climate alone account for about 65% of total projected excess deaths under RCP 4.5. **With lower levels of climate change, socioeconomic developments become a more influential driver of total physical risk for heat exposures; though climate change is still the most important driver of projected excess deaths under the lower emissions pathway**.

As described in Section 5.1.1, we applied ERFs derived from urban studies to the entire population of each Census Division—thereby treating urban and rural populations alike. However, heat tends to impact people living in urban centres more so than populations in rural areas.[99] We are therefore likely overestimating projected heat-related mortality. Ideally, urban-specific and rural-specific ERFs should be applied to the respective populations of each Census Division, as per Paci (2014) for Europe. This was not possible due to a lack of rural-specific heat-related mortality ERFs for Canada; moreover, we did not have rural-urban population splits for each Census Division. Population splits were nonetheless available at the provincial and territorial level for 2016. Using these data, we performed a sensitivity test—removing the rural population from the analysis. Rural-urban population splits in 2016 were held constant through 2100 and our urban-specific ERFs were applied to the projected urban population. **Looking at RCP 8.5, by the 2050s and 2080s, projected excess deaths for Canada's urban population due to a combination of socioeconomic change and climate change amount to about 435 and 845 deaths per year; a reduction of 19% on our central estimates**. Projected heat-related mortality would be less than half our central estimates for New Brunswick, Nunavut, and Prince Edward Island if we restricted the analysis to urban populations.

Though our results are not strictly comparable with those produced by NRTEE (2011) for heat-related mortality for Vancouver, Calgary, Toronto and Montreal—due to *inter alia* differences in climate and socioeconomic scenarios, averaging periods and methodology—our results are considerably lower. Across these four cities projected excess deaths under the high-climate scenario by the 2080s were roughly 7-9 per 100,000 population.[100] Across the same four cities our results for the 2080s under RCP 8.5 equate to just under 2 excess deaths per 100,000.[101] Similarly, a climate costing study by Larrivée et al. (2015) focused on Quebec estimated the costs of heatwaves and applied a mortality rate due to heat in 2050s of 7.1/100,000 for people under 64 years old and 12.5/100,000 for people 65 and older. These excess mortality rates are also higher than our results.

We originally proposed two approaches to model temperature-related mortality; the one we adopted, based on Gasparrini et al. (2015) and an alternative approach based on Martin et al. (2012). We discarded the latter approach because it would not have allowed us to calculate baseline impacts and costs and consequently separate the influence of socioeconomic change from climate change on total risk. To further contextualize our results, we have estimated relationships between increases in annual heat-related mortality and a 1°C change in mean summer temperatures from Martin et al. (2012) and used those relationships to estimate the excess mortality rate for the same four cities for the 2080s under RCP 8.5.[102] The resultant average excess death rate is just under 5/100,000. This **suggests our projected excess deaths from heat exposures in urban areas may be conservative in magnitude**.

Using the Martin et al. (2012) ERFs, we also performed a sensitivity test for acclimatization for the same four cities for the 2080s under RCP 8.5. Assuming people acclimatize to 0.5°C of warming every three decades[103], the average projected excess death rate falls by about 20%, from just under 5/100,000 to just under 4/100,000. PESETA II assumed people acclimatize faster; 0.75°C every three decades[104]. At this rate of acclimatization, the average projected excess death rate falls by 30% to about 3.4/100,000. **Allowing for acclimatization to warmer temperatures in Vancouver, Calgary, Toronto and Montreal, reduces projected excess mortality by the 2080s under RCP 8.5 by 20% to 30%; projected costs would fall by similar amounts.**

Figure 7-1 contains box-whisker plots for projected excess deaths from heat exposures for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada. The plots show the full range of results across the seven GCMs for central case assumptions for all other input variables. These plots thus isolate the impact of future climate uncertainty on the overall results. By the 2080s under RCP 8.5, for example, projected excess deaths for Canada due to a combination of socioeconomic change and climate change across all seven GCMs range from 780-1,226 [880-1,125] deaths per year. This represents a smaller uncertainty range than for the impact models (ERFs) and socioeconomic data (i.e., 575-1,600 deaths per year). Nonetheless, **combining climate, impact model and socioeconomic uncertainties would lead to a very large interval bounding the results**.

Projected years of life lost (YLL) associated with heat exposures of the general population are summarized in Table 7-3 and Table 7-4 for RCP 4.5 and RCP 8.5, respectively. YLL is an alternative way to express projected excess deaths, accounting for assumptions regarding the age at death and forgone life expectancy—essentially giving lower weight to deaths at older ages (recall the discussion in Section 5.1.1 and Section 6.1.3). By the 2050s and 2080s under RCP 8.5, projected YLL for Canada due to socioeconomic change and climate change are about 915 [545, 1,320] YLL and 1,780 [985, 2,740] YLL. The corresponding values under RCP 4.5 for Canada are 760 [445, 1,110] YLL and 1,225 [675, 1,975] YLL.

Three different approaches were used to value projected physical impacts; excess deaths were monetized using the VSL (see Table 7-5 and Table 7-6) and measures of Human Capital (see Table 7-7 and Table 7-8), while YLL were monetized using the VSLY (see Table 7-9 and Table 7-10). Both VSL and VSLY are measures of welfare loss (or disutility costs). By the 2050s and 2080s under RCP 8.5, projected annual average welfare losses for Canada based on the VSL amount to about $4.7 [$1.5, $10.0] billion and $10.4 [$3.1, $23.5] billion (2015 dollars), respectively. The associated welfare cost of climate change from heat exposures amount to $3.6 [$1.3, $7.2] billion and $7.9 [$2.5, $16.8] billion. **Projected financial costs** under the central case, measured using the Human Capital approach, **are substantially lower than projected welfare costs, by nearly an order of magnitude** for both RCPs.

Morbidity impacts and costs

The projected costs of hospitalizations for heat exposures are summarized in Table 7-11 and Table 7-12 for, respectively, RCP 4.5 and RCP 8.5. These costs include excess hospitalizations associated with CHD, hypertensive diseases, diabetes, and stroke. By the 2050s and 2080s under RCP 8.5, projected annual average financial costs from increased hospitalizations for Canada amount to about $165 [$60, $295] million and $385 [$125, $725] million (2015 dollars), respectively.[105] The corresponding annual average costs of climate change are $125 [$45, $210] million and $285 [$100, $510] million. Figure 7-2 provides box-whisker plots for projected excess hospitalizations from heat exposures for the 2050s and 2080s under RCP 4.5 and RCP 8.5, by individual province and territory. Similar to the discussion of Figure 7-1 above, these box-whisker plots show the impact of future climate uncertainty on the overall results.

Total impacts and costs

Combining both mortality and morbidity impacts, **the total social costs** (using the VSL to value excess deaths) **of heat exposures under RCP 8.5 for the 2050s and 2080s, are about $4.9 [$1.6, $10.3] billion per year and $10.8 [$3.2, $24.2] billion per year, respectively**.[106] The corresponding social costs of climate change are about $3.7 [$1.3, $7.4] billion per year and $8.2 [$2.6, $17.3] billion per year. Hence, **approximately 75%-76% of the projected total social costs of heat-exposures in Canada are due to climate change**, with **the remaining 24%-25% being attributable to socioeconomic growth.**

Morbidity outcomes account for roughly 3%-4% of total social costs, though only hospitalizations from four heat-sensitive diseases and only the financial costs associated with inpatient care and lost productivity were included—we were not able to capture relevant disutility costs within the scope of this study. The total (both mortality and morbidity impacts) financial costs (using the Human Capital approach to value excess deaths + financial costs of inpatient care and lost productivity) of heat exposures under RCP 8.5 for the 2050s and 2080s, are about $0.7 [$0.3, $1.1] billion per year and $1.5 [$0.7, $2.8] billion per year, respectively.[107] The corresponding financial costs of climate change are about $0.5 [$0.2, $0.8] billion per year and $1.1 [$0.5, $2.0] billion per year. In this case, morbidity outcomes account for roughly 24%-25% of total financial costs.

Table 7-1: Projected heat mortality impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental deaths relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in MORTALITY from baseline due to (deaths per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	55	[32 , 76]	98	[52 , 145]
Alberta	37	[24 , 53]	74	[46 , 111]
Saskatchewan	18	[11 , 26]	35	[19 , 52]
Manitoba	20	[11 , 29]	35	[19 , 57]
Ontario	188	[110 , 277]	316	[170 , 503]
Quebec	94	[53 , 140]	135	[68 , 221]
New Brunswick	10	[6 , 15]	12	[6 , 21]
Nova Scotia	14	[7 , 21]	17	[8 , 30]
Prince Edward Island	3	[2 , 4]	4	[2 , 7]
Newfoundland and Labrador	4	[2 , 5]	4	[2 , 6]
Sub-total Canada	**442**	**[259 , 646]**	**732**	**[391 , 1152]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	11	[4 , 18]	22	[8 , 36]
Alberta	13	[8 , 19]	27	[16 , 43]
Saskatchewan	7	[3 , 10]	14	[6 , 22]
Manitoba	8	[3 , 13]	15	[7 , 27]
Ontario	67	[32 , 113]	134	[60 , 237]
Quebec	20	[6 , 41]	38	[10 , 80]
New Brunswick	1	[0 , 2]	1	[-1 , 5]
Nova Scotia	1	[0 , 4]	2	[-1 , 8]
Prince Edward Island	1	[0 , 1]	1	[1 , 3]
Newfoundland and Labrador	0	[-1 , 0]	-1	[-1 , -1]
Sub-total Canada	**127**	**[55 , 221]**	**255**	**[106 , 460]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	44	[28 , 59]	76	[44 , 108]
Alberta	25	[17 , 33]	47	[30 , 68]
Saskatchewan	12	[7 , 15]	21	[12 , 30]
Manitoba	12	[8 , 17]	20	[12 , 30]
Ontario	121	[79 , 164]	181	[109 , 265]
Quebec	73	[47 , 99]	97	[58 , 141]
New Brunswick	9	[6 , 13]	11	[7 , 17]
Nova Scotia	12	[8 , 17]	15	[9 , 22]
Prince Edward Island	2	[1 , 2]	3	[2 , 4]
Newfoundland and Labrador	4	[3 , 6]	5	[3 , 6]
Sub-total Canada	**315**	**[204 , 425]**	**477**	**[285 , 692]**

Note: zero values are due to rounding

Table 7-2: Projected heat mortality impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental deaths relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in MORTALITY from baseline due to (deaths per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	73	[43 , 100]	153	[83 , 223]
Alberta	47	[31 , 65]	104	[65 , 153]
Saskatchewan	22	[13 , 31]	47	[26 , 70]
Manitoba	24	[14 , 35]	47	[25 , 73]
Ontario	217	[129 , 317]	425	[235 , 664]
Quebec	112	[65 , 165]	201	[107 , 317]
New Brunswick	13	[7 , 19]	20	[11 , 33]
Nova Scotia	17	[10 , 26]	27	[14 , 45]
Prince Edward Island	3	[2 , 5]	6	[3 , 10]
Newfoundland and Labrador	5	[3 , 7]	8	[4 , 11]
Sub-total Canada	**533**	**[317 , 770]**	**1,039**	**[574 , 1599]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	11	[4 , 18]	22	[8 , 37]
Alberta	13	[8 , 19]	27	[16 , 43]
Saskatchewan	7	[3 , 10]	14	[6 , 22]
Manitoba	8	[3 , 13]	15	[7 , 27]
Ontario	67	[31 , 113]	134	[60 , 237]
Quebec	20	[5 , 41]	38	[10 , 79]
New Brunswick	1	[0 , 2]	1	[-1 , 5]
Nova Scotia	1	[0 , 4]	2	[-1 , 8]
Prince Edward Island	1	[0 , 1]	1	[1 , 3]
Newfoundland and Labrador	0	[-1 , 0]	-1	[-1 , -1]
Sub-total Canada	**127**	**[55 , 221]**	**254**	**[106 , 459]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	62	[39 , 83]	131	[75 , 186]
Alberta	34	[23 , 46]	77	[49 , 110]
Saskatchewan	16	[10 , 21]	34	[20 , 48]
Manitoba	16	[10 , 22]	31	[19 , 46]
Ontario	150	[97 , 204]	291	[175 , 428]
Quebec	92	[60 , 125]	163	[97 , 238]
New Brunswick	12	[8 , 16]	19	[11 , 28]
Nova Scotia	16	[10 , 22]	25	[15 , 37]
Prince Edward Island	2	[1 , 3]	4	[3 , 7]
Newfoundland and Labrador	6	[4 , 8]	9	[5 , 12]
Sub-total Canada	**406**	**[262 , 549]**	**785**	**[468 , 1140]**

Note: zero values are due to rounding

Table 7-3: Projected heat mortality impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental years of life lost (YLL) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in MORTALITY from baseline due to (years of life lost per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	83	[49 , 116]	149	[79 , 219]
Alberta	73	[47 , 102]	144	[90 , 215]
Saskatchewan	29	[17 , 41]	57	[31 , 84]
Manitoba	35	[20 , 52]	63	[33 , 100]
Ontario	328	[192 , 483]	550	[295 , 876]
Quebec	155	[88 , 232]	225	[113 , 367]
New Brunswick	18	[10 , 28]	22	[11 , 38]
Nova Scotia	24	[13 , 36]	30	[14 , 51]
Prince Edward Island	4	[3 , 7]	7	[4 , 12]
Newfoundland and Labrador	8	[4 , 11]	8	[3 , 11]
Sub-total Canada	**758**	**[444 , 1108]**	**1,255**	**[673 , 1975]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	17	[7 , 27]	33	[13 , 55]
Alberta	24	[15 , 37]	52	[31 , 84]
Saskatchewan	11	[5 , 17]	22	[10 , 36]
Manitoba	13	[6 , 23]	27	[12 , 47]
Ontario	117	[55 , 197]	234	[105 , 414]
Quebec	34	[9 , 68]	63	[16 , 132]
New Brunswick	1	[-1 , 4]	2	[-1 , 8]
Nova Scotia	2	[-1 , 7]	4	[-1 , 13]
Prince Edward Island	1	[1 , 2]	3	[1 , 5]
Newfoundland and Labrador	-1	[-1 , -1]	-2	[-2 , -1]
Sub-total Canada	**219**	**[95 , 381]**	**439**	**[184 , 793]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	67	[42 , 89]	116	[66 , 164]
Alberta	48	[33 , 65]	92	[59 , 132]
Saskatchewan	19	[12 , 25]	34	[20 , 49]
Manitoba	22	[14 , 30]	36	[22 , 53]
Ontario	211	[137 , 286]	316	[190 , 462]
Quebec	122	[79 , 164]	161	[96 , 234]
New Brunswick	17	[11 , 23]	20	[12 , 30]
Nova Scotia	21	[14 , 29]	26	[15 , 38]
Prince Edward Island	3	[2 , 4]	4	[3 , 7]
Newfoundland and Labrador	9	[6 , 12]	10	[5 , 13]
Sub-total Canada	**538**	**[349 , 727]**	**815**	**[489 , 1182]**

Note: zero values are due to rounding

Table 7-4: Projected heat mortality impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental years of life lost (YLL) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in MORTALITY from baseline due to (years of life lost per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	1	[0 , 1]
Northwest Territories	0	[0 , 0]	1	[0 , 1]
British Columbia	111	[66 , 152]	232	[126 , 338]
Alberta	91	[59 , 127]	201	[126 , 298]
Saskatchewan	36	[21 , 50]	77	[42 , 113]
Manitoba	42	[24 , 61]	82	[45 , 129]
Ontario	378	[224 , 552]	741	[409 , 1157]
Quebec	187	[108 , 275]	334	[178 , 526]
New Brunswick	23	[13 , 34]	36	[20 , 59]
Nova Scotia	30	[17 , 45]	47	[24 , 77]
Prince Edward Island	5	[3 , 8]	10	[6 , 16]
Newfoundland and Labrador	11	[6 , 15]	16	[8 , 22]
Sub-total Canada	**913**	**[543 , 1319]**	**1,778**	**[984 , 2739]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	17	[7 , 27]	33	[13 , 55]
Alberta	24	[15 , 37]	52	[31 , 83]
Saskatchewan	11	[5 , 16]	22	[10 , 36]
Manitoba	13	[6 , 23]	27	[12 , 47]
Ontario	116	[55 , 197]	233	[105 , 412]
Quebec	34	[9 , 67]	63	[16 , 132]
New Brunswick	1	[-1 , 4]	2	[-1 , 8]
Nova Scotia	2	[-1 , 7]	4	[-1 , 13]
Prince Edward Island	1	[1 , 2]	3	[1 , 5]
Newfoundland and Labrador	-1	[-1 , -1]	-2	[-2 , -1]
Sub-total Canada	**219**	**[95 , 380]**	**438**	**[184 , 791]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	1	[0 , 1]
Northwest Territories	0	[0 , 0]	1	[0 , 1]
British Columbia	94	[59 , 125]	199	[113 , 282]
Alberta	66	[45 , 90]	149	[96 , 214]
Saskatchewan	25	[16 , 34]	54	[32 , 77]
Manitoba	28	[18 , 39]	56	[33 , 82]
Ontario	261	[169 , 355]	507	[304 , 745]
Quebec	153	[99 , 207]	271	[162 , 394]
New Brunswick	22	[14 , 30]	34	[21 , 51]
Nova Scotia	27	[17 , 38]	43	[25 , 64]
Prince Edward Island	4	[3 , 5]	8	[5 , 12]
Newfoundland and Labrador	12	[7 , 16]	18	[10 , 24]
Sub-total Canada	**694**	**[448 , 939]**	**1,340**	**[801 , 1947]**

Note: zero values are due to rounding

Table 7-5: Projected heat mortality impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (valued using the VSL) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5

WELFARE LOSS (valued with VSL) due to ($ million per year):	2050s Central	2050s Interval	2080s Central	2080s Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 1]	1	[0 , 2]
Northwest Territories	0	[0 , 1]	1	[0 , 2]
British Columbia	490	[154 , 992]	990	[282 , 2129]
Alberta	333	[117 , 684]	746	[250 , 1628]
Saskatchewan	162	[51 , 334]	353	[102 , 770]
Manitoba	177	[55 , 384]	357	[102 , 833]
Ontario	1,675	[528 , 3611]	3,178	[919 , 7397]
Quebec	833	[254 , 1818]	1,362	[368 , 3247]
New Brunswick	89	[28 , 198]	124	[33 , 312]
Nova Scotia	121	[36 , 272]	172	[43 , 435]
Prince Edward Island	22	[7 , 49]	41	[12 , 99]
Newfoundland and Labrador	35	[10 , 68]	39	[9 , 82]
Sub-total Canada	**3,938**	**[1240 , 8413]**	**7,362**	**[2121 , 16936]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	98	[21 , 229]	221	[46 , 537]
Alberta	112	[36 , 250]	271	[85 , 632]
Saskatchewan	59	[16 , 134]	139	[35 , 326]
Manitoba	67	[17 , 166]	152	[36 , 394]
Ontario	597	[151 , 1475]	1,352	[328 , 3492]
Quebec	181	[26 , 530]	384	[54 , 1171]
New Brunswick	6	[-2 , 32]	12	[-3 , 68]
Nova Scotia	11	[-2 , 53]	23	[-4 , 112]
Prince Edward Island	7	[2 , 17]	15	[4 , 42]
Newfoundland and Labrador	-4	[-3 , -6]	-8	[-5 , -11]
Sub-total Canada	**1,134**	**[262 , 2881]**	**2,562**	**[574 , 6764]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 1]	1	[0 , 1]
Northwest Territories	0	[0 , 1]	1	[0 , 1]
British Columbia	392	[133 , 764]	769	[236 , 1592]
Alberta	221	[80 , 434]	474	[164 , 996]
Saskatchewan	103	[35 , 201]	214	[68 , 444]
Manitoba	110	[38 , 218]	205	[66 , 439]
Ontario	1,078	[377 , 2136]	1,825	[591 , 3905]
Quebec	652	[228 , 1287]	977	[315 , 2076]
New Brunswick	83	[29 , 166]	112	[37 , 244]
Nova Scotia	110	[38 , 220]	149	[47 , 322]
Prince Edward Island	16	[6 , 32]	26	[9 , 58]
Newfoundland and Labrador	39	[13 , 74]	47	[14 , 93]
Sub-total Canada	**2,804**	**[977 , 5533]**	**4,800**	**[1546 , 10172]**

Note: zero values are due to rounding

Table 7-6: Projected heat mortality impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (valued using the VSL) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
WELFARE LOSS (valued with VSL) due to ($ million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	1	[0 , 1]	3	[1 , 5]
Northwest Territories	1	[0 , 1]	2	[1 , 4]
British Columbia	650	[208 , 1307]	1,543	[450 , 3279]
Alberta	416	[147 , 849]	1,042	[352 , 2253]
Saskatchewan	198	[63 , 404]	478	[142 , 1030]
Manitoba	209	[66 , 449]	468	[138 , 1073]
Ontario	1,932	[617 , 4127]	4,281	[1274 , 9772]
Quebec	1,002	[312 , 2153]	2,024	[581 , 4661]
New Brunswick	112	[36 , 246]	202	[59 , 482]
Nova Scotia	152	[46 , 334]	273	[74 , 656]
Prince Edward Island	27	[9 , 59]	59	[18 , 140]
Newfoundland and Labrador	48	[14 , 94]	78	[20 , 159]
Sub-total Canada	**4,748**	**[1519 , 10024]**	**10,452**	**[3109 , 23515]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	98	[21 , 229]	222	[46 , 538]
Alberta	112	[36 , 250]	271	[85 , 631]
Saskatchewan	59	[16 , 133]	139	[35 , 325]
Manitoba	67	[17 , 166]	152	[36 , 393]
Ontario	596	[151 , 1471]	1,349	[327 , 3483]
Quebec	181	[26 , 529]	383	[54 , 1167]
New Brunswick	6	[-2 , 32]	12	[-3 , 68]
Nova Scotia	11	[-2 , 53]	23	[-4 , 112]
Prince Edward Island	7	[2 , 17]	15	[4 , 42]
Newfoundland and Labrador	-4	[-3 , -6]	-8	[-5 , -11]
Sub-total Canada	**1,131**	**[262 , 2874]**	**2,556**	**[573 , 6749]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	1	[0 , 1]	3	[1 , 5]
Northwest Territories	1	[0 , 1]	2	[0 , 3]
British Columbia	552	[187 , 1077]	1,321	[405 , 2741]
Alberta	305	[110 , 599]	771	[266 , 1622]
Saskatchewan	139	[48 , 271]	339	[107 , 705]
Manitoba	142	[50 , 283]	317	[102 , 681]
Ontario	1,337	[467 , 2656]	2,932	[947 , 6289]
Quebec	821	[286 , 1624]	1,641	[527 , 3494]
New Brunswick	107	[37 , 213]	190	[62 , 414]
Nova Scotia	140	[48 , 281]	250	[79 , 544]
Prince Edward Island	20	[7 , 41]	44	[15 , 99]
Newfoundland and Labrador	53	[17 , 100]	86	[25 , 169]
Sub-total Canada	**3,617**	**[1257 , 7150]**	**7,895**	**[2535 , 16766]**

Note: zero values are due to rounding

Table 7-7: Projected heat mortality impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (valued using the VSLY) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
WELFARE LOSS (valued with VSLY) due to ($ million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	42	[13 , 86]	78	[22 , 168]
Alberta	37	[13 , 76]	75	[25 , 165]
Saskatchewan	15	[5 , 31]	30	[9 , 65]
Manitoba	18	[6 , 39]	33	[9 , 77]
Ontario	167	[53 , 360]	288	[83 , 671]
Quebec	79	[24 , 173]	118	[32 , 281]
New Brunswick	9	[3 , 20]	12	[3 , 29]
Nova Scotia	12	[4 , 27]	16	[4 , 39]
Prince Edward Island	2	[1 , 5]	4	[1 , 9]
Newfoundland and Labrador	4	[1 , 8]	4	[1 , 9]
Sub-total Canada	**386**	**[122 , 825]**	**657**	**[190 , 1512]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	8	[2 , 20]	17	[4 , 42]
Alberta	12	[4 , 28]	27	[9 , 64]
Saskatchewan	5	[1 , 12]	12	[3 , 27]
Manitoba	7	[2 , 17]	14	[3 , 36]
Ontario	59	[15 , 147]	123	[30 , 317]
Quebec	17	[3 , 50]	33	[5 , 101]
New Brunswick	1	[0 , 3]	1	[0 , 6]
Nova Scotia	1	[0 , 5]	2	[0 , 10]
Prince Edward Island	1	[0 , 2]	1	[0 , 4]
Newfoundland and Labrador	-1	[0 , -1]	-1	[-1 , -1]
Sub-total Canada	**112**	**[26 , 284]**	**230**	**[52 , 607]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	34	[12 , 66]	61	[19 , 126]
Alberta	25	[9 , 48]	48	[17 , 101]
Saskatchewan	9	[3 , 19]	18	[6 , 37]
Manitoba	11	[4 , 22]	19	[6 , 40]
Ontario	107	[38 , 213]	165	[54 , 354]
Quebec	62	[22 , 122]	84	[27 , 179]
New Brunswick	9	[3 , 17]	11	[3 , 23]
Nova Scotia	11	[4 , 22]	13	[4 , 29]
Prince Edward Island	2	[1 , 3]	2	[1 , 5]
Newfoundland and Labrador	5	[2 , 9]	5	[1 , 10]
Sub-total Canada	**274**	**[96 , 541]**	**427**	**[138 , 905]**

Note: zero values are due to rounding

Table 7-8: Projected heat mortality impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (valued using the VSLY) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
WELFARE LOSS (valued with VSLY) due to ($ million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 1]
Northwest Territories	0	[0 , 0]	0	[0 , 1]
British Columbia	56	[18 , 113]	122	[36 , 259]
Alberta	46	[16 , 94]	105	[36 , 228]
Saskatchewan	18	[6 , 37]	40	[12 , 86]
Manitoba	21	[7 , 45]	43	[13 , 99]
Ontario	192	[61 , 411]	388	[115 , 886]
Quebec	95	[30 , 204]	175	[50 , 403]
New Brunswick	12	[4 , 25]	19	[6 , 45]
Nova Scotia	15	[5 , 33]	25	[7 , 59]
Prince Edward Island	3	[1 , 6]	5	[2 , 13]
Newfoundland and Labrador	6	[2 , 11]	8	[2 , 17]
Sub-total Canada	**465**	**[149 , 982]**	**931**	**[278 , 2097]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	8	[2 , 20]	18	[4 , 42]
Alberta	12	[4 , 28]	27	[9 , 64]
Saskatchewan	5	[1 , 12]	12	[3 , 27]
Manitoba	7	[2 , 17]	14	[3 , 36]
Ontario	59	[15 , 146]	122	[30 , 316]
Quebec	17	[2 , 50]	33	[5 , 101]
New Brunswick	1	[0 , 3]	1	[0 , 6]
Nova Scotia	1	[0 , 5]	2	[0 , 10]
Prince Edward Island	1	[0 , 2]	1	[0 , 4]
Newfoundland and Labrador	-1	[0 , -1]	-1	[-1 , -1]
Sub-total Canada	**111**	**[26 , 283]**	**230**	**[52 , 606]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 1]
Northwest Territories	0	[0 , 0]	0	[0 , 1]
British Columbia	48	[16 , 93]	104	[32 , 216]
Alberta	34	[12 , 67]	78	[27 , 164]
Saskatchewan	13	[4 , 25]	28	[9 , 59]
Manitoba	14	[5 , 29]	29	[9 , 63]
Ontario	133	[46 , 265]	266	[86 , 570]
Quebec	78	[27 , 154]	142	[46 , 302]
New Brunswick	11	[4 , 22]	18	[6 , 39]
Nova Scotia	14	[5 , 28]	23	[7 , 49]
Prince Edward Island	2	[1 , 4]	4	[1 , 9]
Newfoundland and Labrador	6	[2 , 12]	9	[3 , 18]
Sub-total Canada	**353**	**[123 , 699]**	**702**	**[226 , 1491]**

Note: zero values are due to rounding

Table 7-9: Projected heat mortality impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental financial costs (valued using Human Capital) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
FINANCIAL LOSS (valued with Human Capital approach) due to ($ million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	52	[27 , 77]	110	[49 , 185]
Alberta	35	[21 , 53]	83	[43 , 141]
Saskatchewan	17	[9 , 26]	39	[18 , 67]
Manitoba	19	[10 , 30]	40	[18 , 72]
Ontario	177	[94 , 281]	353	[160 , 642]
Quebec	88	[45 , 141]	151	[64 , 282]
New Brunswick	9	[5 , 15]	14	[6 , 27]
Nova Scotia	13	[6 , 21]	19	[7 , 38]
Prince Edward Island	2	[1 , 4]	5	[2 , 9]
Newfoundland and Labrador	4	[2 , 5]	4	[2 , 7]
Sub-total Canada	**415**	**[220 , 655]**	**818**	**[369 , 1469]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	10	[4 , 18]	25	[8 , 47]
Alberta	12	[6 , 19]	30	[15 , 55]
Saskatchewan	6	[3 , 10]	15	[6 , 28]
Manitoba	7	[3 , 13]	17	[6 , 34]
Ontario	63	[27 , 115]	150	[57 , 303]
Quebec	19	[5 , 41]	43	[9 , 102]
New Brunswick	1	[0 , 3]	1	[-1 , 6]
Nova Scotia	1	[0 , 4]	3	[-1 , 10]
Prince Edward Island	1	[0 , 1]	2	[1 , 4]
Newfoundland and Labrador	0	[-1 , 0]	-1	[-1 , -1]
Sub-total Canada	**120**	**[47 , 224]**	**285**	**[100 , 587]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	41	[24 , 59]	85	[41 , 138]
Alberta	23	[14 , 34]	53	[29 , 86]
Saskatchewan	11	[6 , 16]	24	[12 , 39]
Manitoba	12	[7 , 17]	23	[11 , 38]
Ontario	114	[67 , 166]	203	[103 , 339]
Quebec	69	[40 , 100]	109	[55 , 180]
New Brunswick	9	[5 , 13]	12	[6 , 21]
Nova Scotia	12	[7 , 17]	17	[8 , 28]
Prince Edward Island	2	[1 , 2]	3	[1 , 5]
Newfoundland and Labrador	4	[2 , 6]	5	[2 , 8]
Sub-total Canada	**296**	**[174 , 431]**	**534**	**[269 , 883]**

Note: zero values are due to rounding

Table 7-10: Projected heat mortality impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental financial costs (valued using Human Capital) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
FINANCIAL LOSS (valued with Human Capital approach) due to ($ million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	69	[37 , 102]	172	[78 , 284]
Alberta	44	[26 , 66]	116	[61 , 195]
Saskatchewan	21	[11 , 31]	53	[25 , 89]
Manitoba	22	[12 , 35]	52	[24 , 93]
Ontario	204	[110 , 321]	476	[222 , 848]
Quebec	106	[55 , 168]	225	[101 , 404]
New Brunswick	12	[6 , 19]	22	[10 , 42]
Nova Scotia	16	[8 , 26]	30	[13 , 57]
Prince Edward Island	3	[2 , 5]	7	[3 , 12]
Newfoundland and Labrador	5	[3 , 7]	9	[3 , 14]
Sub-total Canada	**501**	**[270 , 780]**	**1,162**	**[541 , 2040]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	10	[4 , 18]	25	[8 , 47]
Alberta	12	[6 , 19]	30	[15 , 55]
Saskatchewan	6	[3 , 10]	15	[6 , 28]
Manitoba	7	[3 , 13]	17	[6 , 34]
Ontario	63	[27 , 114]	150	[57 , 302]
Quebec	19	[5 , 41]	43	[9 , 101]
New Brunswick	1	[0 , 3]	1	[-1 , 6]
Nova Scotia	1	[0 , 4]	3	[-1 , 10]
Prince Edward Island	1	[0 , 1]	2	[1 , 4]
Newfoundland and Labrador	0	[-1 , 0]	-1	[-1 , -1]
Sub-total Canada	**119**	**[47 , 224]**	**284**	**[100 , 586]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	58	[33 , 84]	147	[70 , 238]
Alberta	32	[20 , 47]	86	[46 , 141]
Saskatchewan	15	[8 , 21]	38	[19 , 61]
Manitoba	15	[9 , 22]	35	[18 , 59]
Ontario	141	[83 , 207]	326	[165 , 546]
Quebec	87	[51 , 126]	182	[92 , 303]
New Brunswick	11	[7 , 17]	21	[11 , 36]
Nova Scotia	15	[9 , 22]	28	[14 , 47]
Prince Edward Island	2	[1 , 3]	5	[3 , 9]
Newfoundland and Labrador	6	[3 , 8]	10	[4 , 15]
Sub-total Canada	**381**	**[223 , 556]**	**878**	**[441 , 1455]**

Note: zero values are due to rounding

Table 7-11: Projected heat morbidity impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental financial costs of hospitalizations (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in FINANCIAL COSTS from baseline due to ($ million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	13	[4 , 23]	26	[7 , 48]
Alberta	23	[8 , 40]	56	[20 , 105]
Saskatchewan	6	[2 , 10]	15	[4 , 28]
Manitoba	5	[2 , 10]	11	[3 , 23]
Ontario	61	[22 , 110]	116	[39 , 224]
Quebec	23	[8 , 43]	39	[11 , 78]
New Brunswick	2	[1 , 3]	3	[1 , 6]
Nova Scotia	3	[1 , 5]	4	[1 , 9]
Prince Edward Island	1	[0 , 1]	1	[0 , 2]
Newfoundland and Labrador	1	[0 , 2]	1	[0 , 2]
Sub-total Canada	**138**	**[48 , 247]**	**272**	**[87 , 525]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	3	[1 , 5]	6	[1 , 12]
Alberta	8	[3 , 15]	21	[7 , 41]
Saskatchewan	2	[1 , 4]	6	[2 , 12]
Manitoba	2	[0 , 4]	5	[1 , 11]
Ontario	22	[6 , 45]	50	[14 , 106]
Quebec	5	[1 , 13]	11	[2 , 28]
New Brunswick	0	[0 , 1]	0	[0 , 1]
Nova Scotia	0	[0 , 1]	1	[0 , 2]
Prince Edward Island	0	[0 , 0]	0	[0 , 1]
Newfoundland and Labrador	0	[0 , 0]	0	[0 , 0]
Sub-total Canada	**42**	**[11 , 88]**	**99**	**[26 , 214]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	11	[4 , 18]	20	[6 , 36]
Alberta	15	[6 , 25]	36	[13 , 64]
Saskatchewan	4	[1 , 6]	9	[3 , 16]
Manitoba	3	[1 , 5]	7	[2 , 12]
Ontario	39	[16 , 65]	66	[25 , 118]
Quebec	18	[7 , 31]	28	[10 , 50]
New Brunswick	2	[1 , 3]	2	[1 , 4]
Nova Scotia	2	[1 , 4]	3	[1 , 6]
Prince Edward Island	0	[0 , 1]	1	[0 , 1]
Newfoundland and Labrador	1	[0 , 2]	2	[1 , 3]
Sub-total Canada	**96**	**[37 , 159]**	**174**	**[61 , 310]**

Note: zero values are due to rounding

Table 7-12: Projected heat morbidity impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental financial costs of hospitalizations (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5

Change in FINANCIAL COSTS from baseline due to ($ million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	18	[6 , 30]	40	[11 , 73]
Alberta	29	[10 , 50]	79	[28 , 146]
Saskatchewan	7	[2 , 13]	20	[6 , 38]
Manitoba	6	[2 , 11]	15	[4 , 30]
Ontario	71	[26 , 126]	157	[54 , 297]
Quebec	28	[10 , 51]	58	[18 , 112]
New Brunswick	2	[1 , 4]	4	[1 , 9]
Nova Scotia	3	[1 , 6]	6	[2 , 13]
Prince Edward Island	1	[0 , 1]	2	[1 , 3]
Newfoundland and Labrador	1	[0 , 2]	3	[1 , 5]
Sub-total Canada	**167**	**[59 , 295]**	**384**	**[127 , 725]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	3	[1 , 5]	6	[1 , 12]
Alberta	8	[3 , 15]	21	[7 , 41]
Saskatchewan	2	[1 , 4]	6	[2 , 12]
Manitoba	2	[0 , 4]	5	[1 , 11]
Ontario	22	[6 , 45]	49	[14 , 106]
Quebec	5	[1 , 13]	11	[2 , 28]
New Brunswick	0	[0 , 1]	0	[0 , 1]
Nova Scotia	0	[0 , 1]	1	[0 , 2]
Prince Edward Island	0	[0 , 0]	0	[0 , 1]
Newfoundland and Labrador	0	[0 , 0]	0	[0 , 0]
Sub-total Canada	**42**	**[11 , 88]**	**99**	**[26 , 214]**
Climate change only				
Nunavut	0	[0 , 0]	0	[0 , 0]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	15	[5 , 25]	34	[10 , 61]
Alberta	21	[8 , 35]	59	[21 , 105]
Saskatchewan	5	[2 , 8]	14	[5 , 26]
Manitoba	4	[1 , 7]	10	[3 , 19]
Ontario	49	[20 , 81]	107	[40 , 191]
Quebec	23	[9 , 39]	47	[16 , 84]
New Brunswick	2	[1 , 4]	4	[1 , 8]
Nova Scotia	3	[1 , 5]	6	[2 , 11]
Prince Edward Island	1	[0 , 1]	1	[1 , 2]
Newfoundland and Labrador	2	[1 , 3]	3	[1 , 5]
Sub-total Canada	**125**	**[47 , 208]**	**286**	**[101 , 511]**

Note: zero values are due to rounding

Figure 7-1: Projected heat-related mortality impacts for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada, showing incremental deaths relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; "x" indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

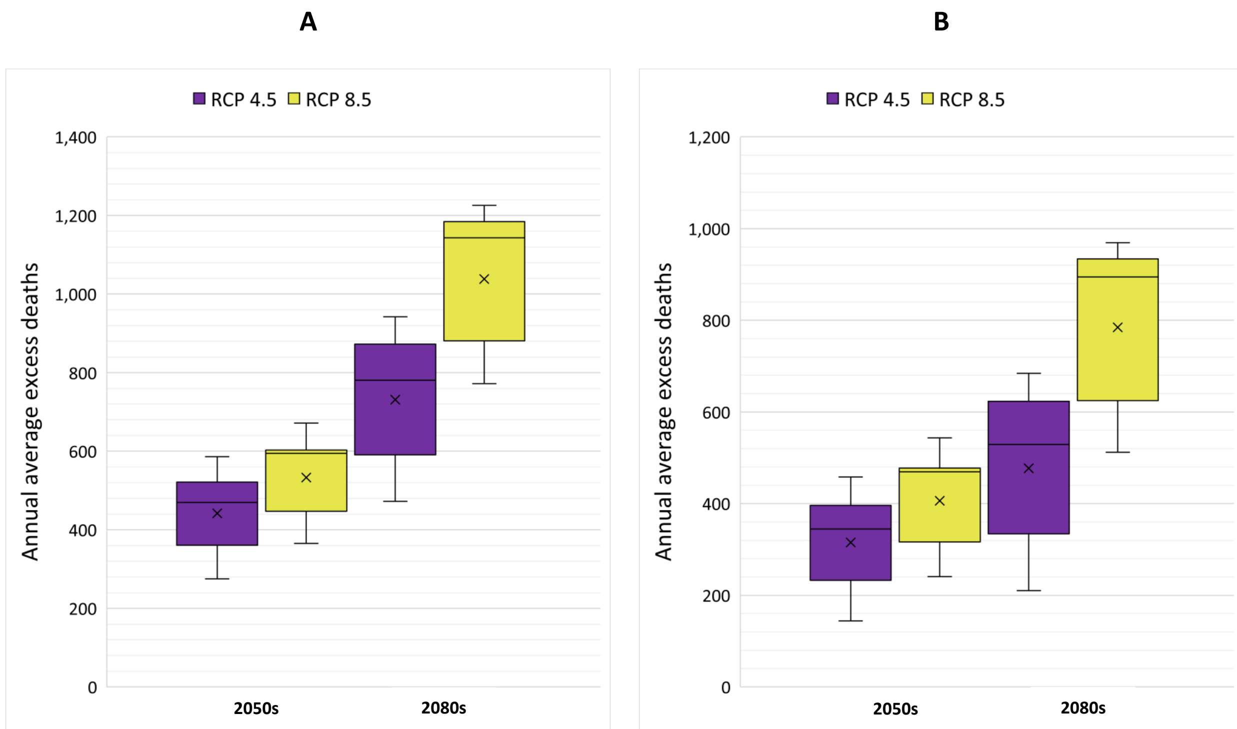
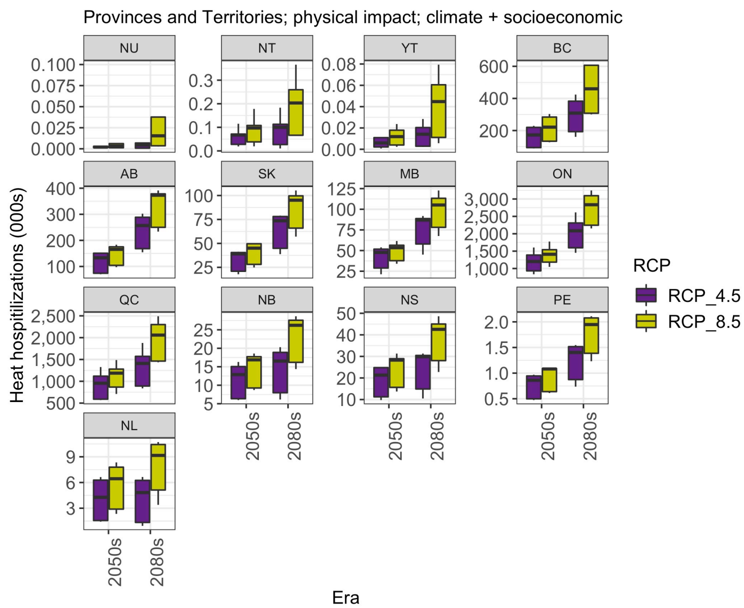
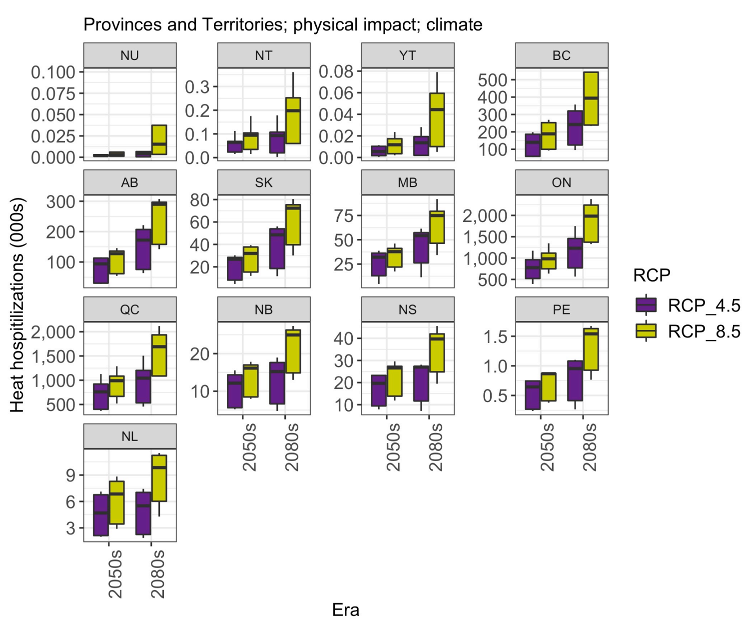


Figure 7-2: Projected heat-related morbidity impacts for the 2050s and 2080s under RCP 4.5 and RCP 8.5 by province and territory, showing incremental hospitalizations relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the dark horizontal line in the box indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

A



B



7.2 Air Quality (Ground-Level Ozone)

Physical Impact

Mortality

Projected excess deaths associated with acute and chronic exposure of the general population and population aged 30 and over, respectively, to climate change-induced increased in ground-level ozone are summarized in Table 7-13, Table 7-14, Table 7-15 and Table 7-16. These results show that: (a) as the number of people exposed to ground-level ozone grows in the future, excess cardiovascular deaths increase, even in the absence of further climate change; and (b) as ozone levels rise because of projected daily and seasonal temperature increases under climate change over time, the number of excess deaths attributable to climate change increases. By the 2050s and 2080s under RCP 8.5, projected annual excess deaths related to acute exposure due to a combination of socioeconomic change and climate change amount to about 6,440 [1,810, 14,250] and 11,740 [2,650, 28,190]. Under RCP 4.5 the corresponding values are 5,530 [1,780, 11,850] and 8,210 [2,530, 18,340]. Projected annual excess deaths related to chronic exposure to ozone air pollution due to a combination of socioeconomic change and climate change by the 2050s and 2080s under RCP 8.5 amount to 3,480 [840, 9,420] and 6,530 [1,240, 20,120]. Under RCP 4.5 the corresponding values are 2,980 [830, 7,710] and 4,550 [1,190, 12,590]. The number of projected excess deaths due to chronic exposure is about half (54%) that of projections for acute exposure.

Looking at acute exposure in the 2080s, approximately 75% of total projected excess deaths are attributable to climate change alone under RCP 8.5. In contrast, deaths attributable to climate alone account for about 65% of total projected excess deaths under RCP 4.5. **With lower levels of climate change, socioeconomic developments become a more influential driver of total physical risk; though still not as important as climate-induced increases in ground level ozone.** The overall influence of climate change is less pronounced in causing excess deaths due to chronic ozone exposure: approximately 64% of total projected excess deaths are attributable to climate change alone under RCP8.5 and that proportion falls to 58% under RCP 4.5.

Regionally, projected excess deaths due to acute exposure to ozone air pollution are most numerous in Ontario (e.g., 4,970 excess deaths annually by the 2080s under RCP 8.5), Quebec (e.g., 2,040 excess deaths annually by the 2080s under RCP 8.5), British Columbia (e.g., 1,570 excess deaths annually by the 2080s under RCP 8.5) and Alberta (e.g., 1,520 excess deaths annually by the 2080s under RCP 8.5) (see Table 7-14). **Ontario experiences the largest relative deaths, even after normalizing for the relative size of the population across provinces and territories. In contrast, Alberta experiences levels of excess deaths disproportionately lower than its population would suggest.** In general, though, projected excess deaths from acute exposure are proportionate (within 3 percentage points) to the all-ages population across provinces and territories. This pattern holds for chronic exposure as well, although the affected population subgroup is people 30 years or older.

Figure 7-3 and Figure 7-4 contains box-whisker plots for projected excess deaths from acute and chronic exposure to climate change-induced increased in ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5, by province and territory. The plots show the full range of results across the seven GCMs for central case assumptions for all other input variables. These plots isolate the impact of future climate uncertainty on the overall results. For 2080s under RCP 8.5 projected annual excess deaths in Ontario from acute exposure due to a combination of socioeconomic change and climate change across all seven GCMs range from 3,500 to 6,000 [central value 5,000] This represents a much smaller uncertainty range than for the impact models (ERFs) and socioeconomic data (i.e., which range from 1,290 to 12,710 excess deaths per year based on the mean GCM projection, see Table 7-14).

Our results for acute exposure mortality due to climate change-induced ozone air pollution can be compared to Marbek's (2011), despite differences in climate and socioeconomic scenarios and in the use of GCMs. For example, Marbek estimated excess deaths from acute exposure in Toronto under the high-climate scenario by the 2080s were roughly 466 to 518 cases due to climate change only (i.e., deaths related to ground-level ozone levels driven by climate change). Our results for the same health endpoint for the 2080s under RCP 8.5 equate to a central value of 691 cases (due to climate change only), which is comparable in magnitude. Our study extends the analysis by Marbek by modelling all Census Divisions in Canada, providing an improved substantiation for the temperature-ozone relationship and explicitly accounting for a wider range of sources of uncertainty. Our results also reflect improvements made to exposure response functions and baseline occurrence rates in AQBAT, since Marbek used a previous version of the tool.

Table 7-13: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental deaths relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ACUTE MORTALITY from baseline due to (deaths per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 10]	10	[0 , 10]
Yukon	10	[0 , 10]	10	[0 , 10]
Northwest Territories	0	[0 , 10]	0	[0 , 10]
British Columbia	670	[180 , 1210]	1,090	[250 , 2010]
Alberta	620	[270 , 1190]	1,140	[480 , 2260]
Saskatchewan	190	[50 , 370]	350	[80 , 650]
Manitoba	180	[50 , 410]	290	[80 , 670]
Ontario	2,350	[850 , 5190]	3,540	[1240 , 8400]
Quebec	1,100	[270 , 2510]	1,320	[300 , 3100]
New Brunswick	130	[30 , 310]	150	[30 , 400]
Nova Scotia	160	[40 , 380]	190	[40 , 500]
Prince Edward Island	30	[10 , 70]	40	[10 , 110]
Newfoundland and Labrador	80	[20 , 180]	80	[10 , 220]
Sub-total Canada	**5,530**	**[1780 , 11850]**	**8,210**	**[2530 , 18340]**
Socioecononomic change only				
Nunavut	10	[10 , 10]	10	[10 , 20]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	10	[0 , 0]	10	[0 , 0]
British Columbia	240	[120 , 210]	340	[260 , 340]
Alberta	320	[230 , 270]	270	[490 , 460]
Saskatchewan	120	[60 , 100]	200	[110 , 90]
Manitoba	70	[80 , 130]	110	[100 , 150]
Ontario	810	[770 , 660]	1,230	[1410 , 1590]
Quebec	340	[350 , 470]	660	[350 , 530]
New Brunswick	40	[80 , 40]	90	[40 , 130]
Nova Scotia	130	[40 , 70]	90	[50 , 160]
Prince Edward Island	10	[10 , 20]	20	[10 , 20]
Newfoundland and Labrador	30	[10 , 60]	20	[10 , 30]
Sub-total Canada	**2,120**	**[1790 , 2040]**	**3,050**	**[2840 , 3520]**
Climate change only				
Nunavut	0	[0 , 10]	0	[0 , 10]
Yukon	0	[0 , 10]	10	[0 , 10]
Northwest Territories	0	[0 , 10]	0	[0 , 10]
British Columbia	430	[10 , 980]	720	[20 , 1650]
Alberta	340	[10 , 870]	640	[20 , 1690]
Saskatchewan	130	[0 , 300]	230	[10 , 530]
Manitoba	130	[0 , 350]	210	[10 , 560]
Ontario	1,470	[50 , 4050]	2,180	[80 , 6480]
Quebec	810	[30 , 2140]	980	[30 , 2670]
New Brunswick	90	[0 , 250]	100	[0 , 330]
Nova Scotia	100	[0 , 300]	130	[0 , 400]
Prince Edward Island	20	[0 , 60]	30	[0 , 90]
Newfoundland and Labrador	50	[0 , 140]	60	[0 , 180]
Sub-total Canada	**3,570**	**[120 , 9470]**	**5,300**	**[180 , 14600]**

Note: zero values are due to rounding

Table 7-14: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental deaths relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ACUTE MORTALITY from baseline due to (deaths per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 10]	10	[0 , 20]
Yukon	10	[0 , 10]	20	[0 , 20]
Northwest Territories	0	[0 , 10]	10	[0 , 20]
British Columbia	820	[180 , 1560]	1,570	[260 , 3130]
Alberta	720	[270 , 1450]	1,520	[490 , 3280]
Saskatchewan	240	[50 , 460]	490	[90 , 980]
Manitoba	220	[50 , 500]	420	[80 , 1000]
Ontario	2,660	[860 , 6050]	4,970	[1290 , 12710]
Quebec	1,300	[280 , 3050]	2,040	[320 , 5070]
New Brunswick	150	[30 , 380]	230	[40 , 650]
Nova Scotia	180	[40 , 460]	270	[50 , 780]
Prince Edward Island	40	[10 , 80]	60	[20 , 180]
Newfoundland and Labrador	90	[20 , 230]	130	[10 , 350]
Sub-total Canada	**6,440**	**[1810 , 14250]**	**11,740**	**[2650 , 28190]**
Socioecononomic change only				
Nunavut	10	[10 , 10]	10	[10 , 20]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	10	[0 , 0]	20	[0 , 10]
British Columbia	200	[130 , 220]	290	[270 , 360]
Alberta	290	[280 , 260]	270	[490 , 430]
Saskatchewan	120	[50 , 110]	150	[100 , 90]
Manitoba	70	[80 , 160]	120	[100 , 180]
Ontario	810	[870 , 750]	1,130	[1410 , 1590]
Quebec	320	[320 , 400]	670	[350 , 470]
New Brunswick	50	[50 , 40]	90	[30 , 160]
Nova Scotia	170	[40 , 70]	100	[50 , 180]
Prince Edward Island	10	[10 , 10]	20	[10 , 20]
Newfoundland and Labrador	10	[10 , 40]	30	[10 , 130]
Sub-total Canada	**2,080**	**[1860 , 2070]**	**2,890**	**[2830 , 3630]**
Climate change only				
Nunavut	0	[0 , 10]	10	[0 , 20]
Yukon	10	[0 , 10]	10	[0 , 20]
Northwest Territories	0	[0 , 10]	10	[0 , 20]
British Columbia	580	[20 , 1330]	1,200	[30 , 2770]
Alberta	440	[20 , 1140]	1,030	[40 , 2700]
Saskatchewan	170	[10 , 400]	380	[10 , 870]
Manitoba	160	[10 , 430]	330	[10 , 900]
Ontario	1,780	[60 , 4900]	3,620	[130 , 10790]
Quebec	1,000	[30 , 2680]	1,700	[60 , 4640]
New Brunswick	110	[0 , 320]	180	[10 , 580]
Nova Scotia	130	[0 , 380]	210	[10 , 680]
Prince Edward Island	20	[0 , 70]	50	[0 , 150]
Newfoundland and Labrador	70	[0 , 190]	100	[0 , 310]
Sub-total Canada	**4,480**	**[160 , 11870]**	**8,840**	**[300 , 24460]**

Note: zero values are due to rounding

Table 7-15: Projected chronic mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental deaths relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in CHRONIC MORTALITY from baseline due to (deaths per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 10]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 10]
Northwest Territories	0	[0 , 10]	0	[0 , 10]
British Columbia	350	[70 , 810]	580	[100 , 1370]
Alberta	360	[130 , 830]	670	[230 , 1680]
Saskatchewan	90	[20 , 220]	180	[30 , 430]
Manitoba	80	[20 , 220]	140	[30 , 380]
Ontario	1,280	[420 , 3310]	1,980	[610 , 5630]
Quebec	630	[140 , 1750]	780	[160 , 2330]
New Brunswick	50	[10 , 160]	60	[10 , 220]
Nova Scotia	80	[10 , 250]	100	[10 , 330]
Prince Edward Island	20	[10 , 50]	30	[10 , 90]
Newfoundland and Labrador	30	[0 , 100]	40	[0 , 120]
Sub-total Canada	**2,980**	**[830 , 7710]**	**4,550**	**[1190 , 12590]**
Sociocononomic change only				
Nunavut	10	[10 , 20]	20	[20 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	20	[60 , 50]	20	[80 , 60]
British Columbia	130	[80 , 80]	210	[90 , 140]
Alberta	150	[50 , 60]	110	[40 , 30]
Saskatchewan	40	[20 , 40]	120	[80 , 40]
Manitoba	120	[70 , 60]	180	[40 , 220]
Ontario	220	[170 , 70]	400	[290 , 190]
Quebec	470	[510 , 460]	710	[810 , 970]
New Brunswick	60	[210 , 250]	70	[430 , 340]
Nova Scotia	110	[160 , 100]	260	[70 , 290]
Prince Edward Island	10	[10 , 10]	40	[0 , 20]
Newfoundland and Labrador	20	[20 , 70]	100	[50 , 40]
Sub-total Canada	**1,360**	**[1380 , 1290]**	**2,240**	**[1990 , 2350]**
Climate change only				
Nunavut	0	[0 , 10]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 10]
British Columbia	230	[10 , 660]	390	[10 , 1140]
Alberta	170	[0 , 560]	340	[10 , 1180]
Saskatchewan	60	[0 , 170]	110	[0 , 340]
Manitoba	50	[0 , 170]	90	[0 , 310]
Ontario	670	[20 , 2320]	1,050	[30 , 3980]
Quebec	410	[10 , 1400]	530	[10 , 1900]
New Brunswick	40	[0 , 140]	50	[0 , 190]
Nova Scotia	60	[0 , 200]	70	[0 , 280]
Prince Edward Island	10	[0 , 40]	20	[0 , 60]
Newfoundland and Labrador	20	[0 , 80]	30	[0 , 110]
Sub-total Canada	**1,730**	**[40 , 5760]**	**2,680**	**[70 , 9500]**

Note: zero values are due to rounding

Table 7-16: Projected chronic mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental deaths relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in CHRONIC MORTALITY from baseline due to (deaths per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0	[0 , 10]	10	[0 , 20]
Yukon	0	[0 , 10]	10	[0 , 10]
Northwest Territories	0	[0 , 10]	0	[0 , 10]
British Columbia	420	[70 , 1030]	870	[100 , 2280]
Alberta	420	[130 , 1020]	910	[230 , 2590]
Saskatchewan	110	[20 , 280]	260	[40 , 690]
Manitoba	100	[20 , 270]	190	[30 , 600]
Ontario	1,450	[420 , 3930]	2,720	[630 , 8660]
Quebec	750	[140 , 2160]	1,210	[170 , 3970]
New Brunswick	60	[10 , 200]	100	[10 , 380]
Nova Scotia	100	[20 , 310]	150	[20 , 560]
Prince Edward Island	20	[10 , 60]	40	[10 , 140]
Newfoundland and Labrador	40	[10 , 130]	60	[0 , 210]
Sub-total Canada	**3,480**	**[840 , 9420]**	**6,530**	**[1240 , 20120]**
Socioecononomic change only				
Nunavut	0	[10 , 10]	10	[10 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[50 , 40]	10	[110 , 40]
British Columbia	50	[80 , 110]	200	[90 , 130]
Alberta	30	[40 , 40]	90	[40 , 50]
Saskatchewan	60	[20 , 50]	80	[30 , 50]
Manitoba	150	[50 , 100]	170	[30 , 160]
Ontario	120	[90 , 90]	180	[180 , 170]
Quebec	510	[530 , 350]	870	[760 , 810]
New Brunswick	60	[200 , 190]	90	[430 , 260]
Nova Scotia	160	[180 , 150]	240	[340 , 310]
Prince Edward Island	10	[20 , 10]	20	[30 , 20]
Newfoundland and Labrador	20	[10 , 70]	110	[20 , 60]
Sub-total Canada	**1,190**	**[1280 , 1230]**	**2,080**	**[2070 , 2070]**
Climate change only				
Nunavut	0	[0 , 10]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 10]
Northwest Territories	0	[0 , 10]	0	[0 , 10]
British Columbia	300	[10 , 880]	680	[10 , 2050]
Alberta	230	[10 , 750]	590	[20 , 2100]
Saskatchewan	80	[0 , 230]	190	[0 , 600]
Manitoba	70	[0 , 230]	150	[0 , 530]
Ontario	840	[20 , 2940]	1,790	[50 , 7020]
Quebec	530	[10 , 1810]	960	[20 , 3540]
New Brunswick	50	[0 , 180]	90	[0 , 360]
Nova Scotia	70	[0 , 260]	120	[0 , 500]
Prince Edward Island	10	[0 , 50]	30	[0 , 110]
Newfoundland and Labrador	30	[0 , 110]	50	[0 , 200]
Sub-total Canada	**2,220**	**[60 , 7470]**	**4,660**	**[110 , 17020]**

Note: zero values are due to rounding

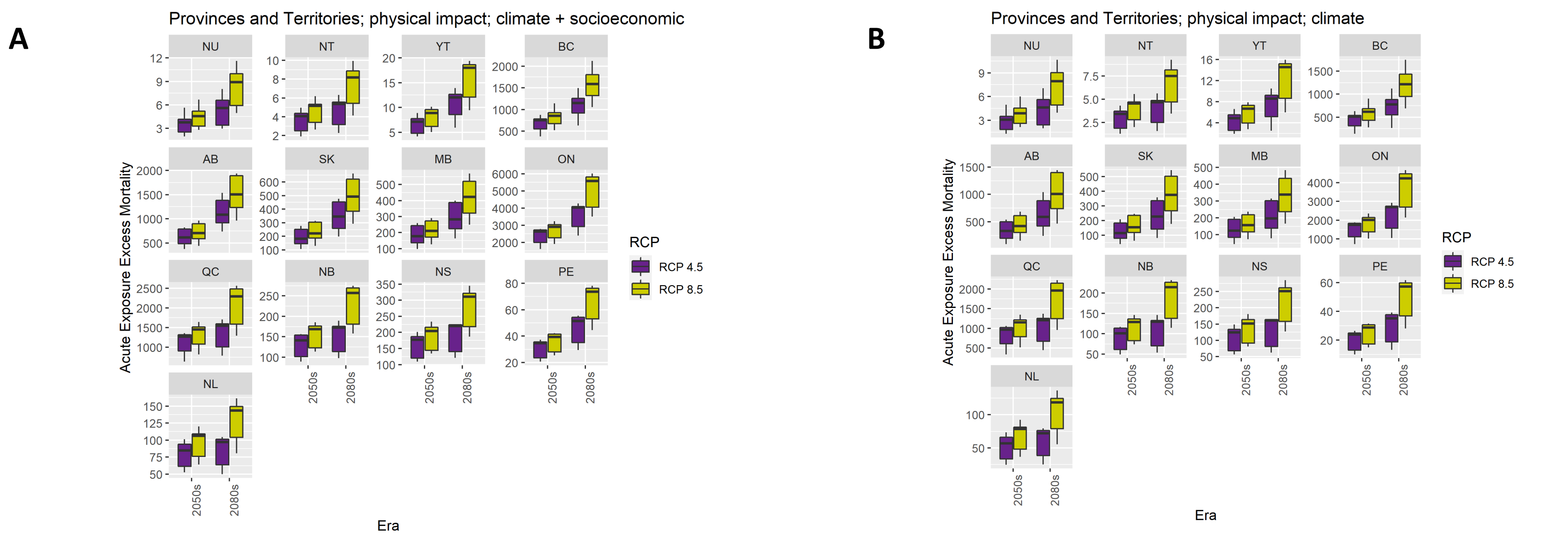


Figure 7-3: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada, showing incremental deaths per year relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the bold line indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

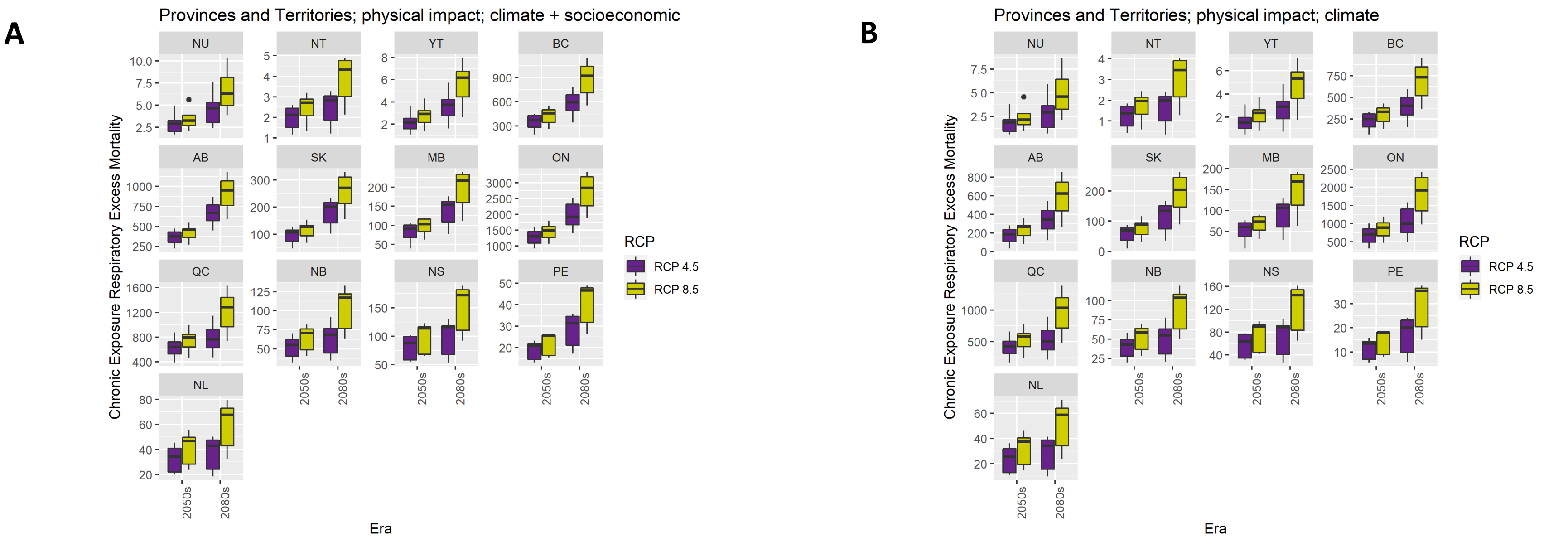


Figure 7-4: Projected mortality impacts from chronic exposure to ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada, showing incremental deaths per year relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the bold line indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

Morbidity

Recalling Section 5.2 (specifically Table 5-3), our study modelled the impacts of climate change-induced ground level ozone increases on three types of morbidity: acute respiratory symptom days (ARSDs), asthma symptom days (ASDs) and respiratory emergency room visits (RERVs). All are a manifestation of respiratory illness. ARSDs apply to all the adult population and non-asthmatic children aged 5 to 19 (i.e., 85.7% of the children population). ASDs apply to asthmatic children aged 5 to 19. RERVs apply to all the population.

Projected excess cases of respiratory illnesses due to exposure to climate change-induced increases in ground-level ozone are summarized in Table 7-18 through Table 7-23. These results show that: (a) as the number of people exposed to ground-level ozone grows in the future, excess cases of respiratory symptoms likewise increase, even in the absence of further climate change; and (b) as ozone levels rise because of projected daily and seasonal temperature increases under climate change over time, the number of excess cases of illness attributable to climate change increases.

- By the 2050s and 2080s under RCP 8.5, projected annual excess cases of ARSDs related to exposure due to a combination of socioeconomic change and climate change amount to about 13,460,000 [1,230,000, 44,610,000] and 28,150,000 [2,410,000, 100,260,000]. Under RCP 4.5 the corresponding values are 11,190,000 [1,180,000, 36,240,000] and 19,130,000 [2,250,000, 64,420,000].
- Projected annual excess cases of ASDs related to asthmatic children's exposure to ozone air pollution due to a combination of socioeconomic change and climate change by the 2050s and 2080s under RCP 8.5 amount to 1,291,000 [19,000, 5,746,000] and 2,729,000 [37,000, 13,454,000]. Under RCP 4.5 the corresponding values are 1,073,000 [18,000, 4,624,000] and 1,848,000 [34,000, 8,341,000].
- Projected annual excess cases of ERVs related to Canadians' exposure to ozone air pollution due to a combination of socioeconomic change and climate change by the 2050s and 2080s under RCP 8.5 amount to 9,910 [1,790, 28,970] and 20,340 [2,980, 64,750]. Under RCP 4.5 the corresponding values are 8,450 [1,760, 23,760] and 14,260 [2,850, 41,770].

Looking at the occurrence of ARSDs in the 2080s, approximately 77% of total projected excess ARSDs are attributable to climate change alone under RCP 8.5. In contrast, deaths attributable to climate alone account for about 67% of total projected excess ARSDs under RCP 4.5. **With lower levels of climate change, socioeconomic developments become a more influential driver of total physical risk; though still not as important as climate-induced increases in ground level ozone.** The overall influence of climate change is similarly pronounced in causing excess ASDs due to ozone exposure: approximately 76% of total projected excess ASDs are attributable to climate change alone under RCP8.5 and that proportion falls to 71% under RCP 4.5. At 72% under RCP 8.5 and 59% under RCP 4.5 the influence of climate change is comparatively less pronounced in causing excess ERVs:

Regionally, projected excess occurrences of ASRDs, ASDs and ERVs due to exposure to ozone air pollution are most numerous in Ontario, Quebec and Alberta and least numerous for Nunavut, Yukon and Northwest Territories, largely consistent with population counts and density. **Ontario and Alberta, in particular, experience morbidity impacts in greater proportions than their population counts.** These provinces have higher percent excess ERV associated with a unit increase in the ozone concentration than other provinces (i.e., a feature of the CRF embedded in AQBAT).

Figure 7-5, Figure 7-6 and Figure 7-7 contains box-whisker plots for projected excess morbidity impacts from exposure to climate change-induced increased in ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5, by province and territory. The plots show the full range of results across the seven GCMs for central case assumptions for all other input variables. These plots isolate the impact of future climate uncertainty on the overall results. For Ontario, for example, by the 2080s under RCP 8.5, projected excess ARSDs due to a combination of socioeconomic change and climate change across all seven GCMs

(Figure 7-5) range from approximately 8 million to 16 million. This represents a much smaller uncertainty range than for the impact models (ERFs) and socioeconomic data (i.e., which range from 1.2 million to 44 million per year based on the mean GCM projection, see Table 7-19).

Our results for excess ARSDs, ASDs and ERVs due to climate change-induced ozone air pollution can be compared to Marbek's (2011), despite differences in climate and socioeconomic scenarios and in the use of GCMs (Table 7-17). For example, Marbek estimated excess ARSDs in Toronto under the high-climate scenario by the 2080s as roughly 1.4 million to 1.6 million annual cases due to climate change only. Our results for the same health endpoint for the 2080s under RCP 8.5 equate to a central value of approximately 1.9 million (due to climate change only), which is comparable in magnitude.

Table 7-17: Comparison of projected morbidity impacts in Toronto from climate change-induced ozone air pollution by 2080s under a high emissions / concentration scenario (climate change only)

Annual cases in 2080s for Toronto	Marbek (2011)[a]	This study[b]
Acute respiratory symptom days	1,434,069 to 1,594,283	1,868,666
Asthma symptom days	213,042 to 236,843	158,031
Emergency room visits	606 to 673	885

[a] Annual cases attributable to climate change under a high emissions scenario (SRES A2) and range of population growth assumptions

[b] Central value

Table 7-18: Projected morbidity impacts (acute respiratory symptom days-ARSDs) from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental ARSDs relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ARSDs from baseline due to (1000 ARSDs per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	10	[0 , 30]	10	[0 , 50]
Yukon	10	[0 , 30]	20	[0 , 50]
Northwest Territories	10	[0 , 30]	10	[0 , 40]
British Columbia	1,200	[90 , 3940]	2,100	[160 , 7200]
Alberta	1,660	[310 , 4870]	3,390	[630 , 10450]
Saskatchewan	340	[40 , 1060]	660	[70 , 2190]
Manitoba	380	[40 , 1250]	680	[70 , 2360]
Ontario	5,140	[620 , 16350]	8,820	[1160 , 29170]
Quebec	2,050	[90 , 7160]	2,940	[150 , 10860]
New Brunswick	140	[0 , 520]	170	[0 , 700]
Nova Scotia	170	[0 , 640]	210	[0 , 860]
Prince Edward Island	50	[0 , 160]	80	[10 , 270]
Newfoundland and Labrador	50	[-10 , 210]	50	[-10 , 230]
Sub-total Canada	**11,190**	**[1180 , 36240]**	**19,130**	**[2250 , 64420]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	250	[70 , 490]	500	[130 , 1010]
Alberta	670	[290 , 1260]	1,450	[600 , 2820]
Saskatchewan	100	[30 , 180]	200	[70 , 390]
Manitoba	100	[30 , 200]	200	[60 , 430]
Ontario	1,670	[550 , 3440]	3,360	[1060 , 7230]
Quebec	320	[60 , 790]	610	[110 , 1540]
New Brunswick	0	[0 , 20]	10	[0 , 40]
Nova Scotia	10	[0 , 40]	20	[0 , 70]
Prince Edward Island	10	[0 , 30]	20	[10 , 60]
Newfoundland and Labrador	-10	[-10 , -10]	-20	[-10 , -20]
Sub-total Canada	**3,130**	**[1030 , 6430]**	**6,360**	**[2030 , 13600]**
Climate change only				
Nunavut	10	[0 , 30]	10	[0 , 40]
Yukon	10	[0 , 30]	10	[0 , 40]
Northwest Territories	10	[0 , 20]	10	[0 , 40]
British Columbia	950	[20 , 3450]	1,590	[30 , 6190]
Alberta	980	[20 , 3620]	1,940	[40 , 7620]
Saskatchewan	240	[0 , 880]	460	[10 , 1790]
Manitoba	280	[10 , 1050]	480	[10 , 1940]
Ontario	3,480	[70 , 12910]	5,460	[100 , 21930]
Quebec	1,720	[30 , 6380]	2,340	[40 , 9320]
New Brunswick	130	[0 , 490]	160	[0 , 660]
Nova Scotia	160	[0 , 600]	190	[0 , 790]
Prince Edward Island	30	[0 , 130]	50	[0 , 210]
Newfoundland and Labrador	60	[0 , 220]	70	[0 , 240]
Sub-total Canada	**8,060**	**[150 , 29810]**	**12,780**	**[220 , 50820]**

Note: zero values are due to rounding

Table 7-19: Projected morbidity impacts (acute respiratory symptom days-ARSDs) from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental ARSDs relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ARSDs from baseline due to (1000 ARSDs per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	10	[0 , 40]	20	[0 , 80]
Yukon	10	[0 , 40]	30	[0 , 80]
Northwest Territories	10	[0 , 40]	20	[0 , 70]
British Columbia	1,500	[90 , 5050]	3,250	[180 , 11690]
Alberta	2,000	[310 , 6110]	4,740	[660 , 15780]
Saskatchewan	420	[40 , 1370]	970	[80 , 3400]
Manitoba	460	[40 , 1570]	990	[80 , 3610]
Ontario	6,010	[630 , 19560]	12,510	[1230 , 44010]
Quebec	2,520	[100 , 8900]	4,750	[180 , 18050]
New Brunswick	170	[0 , 660]	290	[0 , 1210]
Nova Scotia	210	[0 , 800]	350	[0 , 1440]
Prince Edward Island	60	[10 , 190]	110	[10 , 420]
Newfoundland and Labrador	70	[-10 , 290]	100	[-10 , 420]
Sub-total Canada	**13,460**	**[1230 , 44610]**	**28,150**	**[2410 , 100260]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	250	[70 , 490]	500	[130 , 1010]
Alberta	670	[290 , 1260]	1,450	[600 , 2820]
Saskatchewan	100	[30 , 180]	200	[70 , 390]
Manitoba	100	[30 , 200]	200	[60 , 430]
Ontario	1,670	[550 , 3440]	3,360	[1060 , 7230]
Quebec	320	[60 , 790]	610	[110 , 1540]
New Brunswick	0	[0 , 20]	10	[0 , 40]
Nova Scotia	10	[0 , 40]	20	[0 , 70]
Prince Edward Island	10	[0 , 30]	20	[10 , 60]
Newfoundland and Labrador	-10	[-10 , -10]	-20	[-10 , -20]
Sub-total Canada	**3,130**	**[1030 , 6430]**	**6,360**	**[2030 , 13600]**
Climate change only				
Nunavut	10	[0 , 30]	20	[0 , 80]
Yukon	10	[0 , 40]	20	[0 , 80]
Northwest Territories	10	[0 , 30]	20	[0 , 70]
British Columbia	1,250	[20 , 4560]	2,750	[50 , 10680]
Alberta	1,320	[30 , 4850]	3,290	[60 , 12950]
Saskatchewan	330	[10 , 1190]	770	[10 , 3010]
Manitoba	370	[10 , 1360]	790	[10 , 3180]
Ontario	4,340	[80 , 16120]	9,160	[160 , 36780]
Quebec	2,190	[40 , 8120]	4,140	[70 , 16510]
New Brunswick	170	[0 , 640]	290	[10 , 1160]
Nova Scotia	200	[0 , 770]	340	[10 , 1370]
Prince Edward Island	40	[0 , 170]	90	[0 , 370]
Newfoundland and Labrador	80	[0 , 300]	120	[0 , 430]
Sub-total Canada	**10,330**	**[200 , 38180]**	**21,790**	**[380 , 86660]**

Note: zero values are due to rounding

Table 7-20: Projected morbidity impacts (asthma symptom days-ASDs) from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental ASDs relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ASTHMA SYMPTOM DAYS from baseline due to (1000 ASDs per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	2	[0 , 7]	3	[0 , 12]
Yukon	1	[0 , 4]	2	[0 , 6]
Northwest Territories	1	[0 , 4]	1	[0 , 7]
British Columbia	107	[1 , 466]	187	[2 , 862]
Alberta	166	[5 , 650]	340	[10 , 1406]
Saskatchewan	35	[1 , 148]	69	[1 , 309]
Manitoba	41	[1 , 180]	73	[1 , 344]
Ontario	506	[9 , 2147]	869	[18 , 3867]
Quebec	179	[1 , 840]	259	[2 , 1286]
New Brunswick	12	[0 , 60]	15	[0 , 82]
Nova Scotia	15	[0 , 73]	18	[0 , 100]
Prince Edward Island	4	[0 , 20]	7	[0 , 35]
Newfoundland and Labrador	5	[0 , 24]	4	[0 , 26]
Sub-total Canada	**1,073**	**[18 , 4624]**	**1,848**	**[34 , 8341]**
Socioecononomic change only				
Nunavut	0	[0 , 1]	1	[0 , 1]
Yukon	0	[0 , 0]	0	[0 , 1]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	22	[1 , 56]	45	[2 , 117]
Alberta	68	[4 , 165]	146	[9 , 370]
Saskatchewan	10	[1 , 25]	21	[1 , 54]
Manitoba	11	[1 , 28]	21	[1 , 60]
Ontario	165	[8 , 447]	333	[16 , 941]
Quebec	28	[1 , 90]	53	[2 , 177]
New Brunswick	0	[0 , 3]	1	[0 , 5]
Nova Scotia	1	[0 , 4]	2	[0 , 8]
Prince Edward Island	1	[0 , 3]	2	[0 , 7]
Newfoundland and Labrador	-1	[0 , -1]	-1	[0 , -2]
Sub-total Canada	**306**	**[16 , 822]**	**623**	**[31 , 1740]**
Climate change only				
Nunavut	1	[0 , 6]	2	[0 , 10]
Yukon	1	[0 , 3]	1	[0 , 6]
Northwest Territories	1	[0 , 4]	1	[0 , 6]
British Columbia	84	[0 , 410]	142	[0 , 744]
Alberta	98	[0 , 484]	194	[1 , 1036]
Saskatchewan	25	[0 , 123]	48	[0 , 255]
Manitoba	31	[0 , 152]	52	[0 , 284]
Ontario	340	[1 , 1700]	536	[1 , 2926]
Quebec	151	[0 , 750]	205	[1 , 1109]
New Brunswick	11	[0 , 58]	14	[0 , 77]
Nova Scotia	14	[0 , 69]	17	[0 , 92]
Prince Edward Island	3	[0 , 17]	5	[0 , 28]
Newfoundland and Labrador	5	[0 , 25]	6	[0 , 28]
Sub-total Canada	**767**	**[2 , 3802]**	**1,225**	**[3 , 6602]**

Note: zero values are due to rounding

Table 7-21: Projected morbidity impacts (asthma symptom days-ASDs) from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental ASDs relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ASTHMA SYMPTOM DAYS from baseline due to (1000 ASDs per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	2	[0 , 9]	4	[0 , 20]
Yukon	1	[0 , 5]	2	[0 , 11]
Northwest Territories	1	[0 , 6]	2	[0 , 12]
British Columbia	134	[1 , 605]	293	[3 , 1453]
Alberta	200	[5 , 823]	479	[10 , 2205]
Saskatchewan	44	[1 , 194]	103	[1 , 499]
Manitoba	50	[1 , 228]	108	[1 , 545]
Ontario	591	[10 , 2591]	1,240	[19 , 6051]
Quebec	221	[1 , 1056]	421	[2 , 2230]
New Brunswick	15	[0 , 78]	26	[0 , 148]
Nova Scotia	19	[0 , 94]	31	[0 , 174]
Prince Edward Island	5	[0 , 25]	11	[0 , 57]
Newfoundland and Labrador	6	[0 , 33]	9	[0 , 50]
Sub-total Canada	**1,291**	**[19 , 5746]**	**2,729**	**[37 , 13454]**
Socioecononomic change only				
Nunavut	0	[0 , 1]	1	[0 , 1]
Yukon	0	[0 , 0]	0	[0 , 1]
Northwest Territories	0	[0 , 0]	0	[0 , 0]
British Columbia	22	[1 , 56]	45	[2 , 117]
Alberta	68	[4 , 165]	146	[9 , 370]
Saskatchewan	10	[1 , 25]	21	[1 , 54]
Manitoba	11	[1 , 28]	21	[1 , 60]
Ontario	165	[8 , 447]	333	[16 , 941]
Quebec	28	[1 , 90]	53	[2 , 177]
New Brunswick	0	[0 , 3]	1	[0 , 5]
Nova Scotia	1	[0 , 4]	2	[0 , 8]
Prince Edward Island	1	[0 , 3]	2	[0 , 7]
Newfoundland and Labrador	-1	[0 , -1]	-1	[0 , -2]
Sub-total Canada	**306**	**[16 , 822]**	**623**	**[31 , 1740]**
Climate change only				
Nunavut	2	[0 , 8]	4	[0 , 19]
Yukon	1	[0 , 5]	2	[0 , 10]
Northwest Territories	1	[0 , 6]	2	[0 , 12]
British Columbia	112	[0 , 549]	248	[1 , 1335]
Alberta	132	[0 , 658]	333	[1 , 1835]
Saskatchewan	34	[0 , 169]	82	[0 , 445]
Manitoba	40	[0 , 200]	87	[0 , 486]
Ontario	426	[1 , 2144]	907	[2 , 5110]
Quebec	193	[1 , 966]	367	[1 , 2053]
New Brunswick	15	[0 , 75]	25	[0 , 143]
Nova Scotia	18	[0 , 89]	29	[0 , 166]
Prince Edward Island	4	[0 , 22]	9	[0 , 50]
Newfoundland and Labrador	7	[0 , 34]	10	[0 , 51]
Sub-total Canada	**985**	**[3 , 4924]**	**2,106**	**[6 , 11714]**

Note: zero values are due to rounding

Table 7-22: Projected morbidity impacts (respiratory emergency room visits-ERVs) from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental ERVs relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

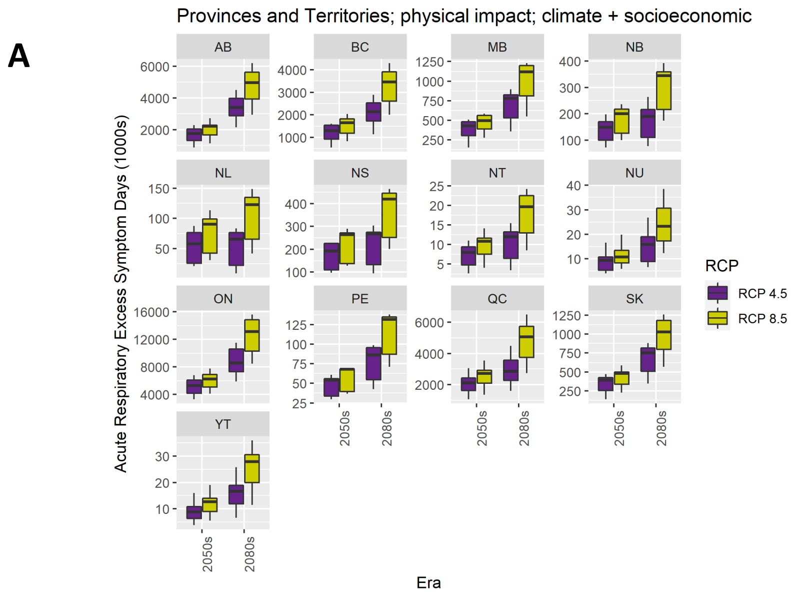
Representative Concentration Pathway 4.5				
Change in RESPIRATORY ERVs from baseline due to (ERVs per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	10	[0 , 40]	20	[0 , 80]
Yukon	10	[0 , 20]	20	[0 , 30]
Northwest Territories	10	[0 , 30]	10	[0 , 50]
British Columbia	860	[130 , 2240]	1,540	[210 , 4120]
Alberta	1,120	[310 , 2830]	2,300	[610 , 6160]
Saskatchewan	370	[60 , 970]	750	[120 , 2040]
Manitoba	260	[50 , 760]	480	[90 , 1450]
Ontario	3,460	[850 , 9640]	5,840	[1370 , 17260]
Quebec	1,860	[290 , 5630]	2,650	[380 , 8330]
New Brunswick	180	[20 , 590]	230	[20 , 820]
Nova Scotia	170	[20 , 560]	220	[30 , 790]
Prince Edward Island	60	[10 , 170]	90	[20 , 300]
Newfoundland and Labrador	90	[10 , 270]	100	[0 , 330]
Sub-total Canada	**8,450**	**[1760 , 23760]**	**14,260**	**[2850 , 41770]**
Sociecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 10]
British Columbia	290	[120 , 410]	500	[190 , 730]
Alberta	560	[300 , 900]	1,110	[580 , 1840]
Saskatchewan	140	[60 , 210]	270	[110 , 420]
Manitoba	100	[50 , 160]	170	[80 , 300]
Ontario	1,570	[810 , 2780]	2,710	[1310 , 5050]
Quebec	570	[260 , 1020]	840	[350 , 1570]
New Brunswick	40	[20 , 70]	50	[20 , 100]
Nova Scotia	50	[20 , 90]	60	[20 , 130]
Prince Edward Island	20	[10 , 40]	40	[20 , 70]
Newfoundland and Labrador	20	[10 , 30]	20	[0 , 30]
Sub-total Canada	**3,360**	**[1650 , 5720]**	**5,790**	**[2680 , 10280]**
Climate change only				
Nunavut	10	[0 , 40]	20	[0 , 70]
Yukon	10	[0 , 20]	10	[0 , 30]
Northwest Territories	10	[0 , 30]	10	[0 , 40]
British Columbia	570	[10 , 1830]	1,040	[20 , 3390]
Alberta	560	[10 , 1930]	1,190	[30 , 4320]
Saskatchewan	230	[0 , 760]	470	[10 , 1620]
Manitoba	170	[0 , 600]	310	[10 , 1150]
Ontario	1,880	[40 , 6860]	3,140	[70 , 12210]
Quebec	1,290	[30 , 4610]	1,810	[40 , 6760]
New Brunswick	140	[0 , 520]	180	[0 , 720]
Nova Scotia	130	[0 , 470]	160	[0 , 650]
Prince Edward Island	30	[0 , 130]	50	[0 , 220]
Newfoundland and Labrador	70	[0 , 240]	80	[0 , 290]
Sub-total Canada	**5,090**	**[110 , 18040]**	**8,470**	**[170 , 31490]**

Note: zero values are due to rounding

Table 7-23: Projected morbidity impacts (respiratory emergency room visits-ERVs) from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental ERVs relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in RESPIRATORY ERVs from baseline due to (ERVs per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	20	[0 , 60]	40	[0 , 140]
Yukon	10	[0 , 30]	30	[0 , 60]
Northwest Territories	10	[0 , 40]	20	[0 , 90]
British Columbia	1,050	[140 , 2850]	2,300	[220 , 6650]
Alberta	1,310	[310 , 3500]	3,140	[630 , 9270]
Saskatchewan	450	[60 , 1240]	1,070	[120 , 3170]
Manitoba	320	[50 , 940]	680	[90 , 2210]
Ontario	3,930	[860 , 11400]	8,000	[1420 , 25800]
Quebec	2,210	[290 , 6910]	4,060	[410 , 13670]
New Brunswick	220	[20 , 750]	370	[20 , 1400]
Nova Scotia	210	[20 , 690]	340	[30 , 1280]
Prince Edward Island	70	[10 , 200]	130	[20 , 460]
Newfoundland and Labrador	110	[10 , 350]	160	[10 , 560]
Sub-total Canada	**9,910**	**[1790 , 28970]**	**20,340**	**[2980 , 64750]**
Socioecononomic change only				
Nunavut	0	[0 , 0]	0	[0 , 10]
Yukon	0	[0 , 0]	0	[0 , 0]
Northwest Territories	0	[0 , 0]	0	[0 , 10]
British Columbia	290	[120 , 410]	500	[190 , 730]
Alberta	560	[300 , 900]	1,110	[580 , 1840]
Saskatchewan	140	[60 , 210]	270	[110 , 420]
Manitoba	100	[50 , 160]	170	[80 , 300]
Ontario	1,570	[810 , 2780]	2,710	[1310 , 5050]
Quebec	570	[260 , 1020]	840	[350 , 1570]
New Brunswick	40	[20 , 70]	50	[20 , 100]
Nova Scotia	50	[20 , 90]	60	[20 , 130]
Prince Edward Island	20	[10 , 40]	40	[20 , 70]
Newfoundland and Labrador	20	[10 , 30]	20	[0 , 30]
Sub-total Canada	**3,360**	**[1650 , 5720]**	**5,790**	**[2680 , 10280]**
Climate change only				
Nunavut	20	[0 , 60]	40	[0 , 130]
Yukon	10	[0 , 20]	20	[0 , 50]
Northwest Territories	10	[0 , 40]	20	[0 , 80]
British Columbia	760	[10 , 2440]	1,790	[30 , 5910]
Alberta	750	[20 , 2610]	2,030	[40 , 7430]
Saskatchewan	310	[10 , 1030]	800	[10 , 2740]
Manitoba	220	[0 , 780]	510	[10 , 1910]
Ontario	2,360	[50 , 8620]	5,290	[110 , 20750]
Quebec	1,640	[30 , 5880]	3,220	[60 , 12110]
New Brunswick	180	[0 , 680]	320	[10 , 1300]
Nova Scotia	160	[0 , 600]	280	[10 , 1140]
Prince Edward Island	40	[0 , 160]	90	[0 , 390]
Newfoundland and Labrador	90	[0 , 320]	140	[0 , 530]
Sub-total Canada	**6,550**	**[140 , 23240]**	**14,560**	**[290 , 54470]**

Note: zero values are due to rounding



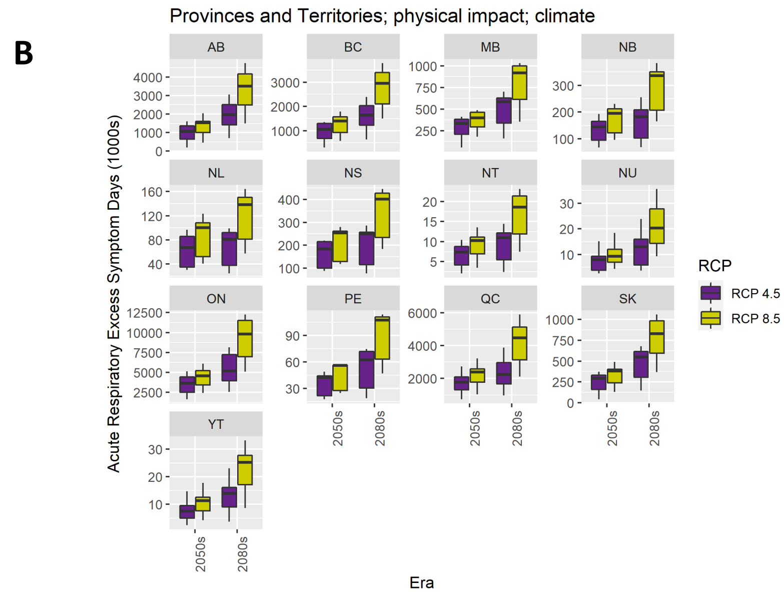


Figure 7-5: Projected morbidity impacts (acute respiratory symptom days-ARSDs) from ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada, showing incremental symptom days per year relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the bold line indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

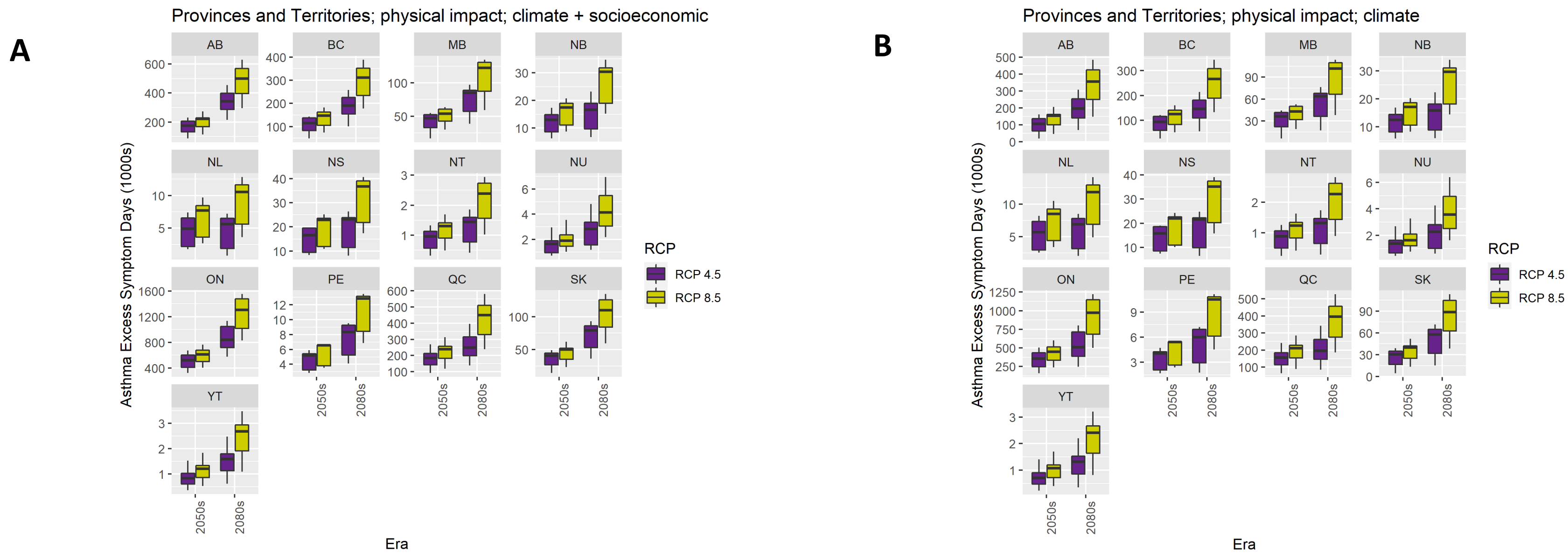


Figure 7-6: Projected morbidity impacts (asthma symptom days-ASDs) from ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada, showing incremental symptom days per year relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the bold line indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

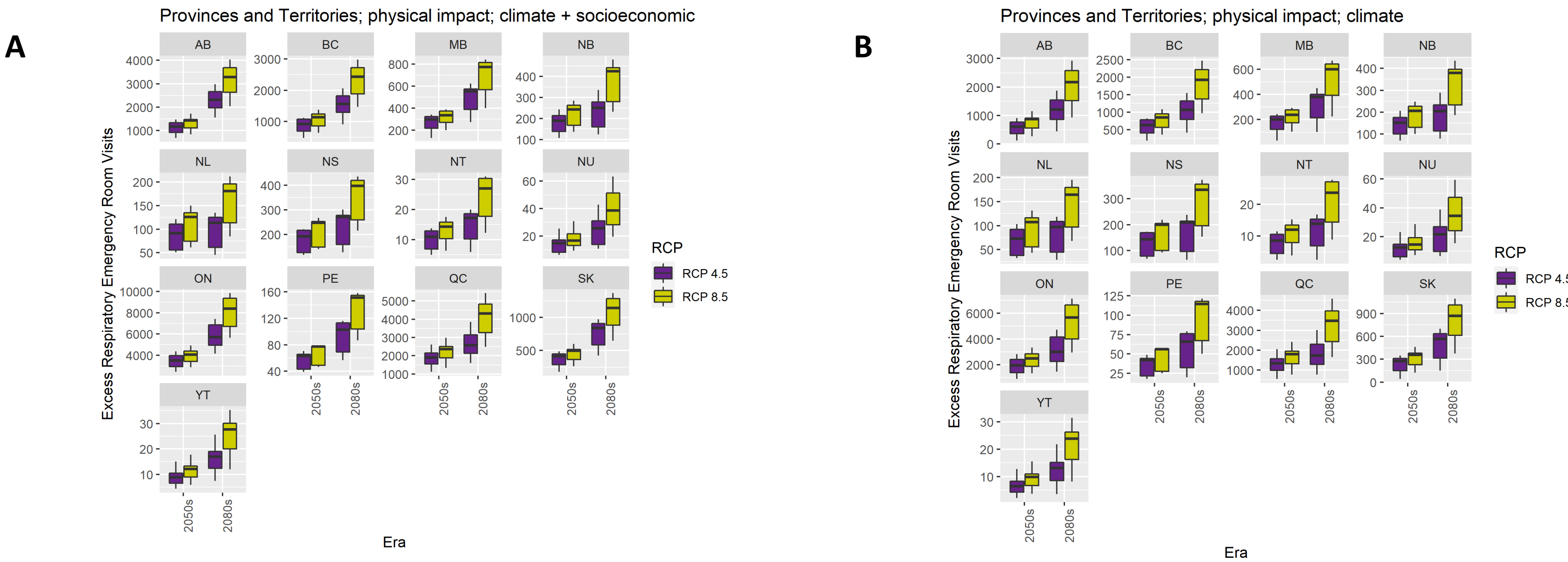


Figure 7-7: Projected morbidity impacts (respiratory emergency room visits-ERVs) from ozone air pollution for the 2050s and 2080s under RCP 4.5 and RCP 8.5 for Canada, showing incremental ERVs per year relative to baseline values attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the bold line indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

Economic Impact

Three different approaches were used to value projected physical impacts from exposure to ozone air pollution; excess deaths were monetized using the VSL (see Table 6-3) and measures of Human Capital (see Table 6-5), while morbidities were monetized using economic unit values embedded in AQBAT (see Table 6-1). By the 2050s and 2080s under RCP 8.5, projected annual average welfare losses for Canada based on the VSL amount to about $88 billion [$12, $308 billion] and $183 billion [$21, $710 billion] (2015 dollars), respectively. The associated annual welfare cost of climate change only amount to $59 billion [$1, $251 billion] and $135 billion [$2.2 billion, $610 billion]. These figures combine welfare costs associated with both acute (Table 7-25) and chronic (Table 7-29) exposure. **Projected financial costs** under the central case, measured using the Human Capital approach, **are substantially lower than projected welfare costs, by nearly an order of magnitude** for both RCPs.

The projected economic costs of respiratory cases of illness for RCP 4.5 are summarized in Table 7-32, Table 7-34 and Table 7-36, and for RCP 8.5 in Table 7-33, Table 7-35 and Table 7-37. By the 2050s and 2080s under RCP 8.5, for example, projected annual average economic costs from increased ARSDs, ASDs and ERVs for Canada amount to about $578 million [$5 million, $3.9 billion]and $1 billion [$9.8 million, 10.7 billion] (2015 dollars), respectively.[108] The corresponding annual average costs of climate change only are $251 million [$0.4 million, $3.3 billion] and $806 million [$1 million, $9.2 billion], for 2050s and 208s, respectively.

Combining both mortality and morbidity impacts, **the total social costs** (using the VSL to value excess deaths) **of exposure to climate change-induced ozone air pollution under RCP 8.5 for the 2050s and 2080s, are about $88 billion [$12, $312 billion] per year and $185 billion [$21, $721 billion] per year, respectively**.[109] The corresponding social costs of climate change are about $60 billion [$1, $255 billion] per year and $137 billion [$2, $619 billion] ($2015) per year. **Morbidity outcomes account for roughly 1% of total social costs.**

Table 7-24: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (valued using the VSL) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ECONOMIC COST (VSL) from baseline due to ($ 2015 billion per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0.1]	0.1	[0 , 0.1]
Yukon	0.1	[0 , 0.1]	0.1	[0 , 0.2]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.2]
British Columbia	6.0	[0.9 , 15.8]	11.0	[1.3 , 29.5]
Alberta	5.5	[1.3 , 15.5]	11.4	[2.6 , 33.2]
Saskatchewan	1.7	[0.2 , 4.8]	3.5	[0.4 , 9.5]
Manitoba	1.6	[0.3 , 5.4]	3.0	[0.4 , 9.8]
Ontario	21.0	[4.1 , 67.6]	35.6	[6.7 , 123.5]
Quebec	9.8	[1.3 , 32.7]	13.3	[1.6 , 45.6]
New Brunswick	1.1	[0.2 , 4]	1.5	[0.2 , 5.9]
Nova Scotia	1.4	[0.2 , 5]	1.9	[0.2 , 7.3]
Prince Edward Island	0.3	[0 , 0.9]	0.5	[0.1 , 1.7]
Newfoundland and Labrador	0.7	[0.1 , 2.4]	0.8	[0.1 , 3.2]
Sub-total Canada	**49.3**	**[8.5 , 154.3]**	**82.6**	**[13.7 , 269.7]**
Socioecononomic change only				
Nunavut	0.1	[0.1 , 0.1]	0.1	[0 , 0.3]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.1	[0 , 0]	0.1	[0 , 0.1]
British Columbia	2.1	[0.6 , 2.7]	3.5	[1.4 , 4.9]
Alberta	2.8	[1.1 , 3.5]	2.7	[2.7 , 6.7]
Saskatchewan	1.0	[0.3 , 1.3]	2.0	[0.6 , 1.4]
Manitoba	0.6	[0.4 , 1.7]	1.1	[0.5 , 2.2]
Ontario	7.2	[3.7 , 8.6]	12.3	[7.6 , 23.4]
Quebec	3.0	[1.7 , 6.1]	6.6	[1.9 , 7.8]
New Brunswick	0.4	[0.4 , 0.5]	0.9	[0.2 , 1.9]
Nova Scotia	1.1	[0.2 , 0.9]	0.9	[0.3 , 2.3]
Prince Edward Island	0.1	[0.1 , 0.2]	0.2	[0.1 , 0.3]
Newfoundland and Labrador	0.3	[0.1 , 0.7]	0.2	[0.1 , 0.5]
Sub-total Canada	**18.9**	**[8.6 , 26.5]**	**30.7**	**[15.4 , 51.7]**
Climate change only				
Nunavut	0.0	[0 , 0.1]	0.0	[0 , 0.1]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.1]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.2]
British Columbia	3.8	[0.1 , 12.8]	7.2	[0.1 , 24.3]
Alberta	3.0	[0.1 , 11.4]	6.5	[0.1 , 24.8]
Saskatchewan	1.1	[0 , 3.9]	2.3	[0 , 7.8]
Manitoba	1.2	[0 , 4.5]	2.1	[0 , 8.3]
Ontario	13.1	[0.3 , 52.7]	22.0	[0.4 , 95.3]
Quebec	7.2	[0.1 , 27.9]	9.9	[0.2 , 39.3]
New Brunswick	0.8	[0 , 3.3]	1.1	[0 , 4.8]
Nova Scotia	0.9	[0 , 3.9]	1.3	[0 , 5.9]
Prince Edward Island	0.2	[0 , 0.7]	0.3	[0 , 1.3]
Newfoundland and Labrador	0.5	[0 , 1.9]	0.6	[0 , 2.6]
Sub-total Canada	**31.8**	**[0.6 , 123.3]**	**53.4**	**[1 , 214.8]**

Note: zero values are due to rounding

Table 7-25: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (valued using the VSL) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ECONOMIC COST (VSL) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Yukon	0.1	[0 , 0.1]	0.2	[0 , 0.3]
Northwest Territories	0.0	[0 , 0.1]	0.1	[0 , 0.3]
British Columbia	7.3	[0.9 , 20.3]	15.8	[1.4 , 46]
Alberta	6.5	[1.3 , 18.9]	15.3	[2.7 , 48.2]
Saskatchewan	2.1	[0.2 , 6]	5.0	[0.5 , 14.5]
Manitoba	1.9	[0.3 , 6.4]	4.2	[0.5 , 14.7]
Ontario	23.7	[4.1 , 78.7]	50.0	[7 , 187]
Quebec	11.6	[1.3 , 39.6]	20.5	[1.8 , 74.6]
New Brunswick	1.4	[0.2 , 5]	2.3	[0.2 , 9.6]
Nova Scotia	1.6	[0.2 , 6]	2.8	[0.2 , 11.5]
Prince Edward Island	0.3	[0 , 1.1]	0.7	[0.1 , 2.6]
Newfoundland and Labrador	0.8	[0.1 , 2.9]	1.3	[0.1 , 5.2]
Sub-total Canada	**57.4**	**[8.7 , 185.5]**	**118.2**	**[14.4 , 414.6]**
Socioecononomic change only				
Nunavut	0.1	[0.1 , 0.1]	0.1	[0 , 0.3]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.2	[0 , 0.1]
British Columbia	1.8	[0.6 , 2.9]	2.9	[1.4 , 5.2]
Alberta	2.6	[1.3 , 3.4]	2.7	[2.7 , 6.3]
Saskatchewan	1.1	[0.2 , 1.4]	1.5	[0.6 , 1.3]
Manitoba	0.6	[0.4 , 2.1]	1.2	[0.5 , 2.7]
Ontario	7.2	[4.2 , 9.8]	11.3	[7.6 , 23.4]
Quebec	2.9	[1.5 , 5.2]	6.8	[1.9 , 7]
New Brunswick	0.4	[0.2 , 0.5]	0.9	[0.2 , 2.3]
Nova Scotia	1.5	[0.2 , 0.9]	1.0	[0.3 , 2.6]
Prince Edward Island	0.1	[0.1 , 0.2]	0.2	[0.1 , 0.3]
Newfoundland and Labrador	0.1	[0.1 , 0.5]	0.3	[0 , 1.9]
Sub-total Canada	**18.5**	**[8.9 , 26.9]**	**29.1**	**[15.3 , 53.3]**
Climate change only				
Nunavut	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Yukon	0.1	[0 , 0.1]	0.1	[0 , 0.2]
Northwest Territories	0.0	[0 , 0.1]	0.1	[0 , 0.3]
British Columbia	5.1	[0.1 , 17.3]	12.1	[0.2 , 40.8]
Alberta	3.9	[0.1 , 14.8]	10.3	[0.2 , 39.8]
Saskatchewan	1.5	[0 , 5.2]	3.8	[0.1 , 12.8]
Manitoba	1.5	[0 , 5.6]	3.4	[0.1 , 13.2]
Ontario	15.8	[0.3 , 63.8]	36.4	[0.7 , 158.8]
Quebec	8.9	[0.2 , 34.8]	17.1	[0.3 , 68.3]
New Brunswick	1.0	[0 , 4.2]	1.8	[0 , 8.5]
Nova Scotia	1.2	[0 , 5]	2.2	[0 , 10.1]
Prince Edward Island	0.2	[0 , 0.9]	0.5	[0 , 2.2]
Newfoundland and Labrador	0.6	[0 , 2.4]	1.0	[0 , 4.6]
Sub-total Canada	**39.9**	**[0.7 , 154.5]**	**88.9**	**[1.6 , 359.7]**

Note: zero values are due to rounding

Table 7-26: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental financial costs (valued using Human Capital) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in FINANCIAL COST (HC) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.6	[0.2 , 1.2]	1.2	[0.2 , 2.6]
Alberta	0.6	[0.2 , 1.2]	1.3	[0.5 , 2.9]
Saskatchewan	0.2	[0 , 0.4]	0.4	[0.1 , 0.8]
Manitoba	0.2	[0 , 0.4]	0.3	[0.1 , 0.9]
Ontario	2.2	[0.7 , 5.3]	4.0	[1.2 , 10.7]
Quebec	1.0	[0.2 , 2.5]	1.5	[0.3 , 4]
New Brunswick	0.1	[0 , 0.3]	0.2	[0 , 0.5]
Nova Scotia	0.1	[0 , 0.4]	0.2	[0 , 0.6]
Prince Edward Island	0.0	[0 , 0.1]	0.1	[0 , 0.1]
Newfoundland and Labrador	0.1	[0 , 0.2]	0.1	[0 , 0.3]
Sub-total Canada	**5.2**	**[1.5 , 12]**	**9.2**	**[2.4 , 23.4]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.2	[0.1 , 0.2]	0.4	[0.2 , 0.4]
Alberta	0.3	[0.2 , 0.3]	0.3	[0.5 , 0.6]
Saskatchewan	0.1	[0.1 , 0.1]	0.2	[0.1 , 0.1]
Manitoba	0.1	[0.1 , 0.1]	0.1	[0.1 , 0.2]
Ontario	0.8	[0.7 , 0.7]	1.4	[1.3 , 2]
Quebec	0.3	[0.3 , 0.5]	0.7	[0.3 , 0.7]
New Brunswick	0.0	[0.1 , 0]	0.1	[0 , 0.2]
Nova Scotia	0.1	[0 , 0.1]	0.1	[0 , 0.2]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.0	[0 , 0]
Sub-total Canada	**2.0**	**[1.5 , 2.1]**	**3.4**	**[2.7 , 4.5]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.4	[0 , 1]	0.8	[0 , 2.1]
Alberta	0.3	[0 , 0.9]	0.7	[0 , 2.2]
Saskatchewan	0.1	[0 , 0.3]	0.3	[0 , 0.7]
Manitoba	0.1	[0 , 0.4]	0.2	[0 , 0.7]
Ontario	1.4	[0 , 4.1]	2.4	[0.1 , 8.3]
Quebec	0.8	[0 , 2.2]	1.1	[0 , 3.4]
New Brunswick	0.1	[0 , 0.3]	0.1	[0 , 0.4]
Nova Scotia	0.1	[0 , 0.3]	0.1	[0 , 0.5]
Prince Edward Island	0.0	[0 , 0.1]	0.0	[0 , 0.1]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Sub-total Canada	**3.4**	**[0.1 , 9.6]**	**5.9**	**[0.2 , 18.6]**

Note: zero values are due to rounding

Table 7-27: Projected acute mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental financial costs (valued using Human Capital) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in FINANCIAL COST (HC) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.8	[0.2 , 1.6]	1.8	[0.2 , 4]
Alberta	0.7	[0.2 , 1.5]	1.7	[0.5 , 4.2]
Saskatchewan	0.2	[0 , 0.5]	0.6	[0.1 , 1.3]
Manitoba	0.2	[0 , 0.5]	0.5	[0.1 , 1.3]
Ontario	2.5	[0.7 , 6.1]	5.6	[1.2 , 16.2]
Quebec	1.2	[0.2 , 3.1]	2.3	[0.3 , 6.5]
New Brunswick	0.1	[0 , 0.4]	0.3	[0 , 0.8]
Nova Scotia	0.2	[0 , 0.5]	0.3	[0 , 1]
Prince Edward Island	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Newfoundland and Labrador	0.1	[0 , 0.2]	0.1	[0 , 0.4]
Sub-total Canada	**6.1**	**[1.5 , 14.4]**	**13.1**	**[2.5 , 36]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.2	[0.1 , 0.2]	0.3	[0.3 , 0.5]
Alberta	0.3	[0.2 , 0.3]	0.3	[0.5 , 0.5]
Saskatchewan	0.1	[0 , 0.1]	0.2	[0.1 , 0.1]
Manitoba	0.1	[0.1 , 0.2]	0.1	[0.1 , 0.2]
Ontario	0.8	[0.7 , 0.8]	1.3	[1.3 , 2]
Quebec	0.3	[0.3 , 0.4]	0.8	[0.3 , 0.6]
New Brunswick	0.0	[0 , 0]	0.1	[0 , 0.2]
Nova Scotia	0.2	[0 , 0.1]	0.1	[0 , 0.2]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , 0]	0.0	[0 , 0.2]
Sub-total Canada	**2.0**	**[1.6 , 2.1]**	**3.2**	**[2.7 , 4.6]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.5	[0 , 1.3]	1.3	[0 , 3.5]
Alberta	0.4	[0 , 1.2]	1.1	[0 , 3.5]
Saskatchewan	0.2	[0 , 0.4]	0.4	[0 , 1.1]
Manitoba	0.2	[0 , 0.4]	0.4	[0 , 1.1]
Ontario	1.7	[0.1 , 5]	4.0	[0.1 , 13.8]
Quebec	0.9	[0 , 2.7]	1.9	[0.1 , 5.9]
New Brunswick	0.1	[0 , 0.3]	0.2	[0 , 0.7]
Nova Scotia	0.1	[0 , 0.4]	0.2	[0 , 0.9]
Prince Edward Island	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Newfoundland and Labrador	0.1	[0 , 0.2]	0.1	[0 , 0.4]
Sub-total Canada	**4.2**	**[0.1 , 12]**	**9.9**	**[0.3 , 31.2]**

Note: zero values are due to rounding

Table 7-28: Projected chronic mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (valued using the VSL) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ECONOMIC COST (VSL) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0.1]	0.0	[0 , 0.2]
Yukon	0.0	[0 , 0]	0.0	[0 , 0.1]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.1]
British Columbia	3.1	[0.3 , 10.5]	5.8	[0.5 , 20.1]
Alberta	3.2	[0.6 , 10.7]	6.7	[1.2 , 24.7]
Saskatchewan	0.8	[0.1 , 2.9]	1.8	[0.2 , 6.3]
Manitoba	0.7	[0.1 , 2.9]	1.4	[0.2 , 5.6]
Ontario	11.4	[2 , 43.1]	19.9	[3.3 , 82.7]
Quebec	5.6	[0.7 , 22.8]	7.9	[0.9 , 34.3]
New Brunswick	0.5	[0 , 2.1]	0.6	[0 , 3.2]
Nova Scotia	0.7	[0.1 , 3.2]	1.0	[0.1 , 4.9]
Prince Edward Island	0.2	[0 , 0.7]	0.3	[0 , 1.3]
Newfoundland and Labrador	0.3	[0 , 1.3]	0.4	[0 , 1.8]
Sub-total Canada	**26.6**	**[4 , 100.3]**	**45.8**	**[6.4 , 185.2]**
Sociecononomic change only				
Nunavut	0.1	[0.1 , 0.3]	0.2	[0.1 , 0.2]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.2	[0.3 , 0.7]	0.2	[0.4 , 0.8]
British Columbia	1.2	[0.4 , 1.1]	2.1	[0.5 , 2.1]
Alberta	1.3	[0.2 , 0.8]	1.1	[0.2 , 0.5]
Saskatchewan	0.4	[0.1 , 0.5]	1.2	[0.5 , 0.5]
Manitoba	1.0	[0.3 , 0.8]	1.8	[0.2 , 3.2]
Ontario	1.9	[0.8 , 0.9]	4.0	[1.6 , 2.7]
Quebec	4.2	[2.5 , 6.1]	7.1	[4.4 , 14.3]
New Brunswick	0.5	[1 , 3.3]	0.7	[2.3 , 5.1]
Nova Scotia	1.0	[0.8 , 1.3]	2.6	[0.4 , 4.3]
Prince Edward Island	0.1	[0 , 0.1]	0.4	[0 , 0.3]
Newfoundland and Labrador	0.1	[0.1 , 1]	1.0	[0.3 , 0.5]
Sub-total Canada	**12.1**	**[6.6 , 16.8]**	**22.5**	**[10.8 , 34.6]**
Climate change only				
Nunavut	0.0	[0 , 0.1]	0.0	[0 , 0.1]
Yukon	0.0	[0 , 0]	0.0	[0 , 0.1]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.1]
British Columbia	2.0	[0 , 8.5]	3.9	[0 , 16.7]
Alberta	1.5	[0 , 7.2]	3.4	[0.1 , 17.3]
Saskatchewan	0.5	[0 , 2.2]	1.1	[0 , 5]
Manitoba	0.5	[0 , 2.3]	0.9	[0 , 4.5]
Ontario	6.0	[0.1 , 30.2]	10.6	[0.1 , 58.6]
Quebec	3.7	[0.1 , 18.3]	5.4	[0.1 , 27.9]
New Brunswick	0.4	[0 , 1.8]	0.5	[0 , 2.8]
Nova Scotia	0.5	[0 , 2.6]	0.7	[0 , 4]
Prince Edward Island	0.1	[0 , 0.5]	0.2	[0 , 0.9]
Newfoundland and Labrador	0.2	[0 , 1.1]	0.3	[0 , 1.6]
Sub-total Canada	**15.4**	**[0.2 , 74.9]**	**27.0**	**[0.4 , 139.7]**

Note: zero values are due to rounding

Table 7-29: Projected chronic mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (valued using the VSL) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ECONOMIC COST (VSL) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.1	[0 , 0.3]	0.2	[0 , 0.8]
Yukon	0.1	[0 , 0.2]	0.2	[0 , 0.4]
Northwest Territories	0.1	[0 , 0.3]	0.1	[0 , 0.6]
British Columbia	11.3	[1 , 40.2]	26.4	[1.6 , 100.5]
Alberta	11.2	[1.9 , 40]	27.5	[3.8 , 114.4]
Saskatchewan	3.1	[0.3 , 11.1]	7.8	[0.6 , 30.3]
Manitoba	2.6	[0.3 , 10.7]	5.8	[0.5 , 26.6]
Ontario	38.8	[6 , 153.6]	82.0	[10.2 , 382.1]
Quebec	19.9	[2 , 84.3]	36.5	[2.7 , 175.1]
New Brunswick	1.7	[0.1 , 8]	3.1	[0.1 , 17]
Nova Scotia	2.6	[0.2 , 11.9]	4.5	[0.3 , 24.5]
Prince Edward Island	0.6	[0.1 , 2.4]	1.2	[0.1 , 6]
Newfoundland and Labrador	1.1	[0.1 , 4.9]	1.8	[0.1 , 9.4]
Sub-total Canada	**93.0**	**[12.1 , 367.9]**	**197.1**	**[20.1 , 887.7]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0.1]	0.1	[0 , 0.1]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0.1]
British Columbia	3.3	[0.9 , 5.8]	5.7	[1.4 , 10.2]
Alberta	5.0	[1.8 , 10.6]	9.8	[3.6 , 22]
Saskatchewan	1.0	[0.3 , 2]	2.0	[0.5 , 3.9]
Manitoba	0.8	[0.3 , 1.8]	1.4	[0.5 , 3.4]
Ontario	16.3	[5.7 , 38.7]	27.9	[9.4 , 72.5]
Quebec	5.7	[1.8 , 13.5]	7.6	[2.3 , 19.1]
New Brunswick	0.3	[0.1 , 0.8]	0.4	[0.1 , 1.2]
Nova Scotia	0.6	[0.2 , 1.7]	0.8	[0.2 , 2.5]
Prince Edward Island	0.2	[0.1 , 0.5]	0.3	[0.1 , 0.9]
Newfoundland and Labrador	0.2	[0.1 , 0.6]	0.3	[0 , 0.8]
Sub-total Canada	**33.6**	**[11.3 , 76.2]**	**56.5**	**[18.2 , 136.6]**
Climate change only				
Nunavut	0.1	[0 , 0.3]	0.2	[0 , 0.7]
Yukon	0.1	[0 , 0.2]	0.1	[0 , 0.4]
Northwest Territories	0.0	[0 , 0.2]	0.1	[0 , 0.5]
British Columbia	8.0	[0.1 , 34.3]	20.7	[0.2 , 90.3]
Alberta	6.2	[0.1 , 29.4]	17.7	[0.3 , 92.4]
Saskatchewan	2.0	[0 , 9.1]	5.8	[0.1 , 26.5]
Manitoba	1.8	[0 , 8.9]	4.4	[0.1 , 23.2]
Ontario	22.5	[0.3 , 114.9]	54.1	[0.7 , 309.7]
Quebec	14.2	[0.2 , 70.8]	28.9	[0.4 , 156]
New Brunswick	1.4	[0 , 7.2]	2.7	[0 , 15.7]
Nova Scotia	1.9	[0 , 10.2]	3.6	[0 , 22]
Prince Edward Island	0.4	[0 , 2]	0.9	[0 , 5.1]
Newfoundland and Labrador	0.8	[0 , 4.3]	1.5	[0 , 8.6]
Sub-total Canada	**59.4**	**[0.8 , 291.7]**	**140.7**	**[1.9 , 751.1]**

Note: zero values are due to rounding

Table 7-30: Projected chronic mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental financial costs (valued using Human Capital) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in FINANCIAL COST (HC) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.3	[0.1 , 0.8]	0.7	[0.1 , 1.7]
Alberta	0.3	[0.1 , 0.8]	0.7	[0.2 , 2.1]
Saskatchewan	0.1	[0 , 0.2]	0.2	[0 , 0.5]
Manitoba	0.1	[0 , 0.2]	0.2	[0 , 0.5]
Ontario	1.2	[0.4 , 3.4]	2.2	[0.6 , 7.2]
Quebec	0.6	[0.1 , 1.8]	0.9	[0.1 , 3]
New Brunswick	0.0	[0 , 0.2]	0.1	[0 , 0.3]
Nova Scotia	0.1	[0 , 0.2]	0.1	[0 , 0.4]
Prince Edward Island	0.0	[0 , 0.1]	0.0	[0 , 0.1]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.0	[0 , 0.2]
Sub-total Canada	**2.8**	**[0.7 , 7.8]**	**5.1**	**[1.1 , 16.1]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0.1 , 0.1]	0.0	[0.1 , 0.1]
British Columbia	0.1	[0.1 , 0.1]	0.2	[0.1 , 0.2]
Alberta	0.1	[0 , 0.1]	0.1	[0 , 0]
Saskatchewan	0.0	[0 , 0]	0.1	[0.1 , 0]
Manitoba	0.1	[0.1 , 0.1]	0.2	[0 , 0.3]
Ontario	0.2	[0.1 , 0.1]	0.4	[0.3 , 0.2]
Quebec	0.4	[0.4 , 0.5]	0.8	[0.8 , 1.2]
New Brunswick	0.1	[0.2 , 0.3]	0.1	[0.4 , 0.4]
Nova Scotia	0.1	[0.1 , 0.1]	0.3	[0.1 , 0.4]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.1	[0 , 0]
Sub-total Canada	**1.3**	**[1.2 , 1.3]**	**2.5**	**[1.9 , 3]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.2	[0 , 0.7]	0.4	[0 , 1.4]
Alberta	0.2	[0 , 0.6]	0.4	[0 , 1.5]
Saskatchewan	0.1	[0 , 0.2]	0.1	[0 , 0.4]
Manitoba	0.0	[0 , 0.2]	0.1	[0 , 0.4]
Ontario	0.6	[0 , 2.4]	1.2	[0 , 5.1]
Quebec	0.4	[0 , 1.4]	0.6	[0 , 2.4]
New Brunswick	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Nova Scotia	0.1	[0 , 0.2]	0.1	[0 , 0.4]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0.1]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.0	[0 , 0.1]
Sub-total Canada	**1.6**	**[0 , 5.8]**	**3.0**	**[0.1 , 12.1]**

Note: zero values are due to rounding

Table 7-31: Projected chronic mortality impacts from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental financial costs (valued using Human Capital) (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in FINANCIAL COST (HC) from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.4	[0.1 , 1]	1.0	[0.1 , 2.9]
Alberta	0.4	[0.1 , 1]	1.0	[0.2 , 3.3]
Saskatchewan	0.1	[0 , 0.3]	0.3	[0 , 0.9]
Manitoba	0.1	[0 , 0.3]	0.2	[0 , 0.8]
Ontario	1.4	[0.4 , 4]	3.0	[0.6 , 11.1]
Quebec	0.7	[0.1 , 2.2]	1.4	[0.2 , 5.1]
New Brunswick	0.1	[0 , 0.2]	0.1	[0 , 0.5]
Nova Scotia	0.1	[0 , 0.3]	0.2	[0 , 0.7]
Prince Edward Island	0.0	[0 , 0.1]	0.0	[0 , 0.2]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Sub-total Canada	**3.3**	**[0.7 , 9.5]**	**7.3**	**[1.2 , 25.7]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0.1 , 0.1]
British Columbia	0.0	[0.1 , 0.1]	0.2	[0.1 , 0.2]
Alberta	0.0	[0 , 0]	0.1	[0 , 0.1]
Saskatchewan	0.1	[0 , 0]	0.1	[0 , 0.1]
Manitoba	0.1	[0 , 0.1]	0.2	[0 , 0.2]
Ontario	0.1	[0.1 , 0.1]	0.2	[0.2 , 0.2]
Quebec	0.5	[0.5 , 0.4]	1.0	[0.7 , 1]
New Brunswick	0.1	[0.2 , 0.2]	0.1	[0.4 , 0.3]
Nova Scotia	0.2	[0.2 , 0.2]	0.3	[0.3 , 0.4]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.1	[0 , 0.1]
Sub-total Canada	**1.1**	**[1.1 , 1.2]**	**2.3**	**[2 , 2.6]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.3	[0 , 0.9]	0.8	[0 , 2.6]
Alberta	0.2	[0 , 0.8]	0.7	[0 , 2.7]
Saskatchewan	0.1	[0 , 0.2]	0.2	[0 , 0.8]
Manitoba	0.1	[0 , 0.2]	0.2	[0 , 0.7]
Ontario	0.8	[0 , 3]	2.0	[0 , 9]
Quebec	0.5	[0 , 1.8]	1.1	[0 , 4.5]
New Brunswick	0.0	[0 , 0.2]	0.1	[0 , 0.5]
Nova Scotia	0.1	[0 , 0.3]	0.1	[0 , 0.6]
Prince Edward Island	0.0	[0 , 0.1]	0.0	[0 , 0.1]
Newfoundland and Labrador	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Sub-total Canada	**2.1**	**[0 , 7.6]**	**5.2**	**[0.1 , 21.7]**

Note: zero values are due to rounding

Table 7-32: Projected morbidity impacts (acute respiratory symptom days-ARSDs) from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ECONOMIC COST from baseline due to ($ 2015 million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.2	[0 , 1.5]	0.4	[0 , 3.1]
Yukon	0.2	[0 , 1.5]	0.4	[0 , 3.1]
Northwest Territories	0.2	[0 , 1.4]	0.3	[0 , 2.6]
British Columbia	29.1	[0 , 210.3]	59.2	[0 , 461.6]
Alberta	40.4	[0 , 260.3]	95.7	[0 , 669.4]
Saskatchewan	8.2	[0 , 56.6]	18.7	[0 , 140]
Manitoba	9.3	[0 , 66.9]	19.2	[0 , 151.4]
Ontario	125.1	[0 , 873.1]	248.9	[0 , 1868.5]
Quebec	49.8	[0 , 382.5]	83.1	[0 , 695.8]
New Brunswick	3.3	[0 , 27.6]	4.8	[0 , 44.6]
Nova Scotia	4.1	[0 , 34]	6.0	[0 , 55.2]
Prince Edward Island	1.1	[0 , 8.4]	2.1	[0 , 17.3]
Newfoundland and Labrador	1.3	[0 , 11.2]	1.4	[0 , 14.6]
Sub-total Canada	**272.4**	**[0 , 1935.4]**	**540.2**	**[0 , 4127.2]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.2]
British Columbia	6.1	[0 , 26]	14.1	[0 , 64.9]
Alberta	16.4	[0 , 67.2]	41.0	[0 , 180.9]
Saskatchewan	2.3	[0 , 9.7]	5.7	[0 , 25.2]
Manitoba	2.4	[0 , 10.8]	5.6	[0 , 27.4]
Ontario	40.6	[0 , 183.5]	94.8	[0 , 463.2]
Quebec	7.8	[0 , 42]	17.1	[0 , 98.9]
New Brunswick	0.1	[0 , 1.2]	0.2	[0 , 2.7]
Nova Scotia	0.2	[0 , 2]	0.5	[0 , 4.7]
Prince Edward Island	0.3	[0 , 1.4]	0.7	[0 , 3.6]
Newfoundland and Labrador	-0.2	[0 , -0.5]	-0.4	[0 , -1.1]
Sub-total Canada	**76.1**	**[0 , 343.6]**	**179.5**	**[0 , 871.1]**
Climate change only				
Nunavut	0.2	[0 , 1.4]	0.3	[0 , 2.8]
Yukon	0.2	[0 , 1.4]	0.4	[0 , 2.9]
Northwest Territories	0.2	[0 , 1.3]	0.3	[0 , 2.4]
British Columbia	23.1	[0 , 184.4]	45.0	[0 , 396.6]
Alberta	23.9	[0 , 193.1]	54.7	[0 , 488.5]
Saskatchewan	5.9	[0 , 47]	13.0	[0 , 114.8]
Manitoba	6.9	[0 , 56]	13.6	[0 , 124]
Ontario	84.6	[0 , 689.6]	154.2	[0 , 1405.3]
Quebec	42.0	[0 , 340.5]	66.0	[0 , 596.9]
New Brunswick	3.2	[0 , 26.4]	4.5	[0 , 42]
Nova Scotia	3.9	[0 , 32]	5.5	[0 , 50.6]
Prince Edward Island	0.8	[0 , 7]	1.5	[0 , 13.7]
Newfoundland and Labrador	1.5	[0 , 11.8]	1.9	[0 , 15.7]
Sub-total Canada	**196.2**	**[0 , 1591.8]**	**360.7**	**[0 , 3256.1]**

Note: zero values are due to rounding

Table 7-33: Projected morbidity impacts (acute respiratory symptom days-ARSDs) from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ECONOMIC COST from baseline due to ($ 2015 million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.3	[0 , 2]	0.7	[0 , 5.3]
Yukon	0.3	[0 , 2]	0.7	[0 , 5.2]
Northwest Territories	0.2	[0 , 1.9]	0.5	[0 , 4.6]
British Columbia	36.5	[0 , 269.6]	91.8	[0 , 749]
Alberta	48.5	[0 , 326.3]	133.9	[0 , 1010.8]
Saskatchewan	10.3	[0 , 73.3]	27.5	[0 , 218]
Manitoba	11.3	[0 , 83.7]	27.9	[0 , 231.1]
Ontario	146.1	[0 , 1044.3]	353.3	[0 , 2819.5]
Quebec	61.2	[0 , 475.5]	134.0	[0 , 1156.3]
New Brunswick	4.3	[0 , 35.2]	8.3	[0 , 77.3]
Nova Scotia	5.2	[0 , 42.9]	10.0	[0 , 92.5]
Prince Edward Island	1.4	[0 , 10.3]	3.2	[0 , 27]
Newfoundland and Labrador	1.8	[0 , 15.2]	2.9	[0 , 26.7]
Sub-total Canada	**327.5**	**[0 , 2382.2]**	**794.6**	**[0 , 6423.3]**
Sociececononomic change only				
Nunavut	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.2]
British Columbia	6.1	[0 , 26]	14.1	[0 , 64.9]
Alberta	16.4	[0 , 67.2]	41.0	[0 , 180.9]
Saskatchewan	2.3	[0 , 9.7]	5.7	[0 , 25.2]
Manitoba	2.4	[0 , 10.8]	5.6	[0 , 27.4]
Ontario	40.6	[0 , 183.5]	94.8	[0 , 463.2]
Quebec	7.8	[0 , 42]	17.1	[0 , 98.9]
New Brunswick	0.1	[0 , 1.2]	0.2	[0 , 2.7]
Nova Scotia	0.2	[0 , 2]	0.5	[0 , 4.7]
Prince Edward Island	0.3	[0 , 1.4]	0.7	[0 , 3.6]
Newfoundland and Labrador	-0.2	[0 , -0.5]	-0.4	[0 , -1.1]
Sub-total Canada	**76.1**	**[0 , 343.6]**	**179.5**	**[0 , 871.1]**
Climate change only				
Nunavut	0.2	[0 , 1.9]	0.6	[0 , 4.9]
Yukon	0.3	[0 , 1.9]	0.6	[0 , 4.9]
Northwest Territories	0.2	[0 , 1.8]	0.5	[0 , 4.4]
British Columbia	30.5	[0 , 243.7]	77.6	[0 , 684]
Alberta	32.1	[0 , 259.1]	92.9	[0 , 829.9]
Saskatchewan	7.9	[0 , 63.6]	21.8	[0 , 192.8]
Manitoba	8.9	[0 , 72.8]	22.3	[0 , 203.7]
Ontario	105.6	[0 , 860.8]	258.5	[0 , 2356.3]
Quebec	53.4	[0 , 433.5]	116.9	[0 , 1057.5]
New Brunswick	4.1	[0 , 34]	8.1	[0 , 74.6]
Nova Scotia	5.0	[0 , 40.9]	9.5	[0 , 87.9]
Prince Edward Island	1.1	[0 , 8.9]	2.5	[0 , 23.5]
Newfoundland and Labrador	2.0	[0 , 15.8]	3.3	[0 , 27.8]
Sub-total Canada	**251.3**	**[0 , 2038.6]**	**615.2**	**[0 , 5552.2]**

Note: zero values are due to rounding

Table 7-34: Projected morbidity impacts (asthma symptom days-ASDs) from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ECONOMIC COST from baseline due to ($ 2015 million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.1	[0 , 1.6]	0.2	[0 , 3.4]
Yukon	0.0	[0 , 0.9]	0.1	[0 , 1.8]
Northwest Territories	0.0	[0 , 1]	0.1	[0 , 1.9]
British Columbia	5.6	[0 , 111.9]	11.4	[0 , 248]
Alberta	8.7	[0.1 , 155.9]	20.7	[0.1 , 404.7]
Saskatchewan	1.9	[0 , 35.6]	4.2	[0 , 88.8]
Manitoba	2.2	[0 , 43.3]	4.5	[0 , 99]
Ontario	26.5	[0.1 , 515.1]	52.8	[0.2 , 1112.6]
Quebec	9.4	[0 , 201.7]	15.7	[0 , 370.1]
New Brunswick	0.6	[0 , 14.4]	0.9	[0 , 23.6]
Nova Scotia	0.8	[0 , 17.6]	1.1	[0 , 28.8]
Prince Edward Island	0.2	[0 , 4.8]	0.4	[0 , 10]
Newfoundland and Labrador	0.2	[0 , 5.7]	0.3	[0 , 7.5]
Sub-total Canada	**56.2**	**[0.2 , 1109.6]**	**112.3**	**[0.5 , 2400.1]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0.1]	0.0	[0 , 0.4]
Yukon	0.0	[0 , 0.1]	0.0	[0 , 0.2]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.1]
British Columbia	1.2	[0 , 13.5]	2.7	[0 , 33.8]
Alberta	3.5	[0.1 , 39.6]	8.8	[0.1 , 106.6]
Saskatchewan	0.5	[0 , 5.9]	1.3	[0 , 15.5]
Manitoba	0.6	[0 , 6.8]	1.3	[0 , 17.2]
Ontario	8.7	[0.1 , 107.3]	20.2	[0.2 , 270.7]
Quebec	1.5	[0 , 21.7]	3.3	[0 , 51]
New Brunswick	0.0	[0 , 0.6]	0.0	[0 , 1.4]
Nova Scotia	0.0	[0 , 1]	0.1	[0 , 2.3]
Prince Edward Island	0.1	[0 , 0.8]	0.1	[0 , 2]
Newfoundland and Labrador	0.0	[0 , -0.3]	-0.1	[0 , -0.5]
Sub-total Canada	**16.1**	**[0.2 , 197.3]**	**37.9**	**[0.4 , 500.5]**
Climate change only				
Nunavut	0.1	[0 , 1.5]	0.1	[0 , 3]
Yukon	0.0	[0 , 0.8]	0.1	[0 , 1.6]
Northwest Territories	0.0	[0 , 1]	0.1	[0 , 1.7]
British Columbia	4.4	[0 , 98.4]	8.7	[0 , 214.2]
Alberta	5.2	[0 , 116.3]	11.8	[0 , 298.1]
Saskatchewan	1.3	[0 , 29.6]	2.9	[0 , 73.3]
Manitoba	1.6	[0 , 36.5]	3.2	[0 , 81.8]
Ontario	17.8	[0 , 407.9]	32.6	[0 , 841.9]
Quebec	7.9	[0 , 180]	12.5	[0 , 319.1]
New Brunswick	0.6	[0 , 13.8]	0.9	[0 , 22.2]
Nova Scotia	0.7	[0 , 16.6]	1.0	[0 , 26.4]
Prince Edward Island	0.2	[0 , 4]	0.3	[0 , 8]
Newfoundland and Labrador	0.3	[0 , 6]	0.3	[0 , 8]
Sub-total Canada	**40.2**	**[0 , 912.3]**	**74.4**	**[0 , 1899.5]**

Note: zero values are due to rounding

Table 7-35: Projected morbidity impacts (asthma symptom days-ASDs) from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ECONOMIC COST from baseline due to ($ 2015 million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.1	[0 , 2.1]	0.3	[0 , 5.9]
Yukon	0.1	[0 , 1.2]	0.1	[0 , 3.1]
Northwest Territories	0.1	[0 , 1.4]	0.1	[0 , 3.5]
British Columbia	7.0	[0 , 145.3]	17.8	[0 , 418]
Alberta	10.5	[0.1 , 197.5]	29.1	[0.1 , 634.5]
Saskatchewan	2.3	[0 , 46.5]	6.3	[0 , 143.5]
Manitoba	2.6	[0 , 54.7]	6.6	[0 , 157]
Ontario	31.0	[0.1 , 621.7]	75.4	[0.3 , 1741]
Quebec	11.6	[0 , 253.5]	25.6	[0 , 641.7]
New Brunswick	0.8	[0 , 18.6]	1.6	[0 , 42.5]
Nova Scotia	1.0	[0 , 22.5]	1.9	[0 , 50]
Prince Edward Island	0.3	[0 , 6]	0.7	[0 , 16.3]
Newfoundland and Labrador	0.3	[0 , 7.9]	0.5	[0 , 14.3]
Sub-total Canada	**67.7**	**[0.2 , 1378.9]**	**165.8**	**[0.5 , 3871.1]**
Sociocononomic change only				
Nunavut	0.0	[0 , 0.1]	0.0	[0 , 0.4]
Yukon	0.0	[0 , 0.1]	0.0	[0 , 0.2]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.1]
British Columbia	1.2	[0 , 13.5]	2.7	[0 , 33.8]
Alberta	3.5	[0.1 , 39.6]	8.8	[0.1 , 106.6]
Saskatchewan	0.5	[0 , 5.9]	1.3	[0 , 15.5]
Manitoba	0.6	[0 , 6.8]	1.3	[0 , 17.2]
Ontario	8.7	[0.1 , 107.3]	20.2	[0.2 , 270.7]
Quebec	1.5	[0 , 21.7]	3.3	[0 , 51]
New Brunswick	0.0	[0 , 0.6]	0.0	[0 , 1.4]
Nova Scotia	0.0	[0 , 1]	0.1	[0 , 2.3]
Prince Edward Island	0.1	[0 , 0.8]	0.1	[0 , 2]
Newfoundland and Labrador	0.0	[0 , -0.3]	-0.1	[0 , -0.5]
Sub-total Canada	**16.1**	**[0.2 , 197.3]**	**37.9**	**[0.4 , 500.5]**
Climate change only				
Nunavut	0.1	[0 , 2]	0.2	[0 , 5.5]
Yukon	0.1	[0 , 1.1]	0.1	[0 , 2.9]
Northwest Territories	0.1	[0 , 1.3]	0.1	[0 , 3.3]
British Columbia	5.9	[0 , 131.7]	15.1	[0 , 384.3]
Alberta	6.9	[0 , 157.8]	20.3	[0 , 527.9]
Saskatchewan	1.8	[0 , 40.5]	5.0	[0 , 128.1]
Manitoba	2.1	[0 , 47.9]	5.3	[0 , 139.8]
Ontario	22.3	[0 , 514.5]	55.1	[0 , 1470.3]
Quebec	10.1	[0 , 231.8]	22.3	[0 , 590.7]
New Brunswick	0.8	[0 , 18]	1.5	[0 , 41.1]
Nova Scotia	0.9	[0 , 21.5]	1.8	[0 , 47.6]
Prince Edward Island	0.2	[0 , 5.2]	0.5	[0 , 14.3]
Newfoundland and Labrador	0.4	[0 , 8.1]	0.6	[0 , 14.8]
Sub-total Canada	**51.6**	**[0 , 1181.6]**	**128.0**	**[0.1 , 3370.6]**

Note: zero values are due to rounding

Table 7-36: Projected morbidity impacts (respiratory emergency room visits-ERVs) from ozone air pollution for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental welfare costs (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ECONOMIC COST from baseline due to ($ 2015 million per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.1	[0 , 0.2]	0.1	[0 , 0.5]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Northwest Territories	0.0	[0 , 0.2]	0.1	[0 , 0.3]
British Columbia	3.2	[0.4 , 10.8]	6.7	[0.6 , 23.8]
Alberta	4.2	[0.9 , 13.7]	10.0	[1.9 , 35.6]
Saskatchewan	1.4	[0.2 , 4.7]	3.2	[0.4 , 11.8]
Manitoba	1.0	[0.1 , 3.7]	2.1	[0.3 , 8.4]
Ontario	12.9	[2.4 , 46.5]	25.4	[4.3 , 99.8]
Quebec	7.0	[0.8 , 27.1]	11.5	[1.2 , 48.1]
New Brunswick	0.7	[0.1 , 2.9]	1.0	[0.1 , 4.7]
Nova Scotia	0.6	[0.1 , 2.7]	1.0	[0.1 , 4.6]
Prince Edward Island	0.2	[0 , 0.8]	0.4	[0.1 , 1.7]
Newfoundland and Labrador	0.3	[0 , 1.3]	0.4	[0 , 1.9]
Sub-total Canada	**31.6**	**[4.9 , 114.6]**	**61.9**	**[8.9 , 241.5]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	1.1	[0.3 , 2]	2.2	[0.6 , 4.2]
Alberta	2.1	[0.8 , 4.3]	4.8	[1.8 , 10.7]
Saskatchewan	0.5	[0.2 , 1]	1.2	[0.3 , 2.4]
Manitoba	0.4	[0.1 , 0.8]	0.8	[0.3 , 1.8]
Ontario	5.9	[2.2 , 13.4]	11.8	[4.1 , 29.2]
Quebec	2.1	[0.7 , 4.9]	3.7	[1.1 , 9.1]
New Brunswick	0.1	[0 , 0.3]	0.2	[0.1 , 0.6]
Nova Scotia	0.2	[0.1 , 0.4]	0.3	[0.1 , 0.8]
Prince Edward Island	0.1	[0 , 0.2]	0.2	[0.1 , 0.4]
Newfoundland and Labrador	0.1	[0 , 0.2]	0.1	[0 , 0.2]
Sub-total Canada	**12.6**	**[4.6 , 27.6]**	**25.1**	**[8.4 , 59.4]**
Climate change only				
Nunavut	0.0	[0 , 0.2]	0.1	[0 , 0.4]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.2]
Northwest Territories	0.0	[0 , 0.1]	0.0	[0 , 0.3]
British Columbia	2.1	[0 , 8.8]	4.5	[0.1 , 19.6]
Alberta	2.1	[0 , 9.3]	5.2	[0.1 , 25]
Saskatchewan	0.8	[0 , 3.7]	2.1	[0 , 9.4]
Manitoba	0.6	[0 , 2.9]	1.3	[0 , 6.6]
Ontario	7.0	[0.1 , 33.1]	13.6	[0.2 , 70.6]
Quebec	4.8	[0.1 , 22.2]	7.9	[0.1 , 39.1]
New Brunswick	0.5	[0 , 2.5]	0.8	[0 , 4.2]
Nova Scotia	0.5	[0 , 2.3]	0.7	[0 , 3.8]
Prince Edward Island	0.1	[0 , 0.6]	0.2	[0 , 1.3]
Newfoundland and Labrador	0.3	[0 , 1.2]	0.3	[0 , 1.7]
Sub-total Canada	**19.0**	**[0.3 , 87]**	**36.8**	**[0.5 , 182.1]**

Note: zero values are due to rounding

Table 7-37: Projected morbidity impacts (respiratory emergency room visits-ERVs) from ozone air pollution for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental welfare costs (2015 dollars) relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ECONOMIC COST from baseline due to ($ 2015 million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.1	[0 , 0.3]	0.2	[0 , 0.8]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Northwest Territories	0.0	[0 , 0.2]	0.1	[0 , 0.5]
British Columbia	3.9	[0.4 , 13.7]	10.0	[0.7 , 38.4]
Alberta	4.9	[0.9 , 16.9]	13.6	[2 , 53.6]
Saskatchewan	1.7	[0.2 , 6]	4.6	[0.4 , 18.3]
Manitoba	1.2	[0.1 , 4.6]	3.0	[0.3 , 12.8]
Ontario	14.7	[2.4 , 55]	34.7	[4.4 , 149.2]
Quebec	8.3	[0.8 , 33.3]	17.6	[1.3 , 79.1]
New Brunswick	0.8	[0.1 , 3.6]	1.6	[0.1 , 8.1]
Nova Scotia	0.8	[0.1 , 3.3]	1.5	[0.1 , 7.4]
Prince Edward Island	0.2	[0 , 1]	0.6	[0.1 , 2.7]
Newfoundland and Labrador	0.4	[0 , 1.7]	0.7	[0 , 3.2]
Sub-total Canada	**37.1**	**[5 , 139.7]**	**88.3**	**[9.3 , 374.4]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	1.1	[0.3 , 2]	2.2	[0.6 , 4.2]
Alberta	2.1	[0.8 , 4.3]	4.8	[1.8 , 10.7]
Saskatchewan	0.5	[0.2 , 1]	1.2	[0.3 , 2.4]
Manitoba	0.4	[0.1 , 0.8]	0.8	[0.3 , 1.8]
Ontario	5.9	[2.2 , 13.4]	11.8	[4.1 , 29.2]
Quebec	2.1	[0.7 , 4.9]	3.7	[1.1 , 9.1]
New Brunswick	0.1	[0 , 0.3]	0.2	[0.1 , 0.6]
Nova Scotia	0.2	[0.1 , 0.4]	0.3	[0.1 , 0.8]
Prince Edward Island	0.1	[0 , 0.2]	0.2	[0.1 , 0.4]
Newfoundland and Labrador	0.1	[0 , 0.2]	0.1	[0 , 0.2]
Sub-total Canada	**12.6**	**[4.6 , 27.6]**	**25.1**	**[8.4 , 59.4]**
Climate change only				
Nunavut	0.1	[0 , 0.3]	0.2	[0 , 0.7]
Yukon	0.0	[0 , 0.1]	0.1	[0 , 0.3]
Northwest Territories	0.0	[0 , 0.2]	0.1	[0 , 0.5]
British Columbia	2.8	[0 , 11.8]	7.8	[0.1 , 34.2]
Alberta	2.8	[0 , 12.6]	8.8	[0.1 , 42.9]
Saskatchewan	1.1	[0 , 5]	3.5	[0 , 15.9]
Manitoba	0.8	[0 , 3.8]	2.2	[0 , 11]
Ontario	8.8	[0.1 , 41.6]	23.0	[0.3 , 120]
Quebec	6.1	[0.1 , 28.4]	14.0	[0.2 , 70]
New Brunswick	0.7	[0 , 3.3]	1.4	[0 , 7.5]
Nova Scotia	0.6	[0 , 2.9]	1.2	[0 , 6.6]
Prince Edward Island	0.2	[0 , 0.8]	0.4	[0 , 2.2]
Newfoundland and Labrador	0.3	[0 , 1.5]	0.6	[0 , 3]
Sub-total Canada	**24.5**	**[0.4 , 112.1]**	**63.2**	**[0.9 , 315]**

Note: zero values are due to rounding

7.3 Lyme Disease

Physical Impact

Projected new annual cases of Lyme disease in the general population associated with climate change are summarized in Table 7-38 and Table 7-39. Results are for Census Divisions below 500 metres above sea level (on average), west of the Rockies and in provinces with established populations of black-legged ticks (i.e., Manitoba, Ontario, Quebec, and Atlantic provinces). These results show that (a) as the number of people exposed to Lyme disease vectors grows in the future, new cases of the disease increase in aggregate terms, even in the absence of further climate change – however, this pattern is regionally variable; and (b) the **growth in new cases of Lyme disease is temperature-limited, with projected changes in temperature under RCP 8.5 showing declining case counts over time and yielding lower case counts compared to the case under RCP 4.5.**

By the 2050s and 2080s under RCP 8.5, projected annual new cases of Lyme disease due to a combination of socioeconomic change and climate change amount to about 7,490 [2,600, 12,380] and 4,990 [1,480, 8,510], respectively. Under RCP 4.5 the corresponding values are 8,460 [2,940, 13,970] and 9,850 [3,080, 16,620]. These total cases amount to aggregate incidence rates in the 2080s of 24/100,000 under RCP 4.5 and 12/100,000 under RCP 8.5, assuming mid-range population projections.

Looking at new annual cases in the 2080s, approximately 67% of total projected new cases of Lyme disease are attributable to climate change alone under RCP 8.5. In contrast, new cases attributable to climate change alone account for about 83% of total projected new cases under RCP 4.5. **With higher levels of climate change, socioeconomic developments increase as a driver of total physical risk; though still not as important as climate-induced increases Lyme disease occurrence.** This pattern of temperature-limited cases stems from the inverted U-shaped curve of the exposure response function in Dumic and Severnini (2018). These researchers justify the parabolic relationship between average annual temperatures and Lyme disease incidence, including reference to Canadian research, suggesting that tick activity and survival peak at a certain temperature then decline. However, expansion of Lyme disease occurrence in southern, hotter US states has been observed and other dynamics such as the expansion of animal reservoirs (i.e., tick vectors) could be at play.[21] Therefore, this apparent reduction in Lyme disease risk at higher temperatures – and related differences between RCP4.5 and RCP8.5 – may be less evident were studies in the U.S. to be repeated in future decades.

Regionally, projected new cases of Lyme disease are most numerous in Ontario (e.g., 1,900 new cases annually by the 2080s under RCP 8.5), Quebec (e.g., 1,860 new cases annually by the 2080s under RCP 8.5) and Manitoba (e.g., 720 new cases annually by the 2080s under RCP 8.5) (see Table 7-39); this pattern tracks population counts and holds true under RCP 4.5 as well. To assess the plausibility of the spatial distribution of our results we can compare our projected Lyme disease cases over the 2080s with projections in published literature of the vector presence in the same timeframe. Figure 7-8 and Figure 7-9 contain maps to facilitate this visual comparison.

[21] https://www.ucsf.edu/news/2018/05/410401/lyme-disease-rise-expert-explains-why

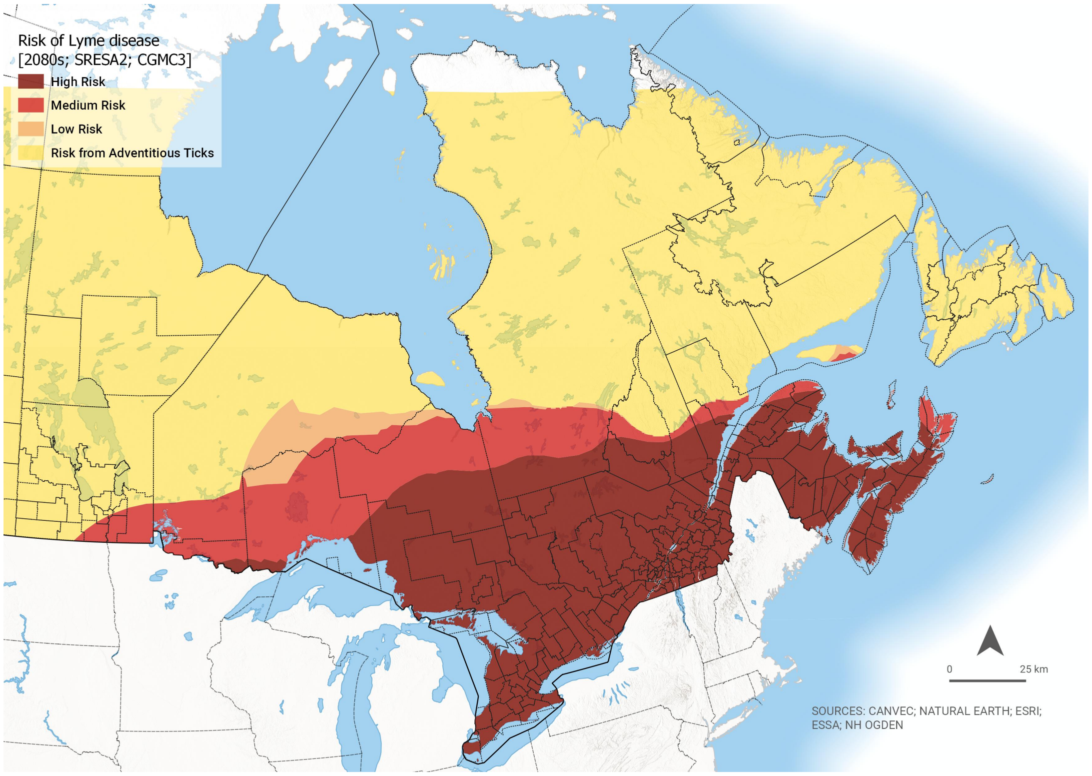


Figure 7-8: Geographic distribution of the risk of contracting Lyme disease based on vector presence in the 2080s under a high emissions scenario (Source: Ogden et al. 2008). “Adventitious ticks” refers to ticks that are not native to the geographic location but introduced by migratory birds and, hence, sporadic.

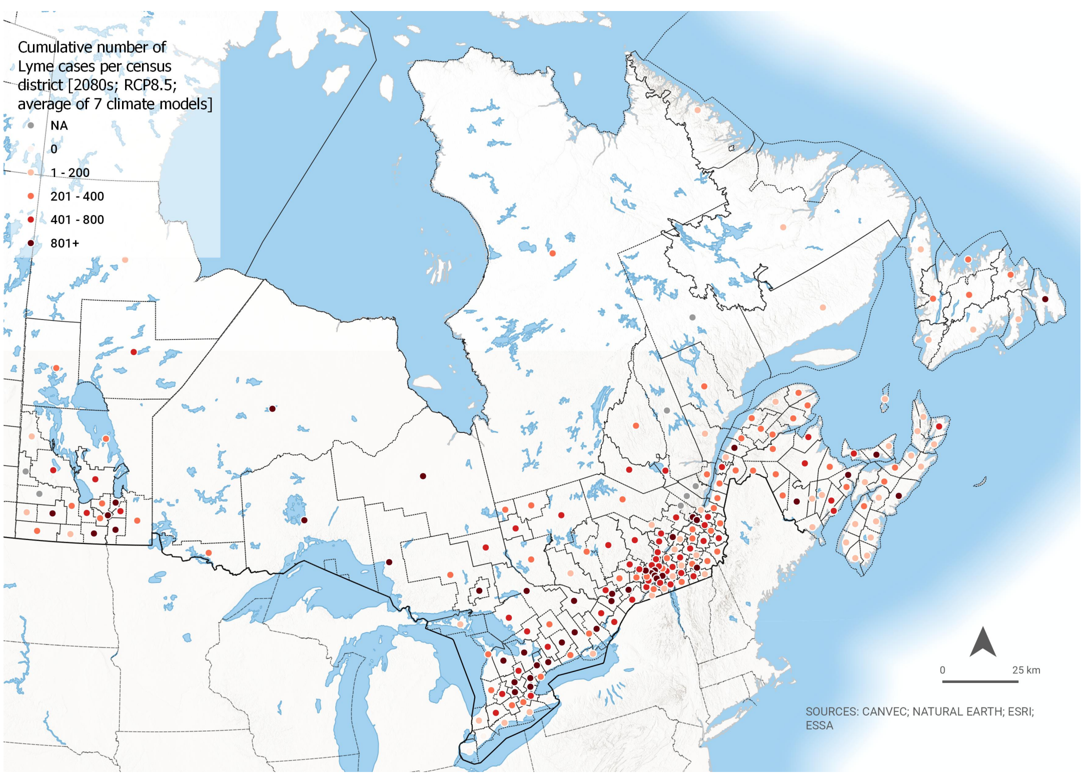


Figure 7-9: Geographic distribution of cumulative new cases of Lyme disease in the 2080s by Census Division under a high emissions concentration scenario (Source: this study).

From this comparison we can observe that projected case counts generally correlate with the risk categories in Ogden et al. (2008). Southern Ontario and Quebec, Nova Scotia, New Brunswick and Prince Edward Island are all in the “High Risk” zones, and have high forecasted case counts. Case counts are generally lower in further north regions (e.g., the far north of Manitoba, Quebec, and Newfound and Labrador. **However, this correlation is not universal.** Even in sparsely-populated regions in the “Risk from Adventitious Ticks” category are forecasted to have moderately high case counts. For example, Division No. 21 and 22 in northern Manitoba and Division no. 5 in Newfoundland and Labrador are forecasted to have case counts in the low hundreds. Low case counts from our study can also be found in “High Risk” zone, for example, in select counties in Southern Ontario (e.g., Brant), southern Quebec (e.g., Le Haut-Saint-Laurent), New Brunswick (e.g., Yarmouth) and Nova Scotia (e.g., Charlotte). **This comparison suggests that we may place greater confidence in our results at aggregate levels (i.e., provincial or national) than we can at the level of Census Divisions.**

Because the Lyme disease-temperature response came from U.S. data, where transmission dynamics and surveillance and control mechanisms differ from Canada’s, it is plausible that projected case counts are overstated (and, hence, so too are economic costs). Larrivée et al. (2015) is the only other Canadian study that has to date estimated the costs of Lyme disease under climate change, although they focused on Quebec. These researchers estimated a Lyme disease incidence rate for 2050 of 22.2/100,000 people in Quebec. In our study, the revealed incidence rate for Quebec in 2050s ranges from 27/100,000 to 29/100,000 and in 2080s from 17/100,000 to 28/100,000. Incidence rates are not entirely comparable to those used in Larrivée et al. (2015) since their rates did not explicitly take climate change projections into account and our population projections are not identical. Still, our rates and theirs are in the same order of magnitude.

Figure 7-10 contains box-whisker plots for projected new Lyme disease cases for the 2050s and 2080s under RCP 4.5 and RCP 8.5, by province. The plots show cumulative cases over the 30-year era as opposed to annual cases and illustrate the full range of results across the seven GCMs for central case assumptions for all other input variables. These plots isolate the impact of future climate uncertainty on the overall results. For 2080s under RCP 8.5 projected annualized new cases in Ontario due to a combination of socioeconomic change and climate change across all seven GCMs range from 0 to 5,000 [central value 833]. This represents a comparable uncertainty range to that from the impact model (ERF) and socioeconomic data (i.e., which range from 170 to 3,640 new cases per year based on the mean GCM projection, see Table 7-39).

Table 7-38: Projected new cases of Lyme Disease for the 2050s and 2080s under RCP 4.5, by province, showing incremental cases per year relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in NEW INCIDENT LYME DISEASE CASES from baseline due to (cases per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	430	[20 , 830]	670	[130 , 1220]
Ontario	4,320	[1340 , 7300]	5,200	[1340 , 9070]
Quebec	2,920	[1210 , 4620]	3,140	[1210 , 5060]
New Brunswick	280	[130 , 420]	300	[150 , 450]
Nova Scotia	320	[150 , 490]	330	[150 , 510]
Prince Edward Island	70	[30 , 110]	100	[40 , 150]
Newfoundland and Labrador	120	[60 , 190]	110	[60 , 160]
Sub-total Canada	**8,460**	**[2940 , 13970]**	**9,850**	**[3080 , 16620]**
Socioecononomic change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	10	[-30 , 90]	20	[-60 , 190]
Ontario	680	[100 , 1670]	1,360	[190 , 3510]
Quebec	130	[-10 , 470]	240	[-20 , 920]
New Brunswick	0	[0 , 20]	0	[0 , 40]
Nova Scotia	10	[0 , 40]	10	[0 , 70]
Prince Edward Island	10	[0 , 20]	10	[0 , 30]
Newfoundland and Labrador	0	[10 , -10]	-10	[10 , -20]
Sub-total Canada	**820**	**[60 , 2300]**	**1,640**	**[120 , 4750]**
Climate change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	420	[50 , 740]	660	[190 , 1030]
Ontario	3,640	[1240 , 5630]	3,840	[1150 , 5560]
Quebec	2,790	[1220 , 4160]	2,900	[1230 , 4150]
New Brunswick	270	[130 , 400]	290	[140 , 410]
Nova Scotia	320	[150 , 460]	320	[150 , 440]
Prince Edward Island	70	[30 , 100]	90	[40 , 120]
Newfoundland and Labrador	130	[50 , 200]	120	[50 , 170]
Sub-total Canada	**7,630**	**[2880 , 11680]**	**8,210**	**[2960 , 11860]**

Note: zero values are due to rounding

Table 7-39: Projected new cases of Lyme Disease for the 2050s and 2080s under RCP 8.5, by province, showing incremental cases per year relative to baseline values, attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in NEW INCIDENT LYME DISEASE CASES from baseline due to (cases per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	500	[120 , 890]	720	[280 , 1160]
Ontario	3,560	[970 , 6160]	1,900	[170 , 3640]
Quebec	2,680	[1150 , 4210]	1,860	[780 , 2950]
New Brunswick	270	[140 , 410]	200	[100 , 290]
Nova Scotia	270	[120 , 420]	160	[60 , 250]
Prince Edward Island	60	[30 , 100]	50	[20 , 90]
Newfoundland and Labrador	130	[70 , 200]	100	[70 , 130]
Sub-total Canada	**7,490**	**[2600 , 12380]**	**4,990**	**[1480 , 8510]**
Socioecononomic change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	10	[-30 , 90]	20	[-60 , 190]
Ontario	680	[100 , 1670]	1,360	[190 , 3510]
Quebec	130	[-10 , 470]	240	[-20 , 920]
New Brunswick	0	[0 , 20]	0	[0 , 40]
Nova Scotia	10	[0 , 40]	10	[0 , 70]
Prince Edward Island	10	[0 , 20]	10	[0 , 30]
Newfoundland and Labrador	0	[10 , -10]	-10	[10 , -20]
Sub-total Canada	**820**	**[60 , 2290]**	**1,640**	**[120 , 4750]**
Climate change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	490	[150 , 790]	700	[340 , 960]
Ontario	2,880	[870 , 4490]	540	[-10 , 130]
Quebec	2,560	[1160 , 3740]	1,630	[800 , 2030]
New Brunswick	270	[140 , 380]	190	[100 , 250]
Nova Scotia	260	[120 , 380]	140	[60 , 180]
Prince Edward Island	60	[30 , 80]	40	[20 , 50]
Newfoundland and Labrador	140	[60 , 210]	110	[50 , 150]
Sub-total Canada	**6,660**	**[2530 , 10090]**	**3,350**	**[1360 , 3760]**

Note: zero values are due to rounding

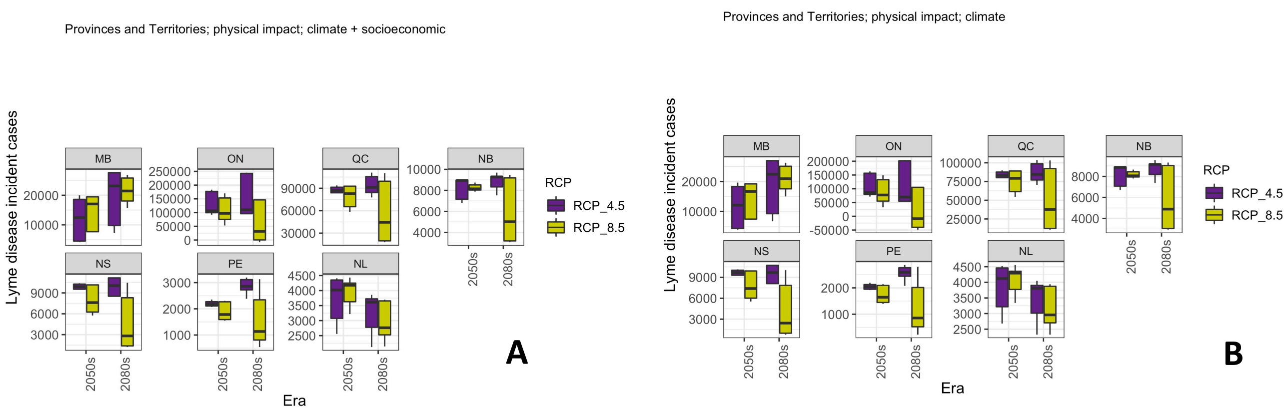


Figure 7-10: Projected new cases of Lyme disease over the 2050s and 2080s (i.e., 30-year totals) under RCP 4.5 and RCP 8.5, by province, showing incremental cases per year relative to baseline values, attributable to (A) a combination of socioeconomic and climate change and (B) climate change only [showing range across the seven GCMs for the central case only; the bold line indicates the mean value, the box shows the quartile range, and the whisker bars show the lowest and highest values across the GCMs]

Economic Impact

Recalling from Section 6.1.4., our economic unit costs[22] for Lyme disease cases comprise three components: direct resource costs, opportunity costs (e.g., lost production) and disutility costs. The projected annual costs from a societal perspective (i.e., economic costs) from new Lyme disease cases under RCP 4.5 and RCP 8.5 appear in Table 7-40 and Table 7-41. **By the 2050s and 2080s under RCP 4.5, projected annual average economic costs for Canada amount to $234 million [$21 million, $1.2 billion] and $282 million [$23 million, $1.5 billion] (2015 dollars), respectively.**[110] The associated annual cost of climate change in 2050s and 2080s amount to $211 million [$21 million, $1 billion] and $235 million [$22 million, $1.1 billion] (2015 dollars); this represents between 83 and 90% of total welfare costs. Consistent with findings for physical impacts, projected costs of new cases of Lyme disease under RCP 8.5 are lower than for the RCP 4.5 case and decline from 2050s to 2080s. **Under RCP 8.5 projected annual average economic costs for Canada in the 2050s amount to $207 million [$19 million, $1.1 billion], dropping to $143 million [$11 million, $764 million] (2015 dollars) in the 2080s.**[111] The proportion of costs attributable to climate change amount to about 90% in the 2050s and 67% in the 2080s.

Figure 7-11 shows projected economic costs of new Lyme disease cases due to the combination of socioeconomic and climate change for both RCPs and eras, broken out by welfare and market-based (i.e., medical resource costs and opportunity costs) components of the cost. These graphics illustrate the importance of welfare effects as a cost driver (and hence the importance of including these types of costs in estimating the impacts of climate change). **Medical resources and opportunity costs only comprise about 3.5% of total economic costs.**

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[22] Excluding costs related to chronic effects.

Table 7-40: Projected incremental annual economic costs (2015 dollars) of new cases of Lyme Disease for the 2050s and 2080s under RCP 4.5, by province and territory, relative to baseline values, attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in ECONOMIC COSTS from baseline due to ($ 2015 million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	12	[0 , 72]	19	[1 , 109]
Ontario	120	[10 , 635]	149	[10 , 814]
Quebec	81	[9 , 402]	90	[9 , 455]
New Brunswick	8	[1 , 37]	9	[1 , 40]
Nova Scotia	9	[1 , 43]	9	[1 , 46]
Prince Edward Island	2	[0 , 10]	3	[0 , 13]
Newfoundland and Labrador	3	[0 , 17]	3	[0 , 14]
Sub-total Canada	**234**	**[21 , 1216]**	**282**	**[23 , 1492]**
Sociocononomic change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	0	[0 , 8]	1	[0 , 17]
Ontario	19	[1 , 145]	39	[1 , 315]
Quebec	3	[0 , 41]	7	[0 , 82]
New Brunswick	0	[0 , 2]	0	[0 , 4]
Nova Scotia	0	[0 , 3]	0	[0 , 7]
Prince Edward Island	0	[0 , 1]	0	[0 , 3]
Newfoundland and Labrador	0	[0 , -1]	0	[0 , -1]
Sub-total Canada	**23**	**[0 , 200]**	**47**	**[1 , 427]**
Climate change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	12	[0 , 64]	19	[1 , 92]
Ontario	101	[9 , 490]	110	[9 , 499]
Quebec	77	[9 , 362]	83	[9 , 372]
New Brunswick	8	[1 , 35]	8	[1 , 36]
Nova Scotia	9	[1 , 40]	9	[1 , 39]
Prince Edward Island	2	[0 , 8]	2	[0 , 10]
Newfoundland and Labrador	4	[0 , 18]	3	[0 , 16]
Sub-total Canada	**211**	**[21 , 1016]**	**235**	**[22 , 1065]**

Note: zero values are due to rounding

Table 7-41: Projected incremental annual economic costs (2015 dollars) of new cases of Lyme Disease for the 2050s and 2080s under RCP 8.5, by province and territory, relative to baseline values, attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in ECONOMIC COSTS from baseline due to ($ 2015 million per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	14	[1 , 77]	21	[2 , 104]
Ontario	99	[7 , 536]	54	[1 , 326]
Quebec	74	[8 , 367]	53	[6 , 265]
New Brunswick	8	[1 , 35]	6	[1 , 26]
Nova Scotia	8	[1 , 37]	4	[0 , 23]
Prince Edward Island	2	[0 , 9]	1	[0 , 8]
Newfoundland and Labrador	4	[0 , 17]	3	[1 , 12]
Sub-total Canada	**207**	**[19 , 1077]**	**143**	**[11 , 764]**
Socioecononomic change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	0	[0 , 8]	1	[0 , 17]
Ontario	19	[1 , 145]	39	[1 , 315]
Quebec	3	[0 , 41]	7	[0 , 82]
New Brunswick	0	[0 , 2]	0	[0 , 4]
Nova Scotia	0	[0 , 3]	0	[0 , 7]
Prince Edward Island	0	[0 , 1]	0	[0 , 3]
Newfoundland and Labrador	0	[0 , -1]	0	[0 , -1]
Sub-total Canada	**23**	**[0 , 200]**	**47**	**[1 , 427]**
Climate change only				
Nunavut	not analyzed		not analyzed	
Yukon	not analyzed		not analyzed	
Northwest Territories	not analyzed		not analyzed	
British Columbia	not analyzed		not analyzed	
Alberta	not analyzed		not analyzed	
Saskatchewan	not analyzed		not analyzed	
Manitoba	14	[1 , 69]	20	[2 , 87]
Ontario	80	[6 , 391]	15	[0 , 12]
Quebec	71	[8 , 326]	47	[6 , 182]
New Brunswick	8	[1 , 33]	6	[1 , 23]
Nova Scotia	7	[1 , 33]	4	[0 , 16]
Prince Edward Island	2	[0 , 7]	1	[0 , 5]
Newfoundland and Labrador	4	[0 , 18]	3	[0 , 13]
Sub-total Canada	**185**	**[18 , 878]**	**96**	**[10 , 337]**

Note: zero values are due to rounding

Figure 7-11: Projected incremental annual economic costs (2015 dollars, central estimates) of new cases of Lyme disease in Manitoba, Ontario, Quebec and Atlantic provinces, broken out by cost component for (A) RCP 4.5 in the 2050s; (B) RCP 8.5 in the 2080s; (C) RCP 4.5 in the 2050s; (D) RCP 8.5 in the 2080s.

Additional Analysis

To further understand the level of confidence to place in our projections of new Lyme disease cases and related economic costs we used an alternate approach to estimate new Lyme disease cases and monetized them using the same economic unit values as applied above. This alternate approach involved using a future risk map projecting vector presence (see Figure 7-8) in the 2080s and applying a constant Lyme disease incidence rate to the population in eastern and central Canada (Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, PEI, and Newfound and Labrador) for the 2080s (2071-2100). In brief, we took the following steps:

- Ogden et al's (2008) projected 2080s Lyme disease risk zones were mapped to Census Divisions in each province in scope. In cases where one Census Division straddled two or more risk zones, the "worst case scenario" risk category was applied to the entire Census Division. This step was accomplished using the "intersect" tool in QGIS and manual processing.
- We assigned multipliers to the levels of risk denoted by the risk zones in Ogden's (2009) Lyme disease risk map. The following numbers were chosen, opting for simplicity as a guiding principle:

- High risk: 1.0
- Medium risk: 0.75
- Low risk: 0.5
- Risk from adventitious ticks: 0.25

- The absolute number of Lyme disease cases for each Census Division was calculated for each year (2071 through 2100). This was accomplished by multiplying the annual population of each census district by the average incidence rate (4.4 per 100,000 people) and the specific risk factor multiplier assigned to Census Divisions. The constant incidence rate was selected based on guidance from Canadian Lyme disease experts.
- The total economic cost for each Census Division (for each year) was calculated by multiplying the year and Census Division-specific case count by the year-specific case cost. Average annual costs were calculated by averaging the 30-year costs per Census Division.

Table 7-42 below compares estimates resulting from this alternate approach to results from our main approach (extracted from Table 7-39 and Table 7-41). **Both physical and economic estimates are significantly different, with aggregate results from our main study about two thirds higher than those derived using the alternate approach.** It's worth recalling that our projections of new Lyme disease cases and related economic costs under RCP 4.5 were higher still. It is, thus, possible that results from our main study are very high. However, the alternate approach assumes that the relatively high incidence rate observed for Quebec in 2019 (and for Ontario between 2015 and 2018) applies into the future, adjusted to exposure risk, which could be considered a lower bound.

Table 7-42: Comparison of projected annual cases of Lyme disease and related economic costs (2015 dollars) for the 2080s, contrasting estimates resulting from applying a static incidence rate to areas of risk based on tick presence and central estimates from this study (combination of socioeconomic and climate change)

Projected LYME DISEASE CASES (cases per year):	**A. Based on risk map for 2080s, high emissions scenario - alternate approach**	**B. RCP 8.5, 2080s, central estimates - this study**	**Proportion (A/B)**
Manitoba	62	720	9%
Ontario	1,072	1,900	56%
Quebec	490	1,860	26%
New Brunswick	36	200	18%
Nova Scotia	45	160	28%
Prince Edward Island	11	50	23%
Newfoundland and Labrador	4	100	4%
Sub-total Canada	**1,721**	**4,990**	**34%**
Related ECONOMIC COSTS from baseline due to ($ 2015 million per year):			
Manitoba	1.7	21	8%
Ontario	29.8	54	55%
Quebec	13.6	53	26%
New Brunswick	1.0	6	17%
Nova Scotia	1.3	4	33%
Prince Edward Island	0.3	1	30%
Newfoundland and Labrador	0.1	3	3%
Sub-total Canada	**47.8**	**142**	**34%**

7.4 Labour Supply

Physical Impact

Rising temperatures are projected to have a sizeable negative impact on labour hours—especially for workers in economic sectors with largely outdoor occupations. For this study the following sectors were classified as “high-risk” and included in the analysis: agriculture, forestry and fisheries (NAICS 11), mining, quarrying and oil and gas extraction (NAICS 21), utilities (NAICS 22), construction (NAICS 23), manufacturing (NAICS 31-33, and transportation and warehousing (NAICS 48-49).

Under RCP 8.5, approximately 68 million and 154 million labour hours across the national workforce in the above high-risk sectors are projected to be lost annually by, respectively, the 2050s and 2080s because of diminished work ability due to temperature stress (see Table 7-44). A loss of 68 million and 154 million hours annually, equates to about 32,750 full-time equivalent (FTE)[112] workers and 74,245 FTEs, respectively. These projections include the influence of both socioeconomic change (both growth and structural change in the labour force) and climate change. Isolating the impact of climate change; projected annual average losses in labour hours by the 2050s and 2080s are estimated at 53 million and 128 million, respectively. These losses equate to about 25,535 FTEs and 61,740 FTEs, respectively. **Climate change is thus the main driver behind projected total losses of labour hours nationally**.

At the national level, **labour hours lost are substantially smaller under RCP 4.5 than RCP 8.5, particularly in the 2080s** (contrast Table 7-43 with Table 7-44). The difference between losses attributable to climate change under RCP 8.5 and RCP 4.5 is about 14 million labour hours annually across the workforce by the 2050s, rising to about 71 million labour hours annually by the 2080s. The loss of labour hours avoided by the 2080 is over five times higher than by the 2050s under RCP 4.5 compared to RCP 8.5.

Projected losses of labour hours are particularly large in the manufacturing sector; 74 million hours (28,150 FTEs) are lost annually by the 2080s under RCP 8.5 (see Table 7-46).[113] However, this result is largely driven by the sector’s relative share of total employment nationally, which is much larger than the other high-risk sectors considered. As a percentage of projected labour hours in the manufacturing sector nationally by the 2080s, losses of 74 million per year amount to approximately 1.9% (see Figure 7-12), compared to national average losses of 1.6% of projected labour hours annually across all six sectors. The next two most impacted high-risk sectors under RCP 8.5 are transportation and warehousing (losses equivalent to 1.6% of projected labour hours by the 2080s), followed by construction (at 1.5%). The least impacted sector nationally is mining, quarrying, and oil and gas extraction (at 1.0%). These results are driven by the location of workers in each sector, the number of days annually above 27°C at that location under baseline climate conditions, and projected shifts in the baseline distribution of daily maximum temperatures as a result of climate change.

Regionally, projected losses of labour hours are particularly large in Ontario (e.g., 74 million labour hours lost annually by the 2080s under RCP 8.5) and Quebec (e.g., 32 million labour hours lost annually by the 2080s under RCP 8.5) (see Table 7-44). **Even after normalizing for the relative size of the workforce across provinces and territories, Ontario and Quebec experience the largest relative losses in labour hours**. As a percentage of projected total labour hours in Ontario across all high-risk sectors by the 2080s, losses of 74 million per year amount to approximately 2.2% (see Figure 7-13). The next two most impacted provinces under RCP 8.5 are Quebec (losses equivalent to 1.7% of projected labour hours by the 2080s), followed by Manitoba (at 1.6%). **The least impacted regions are the territories** (with losses no higher than 0.2% of projected hours). Indeed, Nunavut is projected to realize small increases in labour hours by the 2050s under RCP 8.5 (+0.1%); turning to marginal losses by the 2080s. Though not shown in Figure 7-13 or evident from Table 7-43 due to rounding to the nearest million hours, all three territories are projected to experience small increases in labour hours by the 2050s and 2080s under RCP 4.5. As suggested above, this results primarily from shifts in the baseline daily maximum temperature distribution under RCP 4.5 to a future temperature regime providing more 'ideal' working conditions.

Figure 7-14 contains box-whisker plots for projected labour hours lost from heat stress in the workplace for the 2050s and 2080s under RCP 4.5 and RCP 8.5, by province and territory, and for each region, by high-risk sector. The plots show the full range of results across the seven GCMs for central case assumptions for all other input variables. These plots isolate the impact of future climate uncertainty on the overall results. At the national level, by the 2080s under RCP 8.5, for example, projected annual labour hours lost due to a combination of socioeconomic change and climate change across all seven GCMs range from 70-231 million [104-205 million]. This represents a much smaller uncertainty range than for the impact models (ERFs) and socioeconomic data (i.e., which range from gains of 200 million per year to losses of 439 million per year based on the mean GCM projection, see Table 7-44). Regarding the potential for gains in labour hours, the lower bound 95% CI for the ERFs used in the analysis project increases in the number of minutes allocated to work across the 16 daily maximum temperature bins considered (recall Figure 5-10). Even more so than with the results for temperature stress presented in Section 7.1, **combining climate, impact model and socioeconomic uncertainties would lead to a very large interval bounding the labour supply results**.

Our analysis of labour supply impacts did not explicitly account for projected changes in humidity on hours allocated to work. As explained previously, the climate data made available for this study would not permit the determination of projected Wet Bulb Globe Temperatures—a well-established index that combines temperature and humidity, and is frequently used to set quantitative standards to protect workers from heat stress. Humidity diminishes the evaporation of sweat, reducing the body's ability to cool, and amplifies the impact of high temperatures on work ability. Furthermore, the productivity of outdoor workers can be adversely affected by air quality, the presence of aeroallergens, and various forms of extreme weather events, all of which are affected by climate change, and in a direction that reduces labour supply. The omission of humidity and these other climate-enhanced stressors from our analysis of labour supply impacts, means our results are likely conservative, other things being equal. [23]

[23] Atmospheric humidity is projected to increase with climate change—consistent with the capacity of warmer air to hold more moisture—thereby intensifying heat stress[23].

Table 7-43: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental hours lost per year, on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in HOURS from baseline due to (million hours per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-4.4	[2.6 , -13.4]	-7.4	[4.2 , -26.2]
Alberta	-7.3	[7.1 , -20.5]	-13.2	[13.1 , -43.6]
Saskatchewan	-1.6	[2.3 , -3.9]	-2.5	[3.4 , -7.1]
Manitoba	-1.9	[2.6 , -5.3]	-3.1	[3.8 , -9.7]
Ontario	-27.1	[34.1 , -70.9]	-40.6	[48.4 , -124.5]
Quebec	-10.2	[14 , -28.9]	-14.5	[17.8 , -46.9]
New Brunswick	-0.7	[1 , -2.1]	-0.8	[1.1 , -3.1]
Nova Scotia	-0.6	[0.6 , -2]	-0.8	[0.6 , -3.2]
Prince Edward Island	-0.2	[0.3 , -0.7]	-0.3	[0.3 , -1.2]
Newfoundland and Labrador	-0.2	[0.3 , -0.5]	-0.1	[0.1 , -0.3]
Sub-total Canada	**-54.1**	**[65 , -148.3]**	**-83.2**	**[92.7 , -265.8]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0.1]	0.1	[-0.1 , 0.1]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0.1]	0.1	[-0.1 , 0.1]
British Columbia	-4.0	[1.7 , -12.8]	-6.9	[3.2 , -25.6]
Alberta	-3.4	[0.9 , -12.1]	-6.1	[1.9 , -26.8]
Saskatchewan	-0.1	[0 , -0.7]	-0.1	[-0.1 , -1.6]
Manitoba	0.0	[-0.4 , -1]	0.1	[-0.9 , -2.1]
Ontario	-6.4	[1.9 , -25.4]	-10.6	[3.6 , -51.6]
Quebec	-1.4	[0 , -8.6]	-2.5	[-0.1 , -17.1]
New Brunswick	0.0	[-0.1 , -0.6]	-0.1	[-0.1 , -1.1]
Nova Scotia	-0.1	[-0.2 , -0.9]	-0.2	[-0.3 , -1.8]
Prince Edward Island	-0.1	[0 , -0.3]	-0.1	[0 , -0.6]
Newfoundland and Labrador	0.3	[-0.3 , 0.4]	0.4	[-0.5 , 0.7]
Sub-total Canada	**-15.0**	**[3.4 , -61.6]**	**-26.0**	**[6.6 , -127.4]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0.1 , -0.1]
Yukon	0.0	[0 , 0]	0.0	[0 , -0.1]
Northwest Territories	0.0	[0 , -0.1]	0.0	[0.1 , -0.1]
British Columbia	-0.4	[0.9 , -0.6]	-0.5	[1.1 , -0.6]
Alberta	-4.0	[6.2 , -8.5]	-7.2	[11.3 , -16.8]
Saskatchewan	-1.5	[2.3 , -3.2]	-2.4	[3.5 , -5.5]
Manitoba	-1.9	[3 , -4.3]	-3.1	[4.7 , -7.6]
Ontario	-20.6	[32.2 , -45.5]	-29.9	[44.7 , -72.9]
Quebec	-8.8	[14 , -20.3]	-12.0	[17.9 , -29.8]
New Brunswick	-0.7	[1 , -1.6]	-0.8	[1.1 , -2]
Nova Scotia	-0.5	[0.8 , -1.1]	-0.6	[0.8 , -1.4]
Prince Edward Island	-0.2	[0.3 , -0.4]	-0.2	[0.3 , -0.6]
Newfoundland and Labrador	-0.4	[0.7 , -1]	-0.4	[0.6 , -1]
Sub-total Canada	**-39.1**	**[61.6 , -86.7]**	**-57.2**	**[86.1 , -138.5]**

Note: zero values are due to rounding

Table 7-44: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental hours lost per year, on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in HOURS from baseline due to (million hours per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , -0.1]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , -0.1]
British Columbia	-4.5	[2.8 , -13.5]	-9.2	[6.9 , -30.4]
Alberta	-9.5	[10.5 , -25]	-23.5	[29.2 , -68.2]
Saskatchewan	-2.3	[3.5 , -5.5]	-5.3	[7.4 , -13.7]
Manitoba	-2.6	[3.7 , -6.9]	-6.7	[9.1 , -18.9]
Ontario	-33.5	[44.3 , -85.3]	-73.7	[98.5 , -204.9]
Quebec	-13.5	[19.2 , -36.3]	-32.1	[44.1 , -90.4]
New Brunswick	-0.9	[1.4 , -2.7]	-1.9	[2.6 , -5.7]
Nova Scotia	-0.7	[0.8 , -2.3]	-1.2	[1.3 , -4.4]
Prince Edward Island	-0.3	[0.4 , -0.8]	-0.5	[0.7 , -1.7]
Newfoundland and Labrador	-0.2	[0.5 , -0.7]	-0.3	[0.4 , -0.7]
Sub-total Canada	**-68.1**	**[87.2 , -179.1]**	**-154.4**	**[200.3 , -439.2]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0.1]	0.1	[-0.1 , 0.1]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0.1]	0.1	[-0.1 , 0.1]
British Columbia	-4.0	[1.7 , -12.8]	-6.9	[3.2 , -25.6]
Alberta	-3.4	[0.9 , -12.1]	-6.1	[1.9 , -26.9]
Saskatchewan	-0.1	[0 , -0.7]	-0.1	[-0.1 , -1.6]
Manitoba	0.0	[-0.4 , -1]	0.1	[-0.9 , -2.1]
Ontario	-6.4	[1.9 , -25.4]	-10.7	[3.6 , -51.6]
Quebec	-1.4	[0 , -8.6]	-2.5	[-0.1 , -17.1]
New Brunswick	0.0	[-0.1 , -0.6]	-0.1	[-0.1 , -1.1]
Nova Scotia	-0.1	[-0.2 , -0.9]	-0.2	[-0.2 , -1.8]
Prince Edward Island	-0.1	[0 , -0.3]	-0.1	[0 , -0.6]
Newfoundland and Labrador	0.3	[-0.3 , 0.4]	0.4	[-0.5 , 0.7]
Sub-total Canada	**-15.0**	**[3.4 , -61.7]**	**-26.0**	**[6.6 , -127.4]**
Climate change only				
Nunavut	0.0	[0.1 , -0.1]	-0.1	[0.1 , -0.2]
Yukon	0.0	[0 , -0.1]	-0.1	[0.1 , -0.1]
Northwest Territories	0.0	[0.1 , -0.1]	-0.1	[0.1 , -0.2]
British Columbia	-0.5	[1.1 , -0.7]	-2.3	[3.7 , -5.5]
Alberta	-6.1	[9.6 , -12.9]	-17.4	[27.3 , -45.3]
Saskatchewan	-2.3	[3.5 , -4.8]	-5.2	[7.4 , -13.4]
Manitoba	-2.7	[4.1 , -5.9]	-6.8	[10 , -18.7]
Ontario	-27.1	[42.4 , -59.9]	-63.0	[94.9 , -169.4]
Quebec	-12.1	[19.3 , -27.8]	-29.6	[44.2 , -80.6]
New Brunswick	-0.9	[1.5 , -2.2]	-1.8	[2.7 , -5]
Nova Scotia	-0.6	[1 , -1.4]	-1.0	[1.6 , -2.8]
Prince Edward Island	-0.2	[0.3 , -0.5]	-0.4	[0.7 , -1.2]
Newfoundland and Labrador	-0.5	[0.8 , -1.2]	-0.6	[1 , -1.5]
Sub-total Canada	**-53.1**	**[83.8 , -117.4]**	**-128.4**	**[193.7 , -344]**

Note: zero values are due to rounding

Table 7-45: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5, by “high-risk” sector for Canada, showing incremental hours lost per year, on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in HOURS from baseline due to (million hours per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Agriculture, forestry, fishing & hunting	-2.4	[4 , -5.8]	-2.5	[4.3 , -7.5]
Mining, quarrying, oil & gas extraction	-1.6	[2.2 , -4.3]	-2.1	[2.8 , -6.8]
Utilities	-0.8	[1.3 , -2.5]	-1.1	[1.5 , -3.9]
Construction	-13.4	[16.7 , -38.1]	-19.9	[22.7 , -65]
Manufacturing	-25.7	[28.4 , -68.6]	-41.6	[43.7 , -130.9]
Transportation & warehousing	-10.3	[12.3 , -29]	-16.0	[17.6 , -51.8]
Sub-total Canada	**-54.1**	**[65 , -148.3]**	**-83.2**	**[92.7 , -265.8]**
Socioecononomic change only				
Agriculture, forestry, fishing & hunting	0.1	[0 , -0.3]	0.3	[0 , -0.7]
Mining, quarrying, oil & gas extraction	-0.1	[-0.1 , -1]	-0.1	[-0.2 , -2]
Utilities	0.0	[-0.1 , -0.6]	-0.1	[-0.1 , -1.3]
Construction	-3.1	[0.3 , -15]	-5.4	[0.7 , -29.7]
Manufacturing	-8.9	[2.5 , -32]	-15.4	[4.9 , -68]
Transportation & warehousing	-3.0	[0.7 , -12.7]	-5.3	[1.3 , -25.7]
Sub-total Canada	**-15.0**	**[3.4 , -61.6]**	**-26.0**	**[6.6 , -127.4]**
Climate change only				
Agriculture, forestry, fishing & hunting	-2.5	[3.9 , -5.5]	-2.8	[4.3 , -6.8]
Mining, quarrying, oil & gas extraction	-1.5	[2.3 , -3.2]	-2.0	[3 , -4.7]
Utilities	-0.8	[1.3 , -1.9]	-1.1	[1.6 , -2.6]
Construction	-10.2	[16.4 , -23]	-14.5	[22.1 , -35.3]
Manufacturing	-16.8	[25.9 , -36.6]	-26.1	[38.9 , -62.9]
Transportation & warehousing	-7.3	[11.6 , -16.3]	-10.8	[16.3 , -26.1]
Sub-total Canada	**-39.1**	**[61.6 , -86.7]**	**-57.2**	**[86.1 , -138.5]**

Note: zero values are due to rounding

Table 7-46: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by "high-risk" sector for Canada, showing incremental hours lost per year, on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in HOURS from baseline due to (million hours per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Agriculture, forestry, fishing & hunting	-3.3	[5.4 , -7.8]	-5.9	[9.4 , -15.7]
Mining, quarrying, oil & gas extraction	-2.2	[3.2 , -5.6]	-4.6	[6.7 , -13]
Utilities	-1.1	[1.8 , -3.2]	-2.5	[3.6 , -7.2]
Construction	-17.0	[22.7 , -46.3]	-38.0	[50.4 , -109.5]
Manufacturing	-31.6	[37.6 , -81.4]	-74.0	[92.2 , -209.1]
Transportation & warehousing	-12.8	[16.5 , -34.8]	-29.4	[37.9 , -84.6]
Sub-total Canada	**-68.1**	**[87.2 , -179.1]**	**-154.4**	**[200.3 , -439.2]**
Socioecononomic change only				
Agriculture, forestry, fishing & hunting	0.1	[0 , -0.3]	0.3	[0 , -0.7]
Mining, quarrying, oil & gas extraction	-0.1	[-0.1 , -1]	-0.1	[-0.2 , -2]
Utilities	0.0	[-0.1 , -0.6]	-0.1	[-0.1 , -1.3]
Construction	-3.1	[0.3 , -15]	-5.4	[0.7 , -29.7]
Manufacturing	-8.9	[2.5 , -32]	-15.4	[4.9 , -68]
Transportation & warehousing	-3.0	[0.7 , -12.7]	-5.3	[1.3 , -25.7]
Sub-total Canada	**-15.0**	**[3.4 , -61.7]**	**-26.0**	**[6.6 , -127.4]**
Climate change only				
Agriculture, forestry, fishing & hunting	-3.4	[5.4 , -7.6]	-6.2	[9.5 , -16.6]
Mining, quarrying, oil & gas extraction	-2.1	[3.3 , -4.6]	-4.5	[7 , -12.1]
Utilities	-1.1	[1.8 , -2.6]	-2.4	[3.8 , -6.5]
Construction	-13.9	[22.3 , -31.2]	-32.6	[50.4 , -88.1]
Manufacturing	-22.8	[35.1 , -49.4]	-58.5	[88.6 , -155.7]
Transportation & warehousing	-9.9	[15.8 , -22]	-24.1	[37.1 , -65]
Sub-total Canada	**-53.1**	**[83.8 , -117.4]**	**-128.4**	**[196.4 , -344]**

Note: zero values are due to rounding

Figure 7-12: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by "high-risk" sector, showing the percentage of projected labour hours per year lost, on average, because of a combination of socioeconomic and climate change [central case]

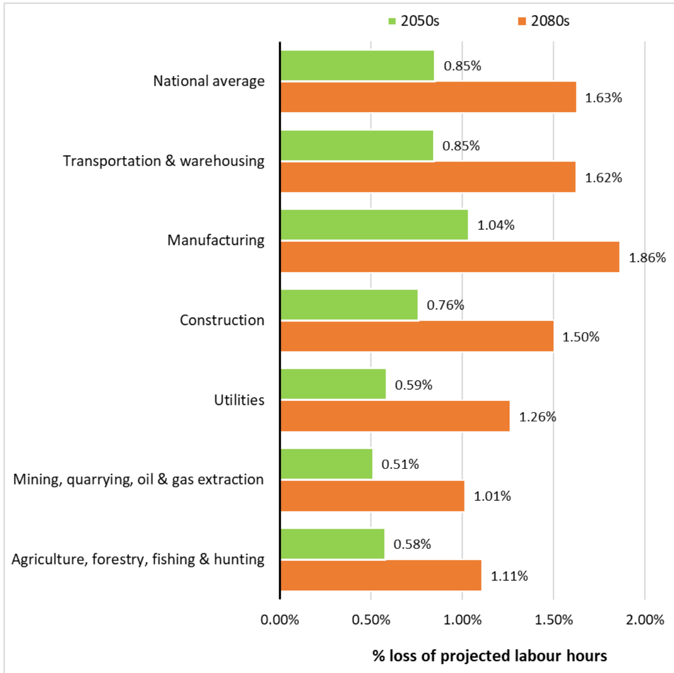


Figure 7-13: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing the percentage of projected labour hours per year lost, on average, because of a combination of socioeconomic and climate change [central case]

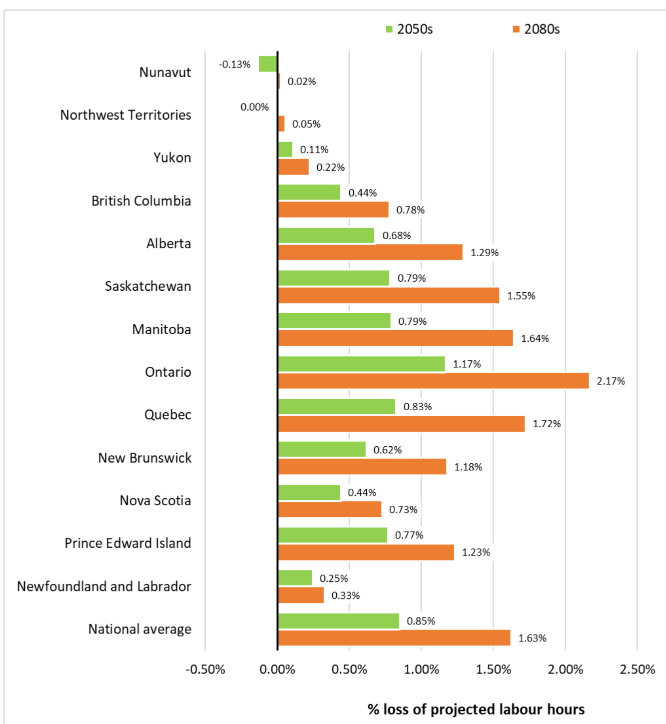
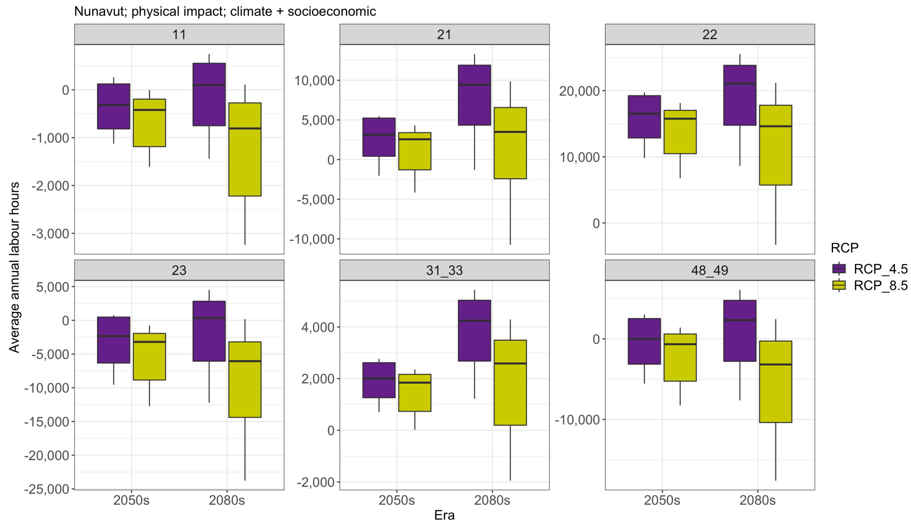
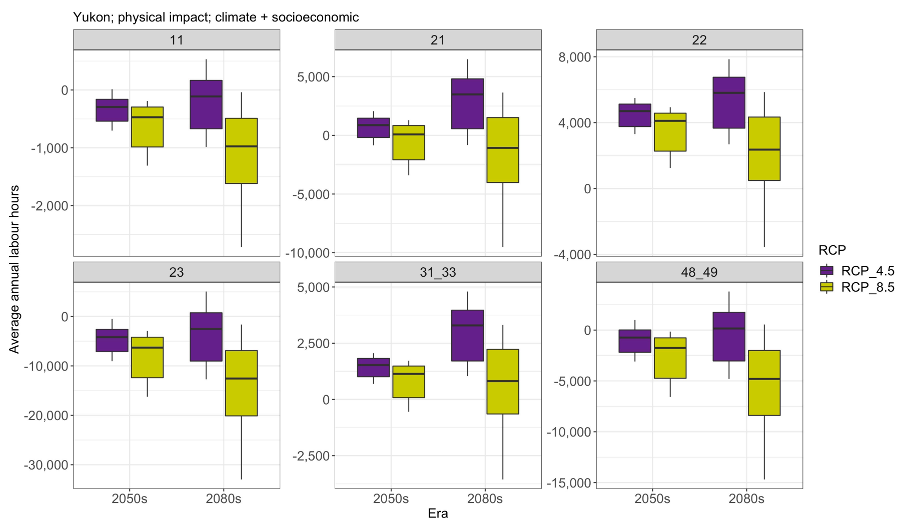
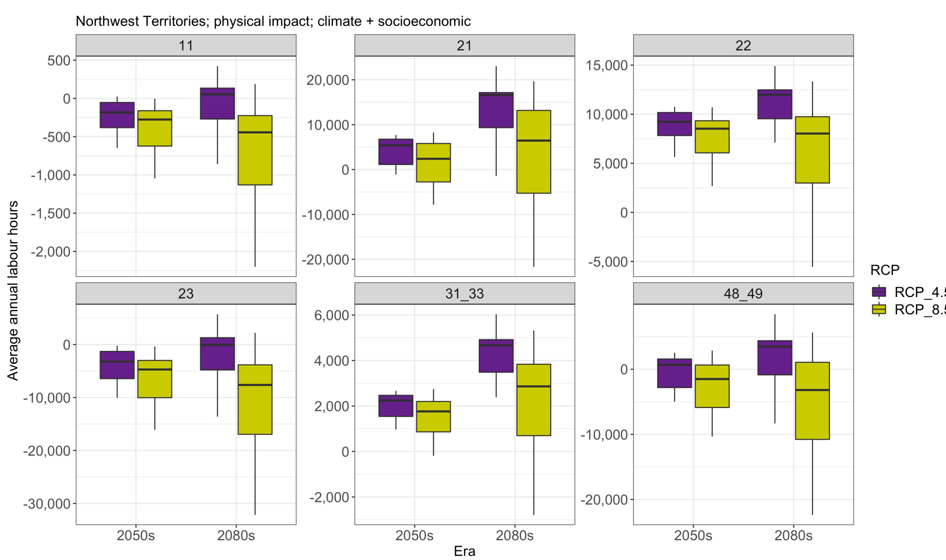
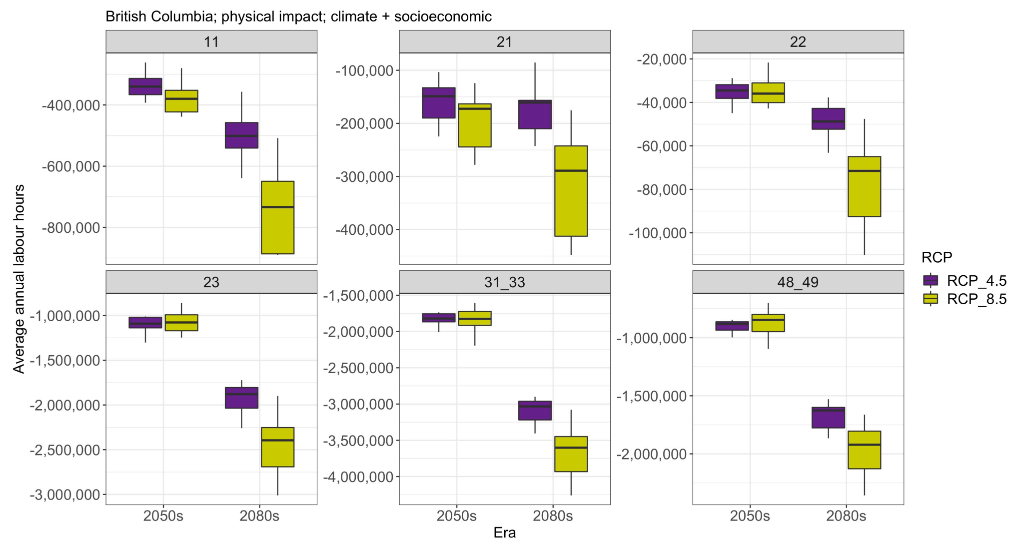


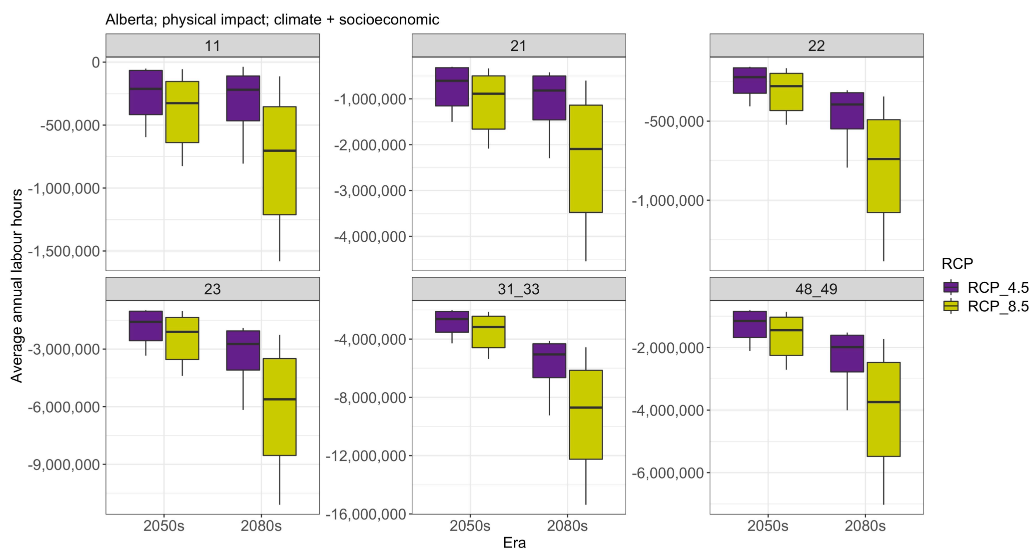
Figure 7-14: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5 and RCP 8.5, by province and territory and "high-risk" sector, showing incremental hours lost per year, on average, relative to baseline values, attributable to a combination of socioeconomic and climate change [showing range of results across the seven GCMs for the central case only]

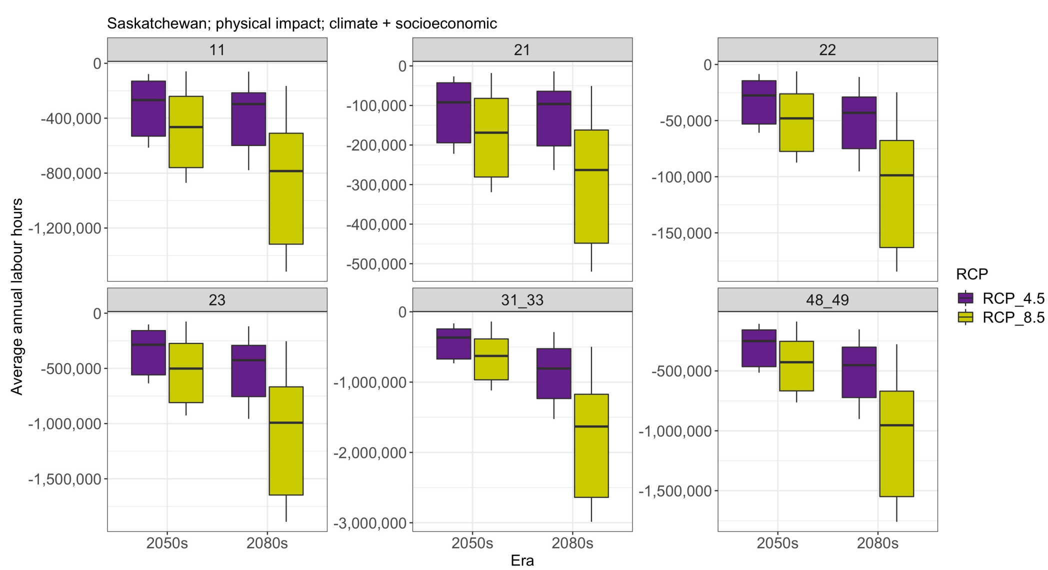


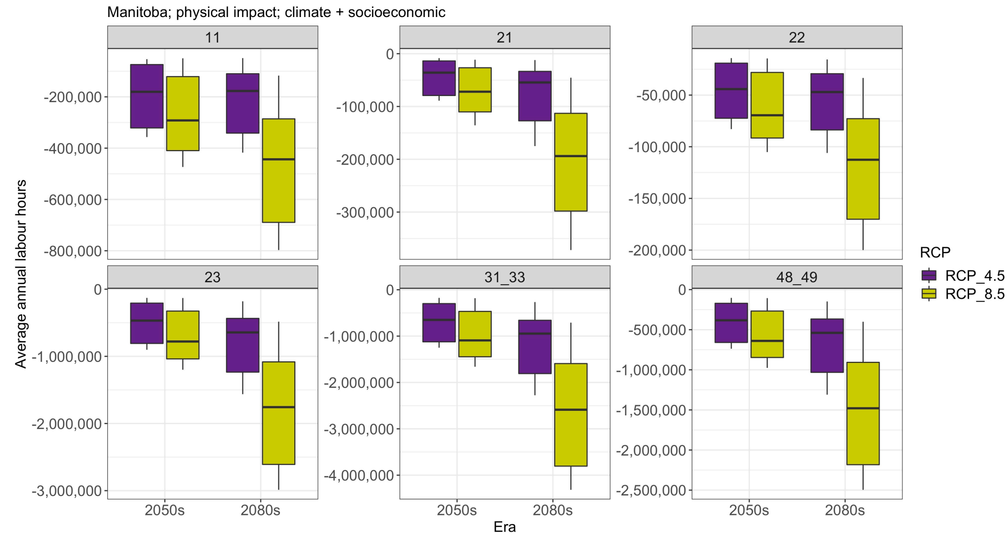


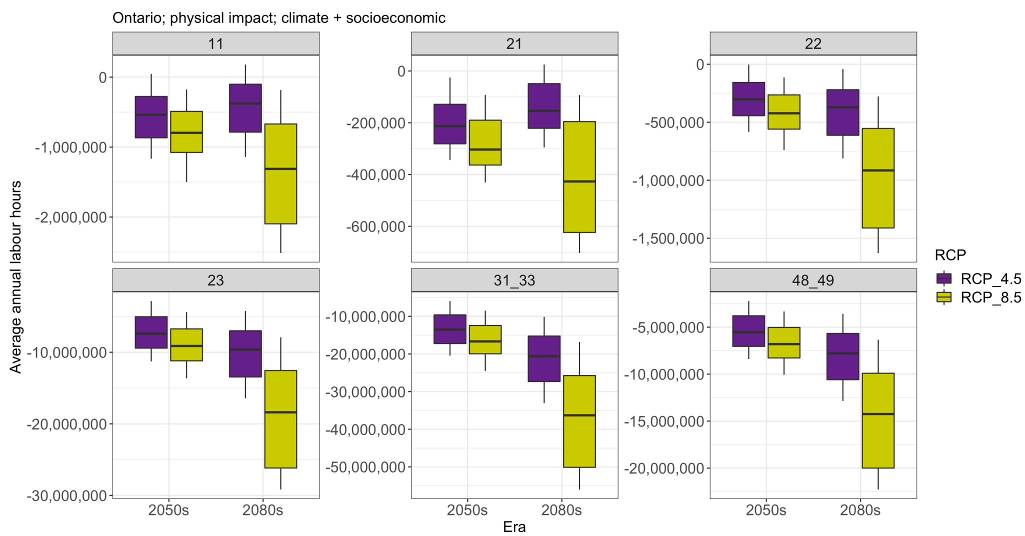


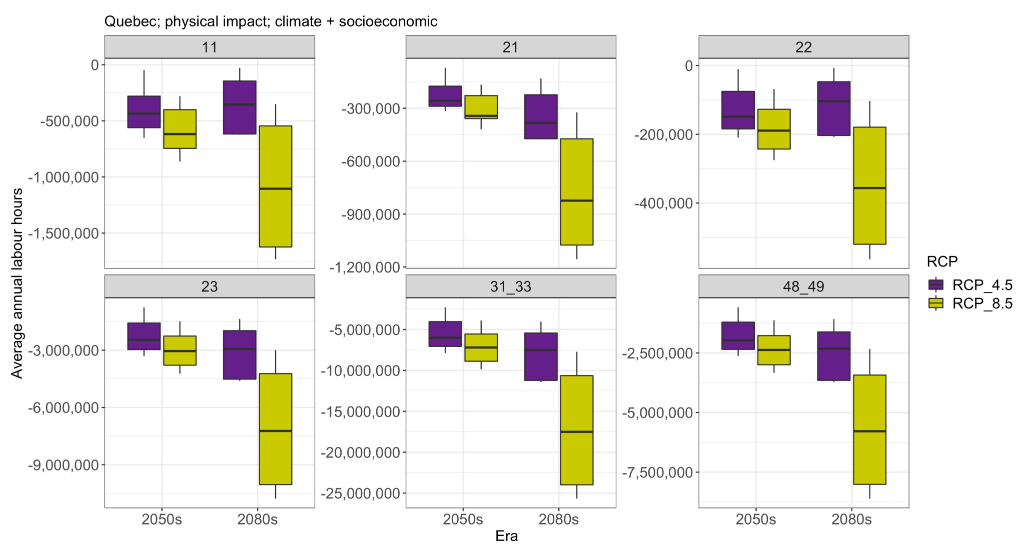

British Columbia; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5

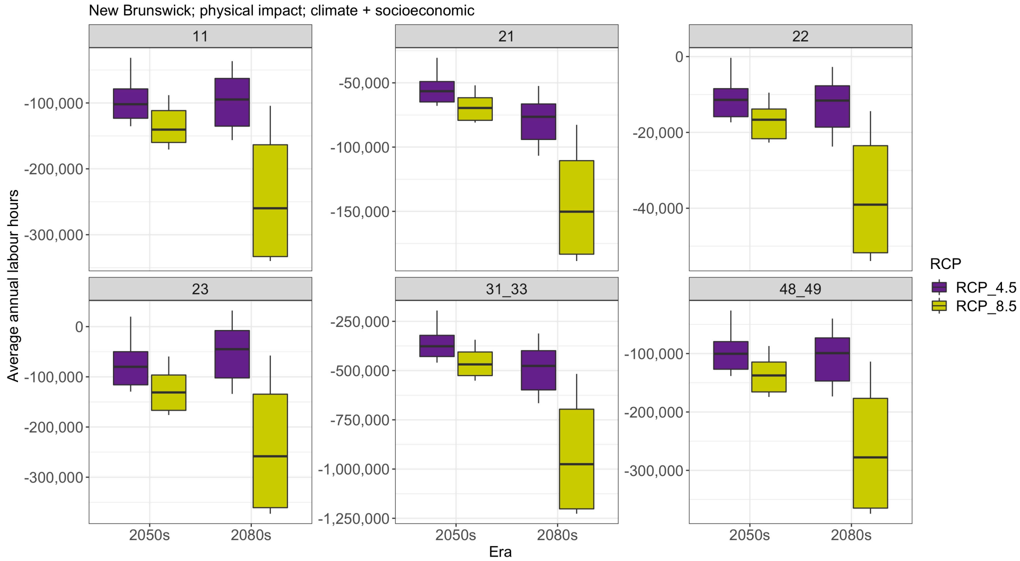

Alberta; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5

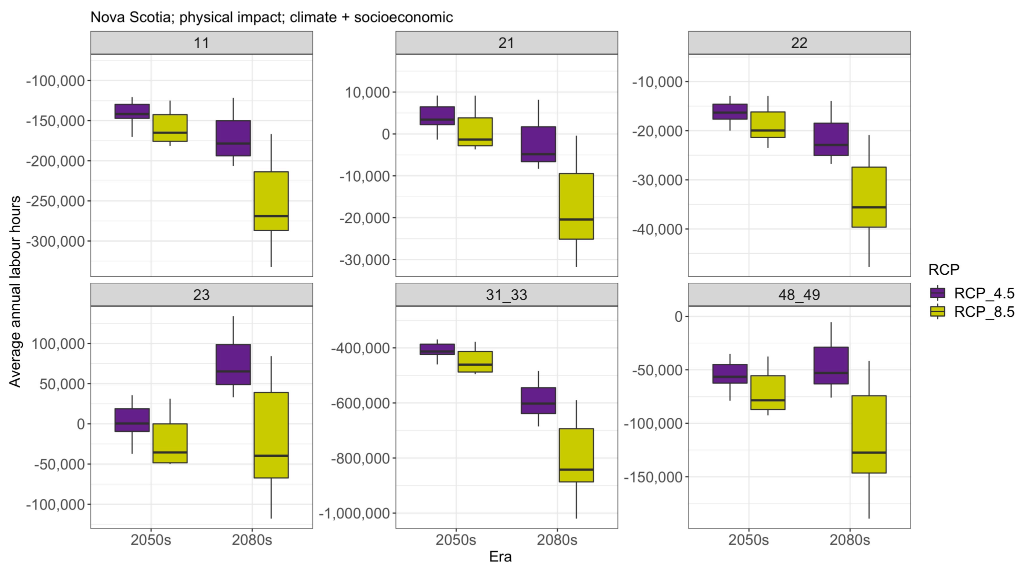

Saskatchewan; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5

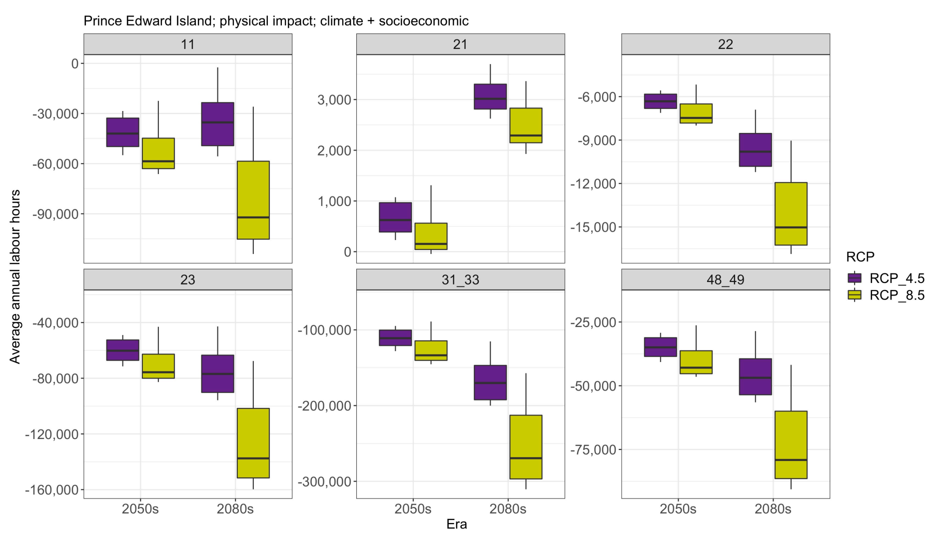

Manitoba; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5

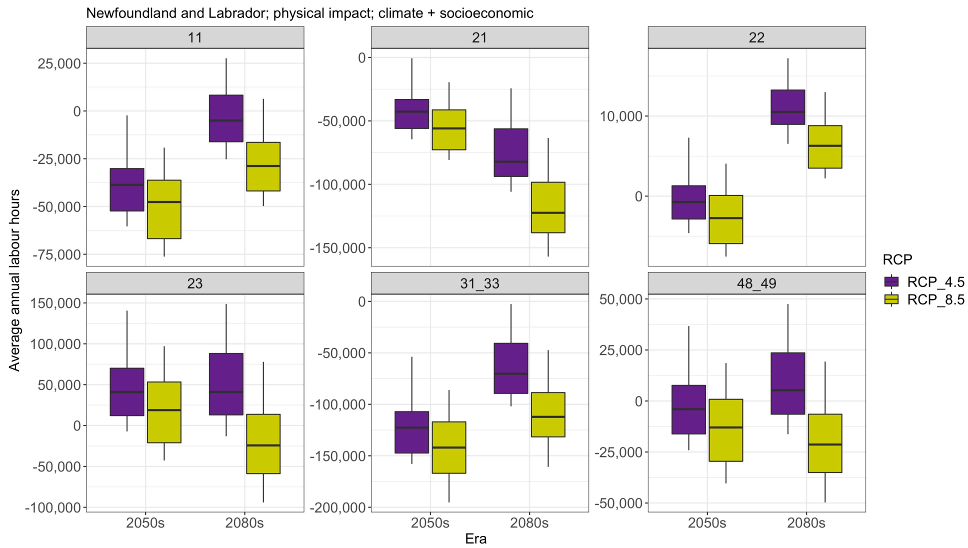

Ontario; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5


Quebec; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5


New Brunswick; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5


Nova Scotia; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5


Prince Edward Island; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5


Newfoundland and Labrador; physical impact; climate + socioeconomic
11
21
22
23
31_33
48_49
Average annual labour hours
Era
2050s
2080s
RCP
RCP_4.5
RCP_8.5

Economic Impact

Under RCP 8.5, approximately $4.0 billion and $9.8 billion (2015 dollars) of labour compensation across the national workforce in high-risk sectors is projected to be lost annually by, respectively, the 2050s and 2080s because of diminished work ability due to temperature stress (see Table 7-48). For the same periods and RCP, projected national labour productivity costs are about $7.5 billion and $18.4 billion per year (see Table 7-50). These projected losses include the influence of both socioeconomic change and climate change. Isolating the impact of climate change; **projected annual average losses of labour compensation by the 2050s and 2080s due to climate change under RCP 8.5 are estimated at $2.6 billion and $7.4 billion**, respectively. **The projected national labour productivity costs of climate change under RCP 8.5 are $5.0 billion and $13.8 billion annually by, respectively, the 2050s and 2080s**.

At the national level, **labour payroll and labour productivity losses are substantially smaller under RCP 4.5 than RCP 8.5, particularly in the 2080s** (contrast Table 7-47 with Table 7-48).The difference between losses attributable to climate change under RCP 8.5 and RCP 4.5 is about $0.7 billion in payroll compensation annually across the workforce in high-risk sectors by the 2050s, rising to about $4.1 billion annually by the 2080s. The loss of payroll compensation avoided by the 2080 is thus just under six times higher than by the 2050s under RCP 4.5 compared to RCP 8.5. The differences are slightly starker for labour productivity losses. Under RCP 4.5 about $7.6 billion in labour productivity losses are avoided annually by the 2080s compared with RCP 8.5; this is over six times the savings in the 2050s.

The breakdown of economic impacts by sector and region, largely reflect the projected losses of labour hours. **Projected losses are largest for the manufacturing sector**; $4.9 billion in payroll compensation (Table 7-52) and $8.5 billion in labour productivity (Table 7-54) is lost annually by the 2080s under RCP 8.5.[114] The next two most impacted high-risk sectors under RCP 8.5 are construction (with annual projected losses by the 2080s of $2.5 billion in payroll compensation and $3.5 billion in labour productivity), followed by transportation and warehousing (with annual projected losses by the 2080s of $1.5 billion in payroll compensation and $3.7 billion in labour productivity). In contrast to the results for labour hours lost, where mining, quarrying, and oil and gas extraction was the least impacted sector nationally, the lowest economic impact is projected for the agriculture, forestry and fisheries sector. Hourly payroll compensation and labour productivity is much lower in the latter sector, so even though more total hours are lost, the financial cost is lower; notwithstanding other disutility costs associated with time spent in unsuitable working conditions. In general, the relative incidence of projected costs across high-risk sectors, is influenced by differences in hourly payroll compensation and labour productivity, which can differ significantly between sectors (and across regions), and sufficiently to make the economic burden higher for a sector with lower hours lost, than for another sector with more projected hours lost.

Regionally, **Ontario and Quebec and projected to experience the largest financial costs, followed by Alberta.** Losses are particularly large in Ontario (e.g., projected annual losses by the 2080s under RCP 8.5 amount to $4.8 billion in payroll compensation and $8.6 billion in labour productivity)[115] (see Table 7-48 and Table 7-50). Projected payroll compensation losses for Quebec and Alberta for the same period and scenario are, respectively, $1.9 billion per year and $1.5 billion per year. Corresponding annual labour productivity costs for each province are $3.3 billion (Quebec) and $3.4 billion (Alberta).

The least impacted regions are the territories (with annual payroll compensation or labour productivity costs no higher than $8 million under RCP 8.5 by the 2080s) (not shown in Table 7-48 or Table 7-50 due to rounding to the nearest billion). Nunavut is projected to realize small financial benefits in the 2050s under RCP 8.5; turning to marginal losses by the 2080s as climate change results in less suitable working conditions. However, with less climate change as per RCP 4.5, all three territories are projected to experience small financial benefits in both the 2050s and 2080s. By the 2080s, annual payroll compensation for workers is projected to increase by $0.8 million (Yukon) to $7.5 million (Northwest Territories); annual labour productivity is projected to increase by $2.1 million (Yukon) to $14.5 million (Northwest Territories). Closer inspection of the results for the territories, across both RCPs and all three scenarios (socioeconomic change, climate change and both), suggests that: (a) the current climate provides relatively suitable working conditions, with growth in the workforce in the absence of further climate change increasing both payroll compensation and labour productivity under both RCPs and future time periods; (b) a smaller amount of climate change under RCP 4.5 has a negative effect, but is not sufficient in magnitude to offset gains from growth in the labour force; and (c) a larger amount of climate change under RCP 8.5 is sufficient to more than offset gains from socioeconomic growth, resulting in economic losses. These results only apply to the territories.

Table 7-47: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental annual payroll compensation losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in PAYROLL COMPENSATION from baseline due to ($ 2015 billion per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.3	[0.1 , -1]	-0.5	[0.2 , -2.2]
Alberta	-0.5	[0.4 , -1.3]	-0.9	[0.8 , -3.1]
Saskatchewan	-0.1	[0.1 , -0.2]	-0.1	[0.1 , -0.5]
Manitoba	-0.1	[0.1 , -0.3]	-0.2	[0.1 , -0.6]
Ontario	-1.7	[1.6 , -4.4]	-2.9	[2.6 , -9.4]
Quebec	-0.6	[0.6 , -1.6]	-0.9	[0.8 , -3.1]
New Brunswick	0.0	[0 , -0.1]	-0.1	[0 , -0.2]
Nova Scotia	0.0	[0 , -0.1]	-0.1	[0 , -0.2]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.1]	-0.1	[0 , -0.2]
Sub-total Canada	**-3.2**	**[2.9 , -9.1]**	**-5.7**	**[4.8 , -19.5]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.3	[0.1 , -1]	-0.5	[0.2 , -2.1]
Alberta	-0.3	[0.1 , -0.9]	-0.5	[0.1 , -2]
Saskatchewan	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Manitoba	0.0	[0 , -0.1]	0.0	[-0.1 , -0.2]
Ontario	-0.6	[0.2 , -2.1]	-1.1	[0.4 , -4.9]
Quebec	-0.1	[0 , -0.7]	-0.3	[0 , -1.5]
New Brunswick	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Nova Scotia	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Sub-total Canada	**-1.3**	**[0.3 , -5]**	**-2.4**	**[0.6 , -11.4]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.0	[0 , 0]	0.0	[0 , 0]
Alberta	-0.2	[0.3 , -0.5]	-0.4	[0.7 , -1]
Saskatchewan	-0.1	[0.1 , -0.1]	-0.1	[0.1 , -0.3]
Manitoba	-0.1	[0.1 , -0.2]	-0.2	[0.2 , -0.4]
Ontario	-1.0	[1.4 , -2.2]	-1.8	[2.2 , -4.5]
Quebec	-0.4	[0.6 , -0.9]	-0.7	[0.8 , -1.6]
New Brunswick	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Nova Scotia	0.0	[0 , 0]	0.0	[0 , -0.1]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Sub-total Canada	**-1.9**	**[2.6 , -4.2]**	**-3.3**	**[4.3 , -8.2]**

Note: zero values are due to rounding

Table 7-48: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental annual payroll compensation losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in PAYROLL COMPENSATION from baseline due to ($ 2015 billion per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.3	[0.1 , -1]	-0.6	[0.3 , -2.4]
Alberta	-0.6	[0.6 , -1.6]	-1.5	[1.8 , -4.6]
Saskatchewan	-0.1	[0.1 , -0.3]	-0.3	[0.3 , -0.9]
Manitoba	-0.1	[0.1 , -0.3]	-0.4	[0.4 , -1.1]
Ontario	-2.0	[2 , -5.1]	-4.8	[5.1 , -14.5]
Quebec	-0.7	[0.8 , -1.9]	-1.9	[2 , -5.6]
New Brunswick	0.0	[0 , -0.1]	-0.1	[0.1 , -0.3]
Nova Scotia	0.0	[0 , -0.1]	-0.1	[0.1 , -0.3]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.1]	-0.1	[0.1 , -0.3]
Sub-total Canada	**-4.0**	**[3.9 , -10.7]**	**-9.8**	**[10.2 , -29.9]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.3	[0.1 , -1]	-0.5	[0.2 , -2.1]
Alberta	-0.3	[0.1 , -0.9]	-0.5	[0.1 , -2]
Saskatchewan	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Manitoba	0.0	[0 , -0.1]	0.0	[-0.1 , -0.2]
Ontario	-0.6	[0.2 , -2.1]	-1.1	[0.4 , -5]
Quebec	-0.1	[0 , -0.7]	-0.3	[0 , -1.5]
New Brunswick	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Nova Scotia	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Sub-total Canada	**-1.3**	**[0.3 , -5]**	**-2.4**	**[0.6 , -11.4]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.0	[0 , 0]	-0.1	[0.2 , -0.3]
Alberta	-0.3	[0.5 , -0.7]	-1.1	[1.7 , -2.8]
Saskatchewan	-0.1	[0.1 , -0.2]	-0.3	[0.3 , -0.8]
Manitoba	-0.1	[0.2 , -0.3]	-0.4	[0.5 , -1]
Ontario	-1.4	[1.8 , -3]	-3.7	[4.7 , -10.5]
Quebec	-0.6	[0.8 , -1.3]	-1.6	[2.1 , -4.5]
New Brunswick	0.0	[0 , -0.1]	-0.1	[0.1 , -0.2]
Nova Scotia	0.0	[0 , -0.1]	0.0	[0.1 , -0.1]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.1]	-0.1	[0.1 , -0.1]
Sub-total Canada	**-2.6**	**[3.6 , -5.7]**	**-7.4**	**[9.6 , -20.4]**

Note: zero values are due to rounding

Table 7-49: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5, by province and territory, showing incremental annual labour productivity losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in LABOUR PRODUCTIVITY from baseline due to ($ 2015 GDP billion per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.5	[0.2 , -1.7]	-0.9	[0.4 , -3.8]
Alberta	-1.1	[0.8 , -2.7]	-2.0	[1.7 , -6.4]
Saskatchewan	-0.2	[0.2 , -0.6]	-0.4	[0.4 , -1.3]
Manitoba	-0.1	[0.1 , -0.5]	-0.3	[0.2 , -1]
Ontario	-3.0	[2.6 , -7.4]	-5.1	[4.3 , -15.9]
Quebec	-1.0	[0.9 , -2.7]	-1.6	[1.3 , -5.2]
New Brunswick	-0.1	[0.1 , -0.2]	-0.1	[0.1 , -0.4]
Nova Scotia	-0.1	[0 , -0.2]	-0.1	[0.1 , -0.4]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , -0.1]
Newfoundland and Labrador	-0.1	[0.1 , -0.4]	-0.3	[0.1 , -0.7]
Sub-total Canada	**-6.2**	**[5.2 , -16.3]**	**-10.8**	**[8.6 , -35.1]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.5	[0.2 , -1.7]	-0.8	[0.3 , -3.7]
Alberta	-0.6	[0.1 , -1.8]	-1.1	[0.3 , -4.3]
Saskatchewan	0.0	[0 , -0.2]	0.0	[0 , -0.4]
Manitoba	0.0	[-0.1 , -0.1]	0.0	[-0.2 , -0.3]
Ontario	-1.2	[0.3 , -3.6]	-2.0	[0.6 , -8.4]
Quebec	-0.3	[0 , -1.1]	-0.5	[0 , -2.5]
New Brunswick	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Nova Scotia	0.0	[0 , -0.1]	-0.1	[0 , -0.3]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.2]	-0.1	[0 , -0.4]
Sub-total Canada	**-2.6**	**[0.5 , -8.9]**	**-4.6**	**[1 , -20.3]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	0.0	[0.1 , -0.1]	-0.1	[0.1 , -0.1]
Alberta	-0.5	[0.7 , -0.9]	-1.0	[1.4 , -2.2]
Saskatchewan	-0.2	[0.3 , -0.4]	-0.3	[0.4 , -0.9]
Manitoba	-0.2	[0.2 , -0.3]	-0.3	[0.4 , -0.7]
Ontario	-1.8	[2.3 , -3.8]	-3.1	[3.7 , -7.5]
Quebec	-0.7	[1 , -1.6]	-1.1	[1.4 , -2.7]
New Brunswick	0.0	[0.1 , -0.1]	-0.1	[0.1 , -0.2]
Nova Scotia	0.0	[0 , -0.1]	0.0	[0 , -0.1]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	-0.1	[0.1 , -0.2]	-0.1	[0.1 , -0.3]
Sub-total Canada	**-3.6**	**[4.8 , -7.5]**	**-6.2**	**[7.6 , -14.7]**

Note: zero values are due to rounding

Table 7-50: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by province and territory, showing incremental annual labour productivity losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in LABOUR PRODUCTIVITY from baseline due to ($ 2015 GDP billion per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.5	[0.3 , -1.7]	-1.0	[0.6 , -4.2]
Alberta	-1.4	[1.2 , -3.3]	-3.4	[3.8 , -9.6]
Saskatchewan	-0.3	[0.4 , -0.8]	-0.8	[0.8 , -2.4]
Manitoba	-0.2	[0.2 , -0.6]	-0.6	[0.7 , -1.9]
Ontario	-3.6	[3.4 , -8.6]	-8.6	[8.5 , -24.4]
Quebec	-1.2	[1.3 , -3.2]	-3.3	[3.4 , -9.2]
New Brunswick	-0.1	[0.1 , -0.2]	-0.2	[0.2 , -0.6]
Nova Scotia	-0.1	[0.1 , -0.2]	-0.2	[0.1 , -0.5]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , -0.1]
Newfoundland and Labrador	-0.1	[0.1 , -0.4]	-0.3	[0.2 , -0.8]
Sub-total Canada	**-7.5**	**[7 , -19.2]**	**-18.4**	**[18.2 , -53.7]**
Socioecononomic change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , 0]
British Columbia	-0.5	[0.2 , -1.7]	-0.8	[0.3 , -3.7]
Alberta	-0.6	[0.1 , -1.8]	-1.1	[0.3 , -4.3]
Saskatchewan	0.0	[0 , -0.2]	0.0	[0 , -0.4]
Manitoba	0.0	[-0.1 , -0.1]	0.0	[-0.2 , -0.3]
Ontario	-1.2	[0.3 , -3.6]	-2.0	[0.6 , -8.4]
Quebec	-0.3	[0 , -1.1]	-0.5	[0 , -2.5]
New Brunswick	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Nova Scotia	0.0	[0 , -0.1]	-0.1	[0 , -0.3]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , 0]
Newfoundland and Labrador	0.0	[0 , -0.2]	-0.1	[0 , -0.4]
Sub-total Canada	**-2.6**	**[0.5 , -8.9]**	**-4.6**	**[1 , -20.4]**
Climate change only				
Nunavut	0.0	[0 , 0]	0.0	[0 , 0]
Yukon	0.0	[0 , 0]	0.0	[0 , 0]
Northwest Territories	0.0	[0 , 0]	0.0	[0 , -0.1]
British Columbia	-0.1	[0.1 , -0.1]	-0.2	[0.3 , -0.6]
Alberta	-0.8	[1.1 , -1.5]	-2.3	[3.5 , -5.9]
Saskatchewan	-0.3	[0.4 , -0.6]	-0.8	[0.9 , -2.1]
Manitoba	-0.2	[0.3 , -0.5]	-0.7	[0.9 , -1.8]
Ontario	-2.4	[3.1 , -5]	-6.5	[7.8 , -17.7]
Quebec	-1.0	[1.3 , -2.1]	-2.8	[3.4 , -7.4]
New Brunswick	-0.1	[0.1 , -0.1]	-0.1	[0.2 , -0.4]
Nova Scotia	0.0	[0.1 , -0.1]	-0.1	[0.1 , -0.2]
Prince Edward Island	0.0	[0 , 0]	0.0	[0 , -0.1]
Newfoundland and Labrador	-0.1	[0.1 , -0.2]	-0.2	[0.2 , -0.4]
Sub-total Canada	**-5.0**	**[6.6 , -10.3]**	**-13.8**	**[17.3 , -36.8]**

Note: zero values are due to rounding

Table 7-51: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5, by "high-risk" sector for Canada, showing incremental annual payroll compensation losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in PAYROLL COMPENSATION from baseline due to ($ 2015 billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Agriculture, forestry, fishing & hunting	-0.1	[0.1 , -0.2]	-0.1	[0.1 , -0.4]
Mining, quarrying, oil & gas extraction	-0.2	[0.2 , -0.5]	-0.2	[0.2 , -0.9]
Utilities	-0.1	[0.1 , -0.3]	-0.2	[0.1 , -0.6]
Construction	-0.8	[0.8 , -2.3]	-1.4	[1.2 , -4.7]
Manufacturing	-1.6	[1.4 , -4.3]	-2.9	[2.4 , -9.8]
Transportation & warehousing	-0.5	[0.5 , -1.5]	-0.9	[0.8 , -3.2]
Sub-total Canada	**-3.2**	**[2.9 , -9.1]**	**-5.7**	**[4.8 , -19.5]**
Socioecononomic change only				
Agriculture, forestry, fishing & hunting	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Mining, quarrying, oil & gas extraction	0.0	[0 , -0.2]	-0.1	[0 , -0.5]
Utilities	0.0	[0 , -0.1]	-0.1	[0 , -0.3]
Construction	-0.3	[0.1 , -1.3]	-0.6	[0.1 , -2.7]
Manufacturing	-0.7	[0.2 , -2.4]	-1.3	[0.4 , -5.8]
Transportation & warehousing	-0.2	[0.1 , -0.9]	-0.4	[0.1 , -1.9]
Sub-total Canada	**-1.3**	**[0.3 , -5]**	**-2.4**	**[0.6 , -11.4]**
Climate change only				
Agriculture, forestry, fishing & hunting	-0.1	[0.1 , -0.1]	-0.1	[0.1 , -0.2]
Mining, quarrying, oil & gas extraction	-0.1	[0.2 , -0.2]	-0.2	[0.2 , -0.4]
Utilities	-0.1	[0.1 , -0.2]	-0.1	[0.1 , -0.3]
Construction	-0.5	[0.7 , -1.1]	-0.8	[1.1 , -2]
Manufacturing	-0.9	[1.2 , -1.9]	-1.6	[2 , -4]
Transportation & warehousing	-0.3	[0.4 , -0.6]	-0.5	[0.7 , -1.3]
Sub-total Canada	**-1.9**	**[2.6 , -4.2]**	**-3.3**	**[4.3 , -8.2]**

Note: zero values are due to rounding

Table 7-52: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by "high-risk" sector for Canada, showing incremental annual payroll compensation losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in PAYROLL COMPENSATION from baseline due to ($ 2015 billion per year):	**2050s**		**2080s**	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Agriculture, forestry, fishing & hunting	-0.1	[0.1 , -0.3]	-0.2	[0.2 , -0.6]
Mining, quarrying, oil & gas extraction	-0.2	[0.2 , -0.6]	-0.5	[0.5 , -1.4]
Utilities	-0.1	[0.1 , -0.4]	-0.3	[0.3 , -0.9]
Construction	-1.0	[1 , -2.8]	-2.5	[2.6 , -7.3]
Manufacturing	-1.9	[1.8 , -5]	-4.9	[5 , -14.8]
Transportation & warehousing	-0.6	[0.6 , -1.7]	-1.5	[1.6 , -4.8]
Sub-total Canada	**-4.0**	**[3.9 , -10.7]**	**-9.8**	**[10.2 , -29.9]**
Socioecononomic change only				
Agriculture, forestry, fishing & hunting	0.0	[0 , -0.1]	0.0	[0 , -0.2]
Mining, quarrying, oil & gas extraction	0.0	[0 , -0.2]	-0.1	[0 , -0.5]
Utilities	0.0	[0 , -0.1]	-0.1	[0 , -0.3]
Construction	-0.3	[0.1 , -1.3]	-0.6	[0.1 , -2.7]
Manufacturing	-0.7	[0.2 , -2.4]	-1.3	[0.4 , -5.8]
Transportation & warehousing	-0.2	[0.1 , -0.9]	-0.4	[0.1 , -1.9]
Sub-total Canada	**-1.3**	**[0.3 , -5]**	**-2.4**	**[0.6 , -11.4]**
Climate change only				
Agriculture, forestry, fishing & hunting	-0.1	[0.1 , -0.2]	-0.1	[0.2 , -0.4]
Mining, quarrying, oil & gas extraction	-0.2	[0.2 , -0.4]	-0.4	[0.6 , -1.1]
Utilities	-0.1	[0.1 , -0.2]	-0.2	[0.3 , -0.7]
Construction	-0.7	[1 , -1.5]	-1.9	[2.5 , -5.1]
Manufacturing	-1.2	[1.6 , -2.6]	-3.6	[4.7 , -10]
Transportation & warehousing	-0.4	[0.6 , -0.9]	-1.1	[1.5 , -3.2]
Sub-total Canada	**-2.6**	**[3.6 , -5.7]**	**-7.4**	**[9.8 , -20.4]**

Note: zero values are due to rounding

Table 7-53: Projected labour supply impacts for the 2050s and 2080s under RCP 4.5, by "high-risk" sector for Canada, showing incremental annual labour productivity losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 4.5				
Change in LABOUR PRODUCTIVITY from baseline due to ($ 2015 GDP billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Agriculture, forestry, fishing & hunting	-0.2	[0.2 , -0.6]	-0.3	[0.3 , -1]
Mining, quarrying, oil & gas extraction	-0.4	[0.5 , -1.3]	-0.7	[0.6 , -2.5]
Utilities	-0.3	[0.3 , -0.9]	-0.4	[0.4 , -1.6]
Construction	-1.2	[1.1 , -3.5]	-2.0	[1.7 , -7.2]
Manufacturing	-2.7	[2.4 , -7.5]	-5.1	[4.2 , -17.2]
Transportation & warehousing	-1.3	[0.8 , -2.6]	-2.2	[1.3 , -5.5]
Sub-total Canada	**-6.2**	**[5.2 , -16.3]**	**-10.8**	**[8.6 , -35.1]**
Socioecononomic change only				
Agriculture, forestry, fishing & hunting	-0.1	[0 , -0.3]	-0.1	[0 , -0.5]
Mining, quarrying, oil & gas extraction	-0.1	[0 , -0.6]	-0.2	[0 , -1.3]
Utilities	-0.1	[0 , -0.4]	-0.1	[0 , -0.9]
Construction	-0.5	[0.1 , -1.9]	-0.8	[0.2 , -4.2]
Manufacturing	-1.2	[0.3 , -4.2]	-2.3	[0.6 , -10.2]
Transportation & warehousing	-0.6	[0.1 , -1.5]	-1.0	[0.2 , -3.3]
Sub-total Canada	**-2.6**	**[0.5 , -8.9]**	**-4.6**	**[1 , -20.3]**
Climate change only				
Agriculture, forestry, fishing & hunting	-0.2	[0.2 , -0.3]	-0.2	[0.3 , -0.5]
Mining, quarrying, oil & gas extraction	-0.3	[0.5 , -0.7]	-0.5	[0.7 , -1.2]
Utilities	-0.2	[0.3 , -0.5]	-0.3	[0.4 , -0.8]
Construction	-0.7	[1 , -1.6]	-1.2	[1.6 , -3]
Manufacturing	-1.5	[2.1 , -3.3]	-2.8	[3.6 , -7]
Transportation & warehousing	-0.7	[0.7 , -1.1]	-1.2	[1.1 , -2.2]
Sub-total Canada	**-3.6**	**[4.8 , -7.5]**	**-6.2**	**[7.6 , -14.7]**

Note: zero values are due to rounding

Table 7-54: Projected labour supply impacts for the 2050s and 2080s under RCP 8.5, by "high-risk" sector for Canada, showing incremental annual labour productivity losses (2015 dollars), on average, relative to baseline values attributable to socioeconomic change, climate change only, and a combination of socioeconomic and climate change [central case and interval (low and high case)]

Representative Concentration Pathway 8.5				
Change in LABOUR PRODUCTIVITY from baseline due to ($ 2015 GDP billion per year):	2050s		2080s	
	Central	Interval	Central	Interval
Climate change and socioeconomic change				
Agriculture, forestry, fishing & hunting	-0.3	[0.3 , -0.7]	-0.5	[0.6 , -1.7]
Mining, quarrying, oil & gas extraction	-0.6	[0.7 , -1.6]	-1.3	[1.5 , -4.1]
Utilities	-0.3	[0.4 , -1]	-0.8	[0.9 , -2.6]
Construction	-1.5	[1.5 , -4.1]	-3.5	[3.7 , -11.1]
Manufacturing	-3.3	[3.1 , -8.7]	-8.5	[8.7 , -26]
Transportation & warehousing	-1.6	[1 , -3]	-3.7	[2.7 , -8.3]
Sub-total Canada	**-7.5**	**[7 , -19.2]**	**-18.4**	**[18.2 , -53.7]**
Socioecononomic change only				
Agriculture, forestry, fishing & hunting	-0.1	[0 , -0.3]	-0.1	[0 , -0.5]
Mining, quarrying, oil & gas extraction	-0.1	[0 , -0.6]	-0.2	[0 , -1.3]
Utilities	-0.1	[0 , -0.4]	-0.1	[0 , -0.9]
Construction	-0.5	[0.1 , -1.9]	-0.8	[0.2 , -4.2]
Manufacturing	-1.2	[0.3 , -4.2]	-2.3	[0.6 , -10.2]
Transportation & warehousing	-0.6	[0.1 , -1.5]	-1.1	[0.2 , -3.3]
Sub-total Canada	**-2.6**	**[0.5 , -8.9]**	**-4.6**	**[1 , -20.4]**
Climate change only				
Agriculture, forestry, fishing & hunting	-0.2	[0.3 , -0.5]	-0.5	[0.6 , -1.3]
Mining, quarrying, oil & gas extraction	-0.5	[0.7 , -1]	-1.1	[1.6 , -3]
Utilities	-0.3	[0.4 , -0.6]	-0.7	[0.9 , -1.9]
Construction	-1.0	[1.4 , -2.2]	-2.7	[3.6 , -7.6]
Manufacturing	-2.1	[2.8 , -4.5]	-6.3	[8.2 , -17.4]
Transportation & warehousing	-0.9	[1 , -1.5]	-2.6	[2.6 , -5.5]
Sub-total Canada	**-5.0**	**[6.6 , -10.3]**	**-13.8**	**[17.5 , -36.8]**

Note: zero values are due to rounding

8. Proactive Adaptation

Adaptation to adverse climate-related health outcomes includes a wide range of actions. In general terms, we can distinguish between: (A) autonomous adaptations – the physiological and behavioural process of adjusting to changing climate conditions among populations (including short-term responses to changes in prices induced by weather and climate conditions); and (B) planned adaptations – interventions (e.g., policy) to reduce the impact of expected (ex-ante adaptation) or experienced (ex-post adaptation) climate change. *For the purpose of this study, a "proactive adaptation" scenario refers to the implementation of planned interventions.* This section presents the methods and results of three national-level proactive adaptation scenarios that we modelled:

- The installation of internal and external shading technologies on the residential housing stock to mitigate the health effects of heat stress on households;
- The installation of living (green) roofs on residential, commercial and institutional buildings in urban areas to mitigate the health effects of heat stress on the general population; and
- The installation of internal and external shading technologies on manufacturing facilities to mitigate the effects of heat exposures on labour supply.

8.1 Approach

We used best practice for the economic appraisal of adaptation options[116], integrating information on the effectiveness and costs of adaptation interventions from the literature with projected costs of inaction (Section 7) and assumptions about the adoption of the interventions. The projected costs of inaction form the Reference Case against which the incremental costs and benefits of the adaptation interventions are appraised (as illustrated in Figure 8-1).

Ideally, to appraise the economic impacts of the three proactive adaptation scenarios listed above, it would be necessary to construct a stock model of adapted and un-adapted buildings over time, define adoption (or technology penetration) scenarios for the existing building stock and new construction (e.g., 2% of existing buildings are retrofitted annually with shading technologies starting in year t, rising to 5% by year t+10), and perform discounted cash-flow analysis to calculate net present values for each adoption scenario. It would also be necessary to determine the annual impact of the adoption scenario on projected temperatures and the frequency distribution of days per year falling within each of the temperature bins that define the exposure-response functions used to calculate the costs of inaction (recall Section 5). Implementing this "ideal" approach is not feasible with resources available for this study. As a practical alternative, we have developed and assessed the impacts of a single "what-if" proactive adaptation scenario for 2055 and 2085, using outputs from a single GCM. These "what-if" scenarios provide a snapshot of potential costs and benefits in these years for a specified level of technology penetration. The approach is illustrated in Figure 8-1. Note that the approach is applied at the Census Division level and subsequently aggregated to provide provincial/territorial and national-level results. These are the steps we took:

First, we determined the most "centralist" GCM for each impact of interest—i.e., the model generating projected physical impacts for the 2050s and 2080s closest to the ensemble mean. For heat-related mortality the most centralist GCM was CCSM4; for labour supply it was MIROC-ESM-CHEM.

Second, we estimated the physical impacts (e.g., labour hours lost) and associated costs (e.g., forgone payroll compensation) in the absence of our "what-if" adaption scenarios (denoted by the orange dots on the blue "cost of inaction" line in Figure 8-1). These are the results in Section 7.

Third, we defined a hypothetical level of adaptation technology penetration in 2055 and 2085 (e.g., internal and external shading technologies have been installed on 25% of the residential housing stock in 2055).

Fourth, we estimated the corresponding change in temperature and generated new daily (mean and maximum) temperature frequency distributions.

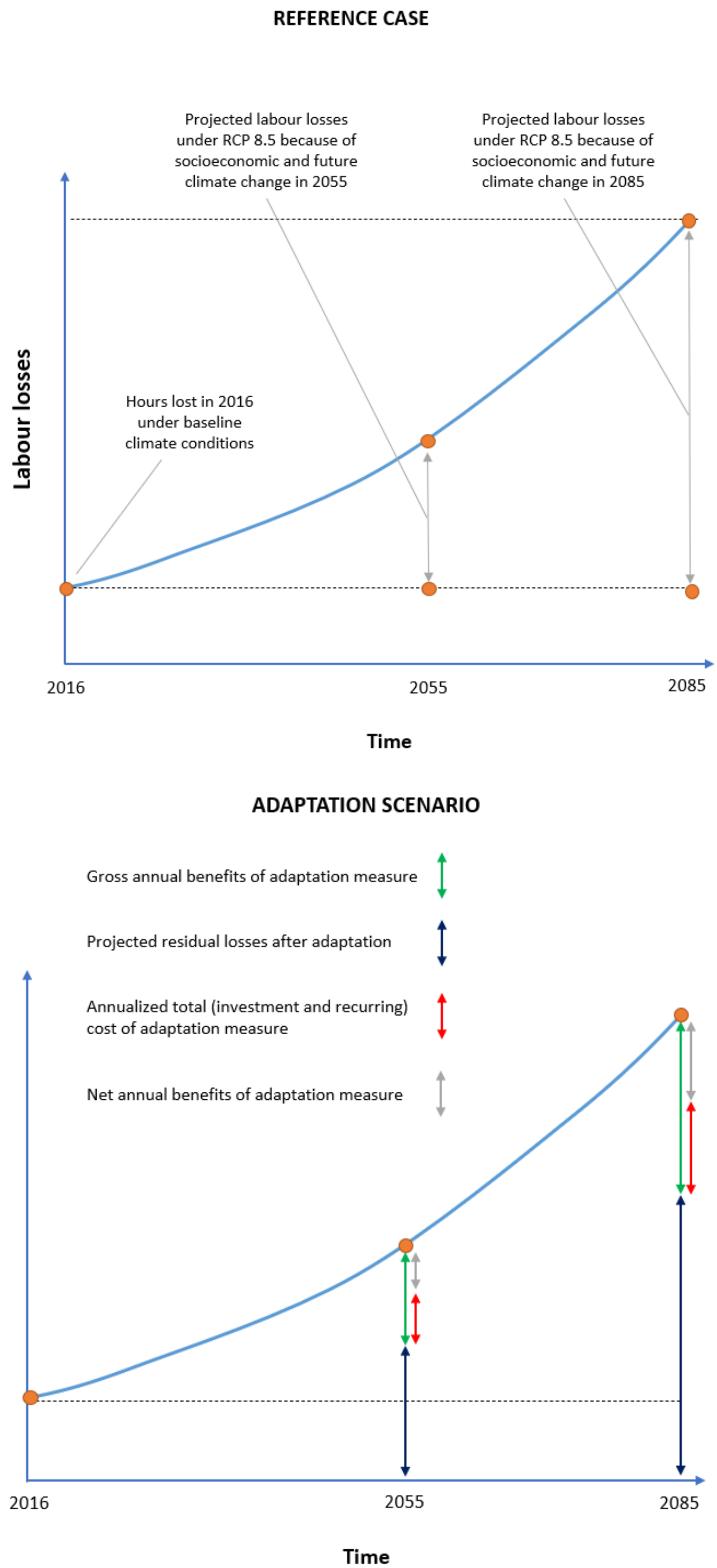
Fifth, the impact models were re-run using the new daily temperature frequency distributions and the difference compared with the costs of inaction model run is calculated. This difference defines the gross annual benefits of the “what-if” adaptation scenario (the green arrow in Figure 8-1).

Sixth, we estimated the total incremental investment costs and, where relevant, incremental annual operation and maintenance (O&M) costs of the adaptation scenario. A measure of annualized total cost was then constructed for comparison with the gross annual benefits (the red arrow in Figure 8-1).

Seventh, we calculated the net annual benefits of the “what-if” adaptation scenario (the grey arrow in Figure 8-1). Although not shown in Figure 8-1, we also generated estimates of key co-benefits, since the adaptation technologies considered will likely not be installed solely to address temperature-related health impacts. For example, shading technologies are often used to improve the energy efficiency of buildings; consequently, we included energy cost savings in our calculation of net benefits for the shading scenarios. We did not estimate the annual residual costs for each “what-if” adaptation scenario; however, residual costs can be approximated by deducting the gross annual benefits of adaptation reported below from the corresponding projected costs of inaction provided in Section 7.[117]

It should be noted that our approach will underestimate the net annual benefits of each adaptation scenario, since a technology installed in (say) 2055 will provide a stream of benefits over its function life (over 40 years in the case of living roofs), and as temperatures continue to rise from 2055, these annual benefits will increase, other things being equal. We have not allowed for growth in annual benefits in our calculation of gross annual benefits in 2055 (or 2085).

Figure 8-1: Framework for economic analysis of adaptation scenarios – projected annual net benefits in 2055 and 2085. It uses labour losses as an example.



8.2 Hot Temperatures

There are multiple ways to mitigate the adverse health effects associated with the exposure of people to heat stress, either by managing the build-up of ambient heat or applying techniques to cool the air. Here, we investigate two approaches commonly considered for buildings: internal and external shading devices and living (vegetated) roofs (also referred to as "green roofs"). Specifically, we developed and appraised the following "what-if" proactive adaptation scenarios for heat exposures under future climate conditions:

- **25% and 50% of private dwellings have installed internal and external shading technologies in 2055 and 2085, respectively**.
- **50% and 100% of available residential, commercial and institutional roof space in urban areas have installed living roofs in 2055 and 2085, respectively**.

In both cases, we only considered mortality impacts.

Shading technologies for homes

Key assumptions underpinning the analysis, in addition to those used in the cost of inaction calculations, include:

- Shades reduce internal temperatures during daylight hours by 2-3°C (we modelled a reduction of 2.5°C) (Vivid Economics, 2017; Kjellstrom et al., 2014 and 2016).
- Average floor space of residential dwellings across Canada is 116.4 m^2 to 141.8 m^2, depending on province or territory (average size in 2017) (NRCAN, 2020).
- Average window-to-floor ratio is 15% [10%-20%] (US DOE, 2013).
- Shades are applied to 50% of windows (south and west walls).
- Average installed costs of 12 different internal and external shading technologies in 2015 are $81 per m^2 [$42-$140 per m^2] (2015 dollars) (Consortium for Building Energy Conservation, 2016).
- Unit investment costs in 2015 are reduced by 10% and 16% by 2055 and 2085, respectively, due to learning effects (Karali, Park and McNeil, 2015).
- The functional life of the shading technologies is 20 years [15-25 years] (Consortium for Building Energy Conservation, 2016).
- Real annual discount rate is 3% [1.5%-8.0%].
- Average total energy savings from shading technologies is 6.3% [0.2%-10.1%] reduction in baseline consumption (US DOE, 2013).
- Average total energy (electricity and natural gas) consumption is 0.75 GJ per m^2 in 2016 and assumed to fall to 0.39 GJ per m^2 and 0.24 GJ per m^2 by 2055 and 2085, respectively (based on NRCAN, 2020).
- Average total energy costs (electricity and natural gas) in 2055 and 2085 is $43 per GJ and $54 per GJ (2015 dollars), respectively (based on CER, 2019).
- Members of a household are assumed to be at home 70% of the year (assumed exposure to temperature).
- Household size (persons per dwelling) was calculated for 2016 for each Census Division and assumed to decline at 0.1 persons per year based on historic trends.
- Dwellings in Census Divisions with no heat-related deaths under the projected Reference Case do not adopt shading technologies.

Modelled results for 2055 and 2085 and presented in Table 8-1 and Table 8-2, respectively. Relative to the cost of inaction Reference Case, **if 25% of private residential dwellings in Canada had shading technologies** installed in 2055, about **21 heat-related deaths would be avoided**. The corresponding annual benefits are $183 million (with deaths avoided valued using the VSL) and $19 million (with deaths avoided valued using the human capital approach). Annual co-benefits associated with energy savings are about $580 million. Annualized investment costs are $199 million, resulting in net annual benefits of positive $564 million (based on the VSL) and $401 million (based on the Human Capital approach). In this case, **net annual benefits are positive—and the adaptation investment is justified on economic efficiency grounds—but only when co-benefits are included**. If energy saving co-benefits are not included, the net annual benefit is negative $16.4 million (based on the VSL) and negative $180 million (based on the Human Capital approach). Note that shades are not installed on dwellings in the territories in either 2055 or 2085 since there are no heat-related deaths under the Reference Case. Installing shades in this case only generates energy saving co-benefits. In 2085, annual net benefits associated with 50% of private residential dwellings in Canada adopting shades is estimated at positive $1,252 million (based on the VSL) and $807 million (based on the Human Capital approach). Similar to 2055, however, **in the absence of the energy saving co-benefits the net annual benefits in 2085 would be negative**; about negative $40 million when deaths avoided are valued using the VSL.

Figure 8-2 provides a tornado chart showing the sensitivity of the results for 2085 to our central case assumptions (with the valuation of deaths based on the VSL). Given the importance of energy saving co-benefits as a determinant of estimated net annual benefits, it is no surprise **the results are most sensitive to assumptions about the magnitude of energy savings**. Indeed, the net annual benefits are marginally negative ($8 million) if estimated energy savings are based on lower bound assumptions.

Living roofs for urban heat exposures

Key assumptions underpinning the analysis, in addition to those used in the cost of inaction calculations, include:

- 50% penetration of living roofs on available roof space in urban areas will reduce ambient temperature by 0.17°C; and 100% penetration of living roofs on available roof space in urban areas will reduce ambient temperature by 0.34°C (derived from Rosenzweig et al., 2006).
- Average floor space of residential dwellings across Canada is 116.4 m^2 to 141.8 m^2, depending on province or territory (average size 2017) (NRCAN, 2020).
- Average roof space in an urban area is 20% [20%-25%] of the total land area (US EPA, 2008).
- Average share of residential roof space is 55% [50%-60%] of total roof space in urban areas (City of Edmonton City Plan 2065).
- Average roof space of a private dwelling is 66.1 m^2 [53.4 m^2 to 80.2 m^2] (calculated).
- 75% of available roof space is planted (GSA, 2011).
- The population living in urban area across Canada ranges from 45.1% to 86.4% of the total population, depending on province or territory (data provided by the Institute).
- Average, incremental installed costs of 6 different extensive and intensive living roofs in 2015 is $159 per m^2 [$140-$178 per m^2] (2015 dollars) (Feng, 2017).
- Unit investment costs in 2015 are reduced by 33% and 50% by 2055 and 2085, respectively, due to learning effects (Feng, 2017).
- The functional life of living roofs is 42 years [25-60 years] (GSA, 2011).
- Average annual O&M costs are $4.81 per m^2 [$3.76 per m^2 to $5.87 per m^2] (2015 dollars) (TRC, 2007).
- Real annual discount rate is 3% [1.5%-8.0%].
- Average annual heating savings are $0.34 per m^2 [$0.15 per m^2 to $0.53 per m^2] (2015 dollars) (private co-benefit) (TRC, 2007 and Biachini and Hewage, 2012).
- Average annual cooling savings are $0.75 per m^2 [$0.31 per m^2 to $1.18 per m^2] (2015 dollars) (private co-benefit) (TRC, 2007 and Biachini and Hewage, 2012).
- Average annual aesthetic benefits for owners are $0.0027 per m^2 [$0.0022 per m^2 to $0.0033 per m^2] (2015 dollars) (private co-benefit) (TRC, 2007 and Biachini and Hewage, 2012).

- Average annual air quality benefits are \$0.25 per m^2 [\$0.04 per m^2 to \$0.46 per m^2] (2015 dollars) (public co-benefit) (Feng, 2017 and GSA, 2011).
- Average annual biodiversity and habitat benefits are \$5.35 per m^2 [no range available] (2015 dollars) (public co-benefit) (GSA, 2011).
- Average annual stormwater management benefits are \$5.57 per m^2 [\$4.01 per m^2 to \$7.08 per m^2] (2015 dollars) (public co-benefit) (Sproul et al., 2012 and GSA, 2011).
- Average annual carbon management benefits are \$0.71 per m^2 [\$0.58 per m^2 to \$0.85 per m^2] (2015 dollars) (public co-benefit) (GSA, 2011).
- Members of a household are assumed to be at home 70% of the year (assumed exposure to temperature).
- Household size (persons per dwelling) was calculated for 2016 for each Census Division and assumed to decline at 0.1 persons per year based on historic trends.
- Dwellings in Census Divisions with no heat-related deaths under the projected Reference Case do not adopt shading technologies.

Modelled results for 2055 and 2085 and presented in Table 8-3 and Table 8-4, respectively. Relative to the cost of inaction Reference Case**, if 50% of available residential, commercial and institutional roof space in Canada had living roofs installed in 2055, about 46 heat-related deaths would be avoided**. In contrast to the shading scenario, this includes both reduced heat exposure in people's home and reduced heat exposure outside of the home. The corresponding annual benefits are \$414 million (with deaths avoided valued using the VSL) and \$44 million (with deaths avoided valued using the human capital approach). Annual co-benefits are about \$9,668 million, of which about 8.5% accrue to the property owner while the remaining 91.5% are public benefits. Annualized investment costs are \$6,940 million, resulting in net annual benefits of positive \$3,143 million (based on the VSL) and \$2,772 million (based on the Human Capital approach). **Net annual benefits are positive—and the adaptation investment is justified on economic efficiency grounds—but only when co-benefits are included**. If the co-benefits are not included, the net annual benefit is negative \$6,526 million (based on the VSL) and negative \$6,896 million (based on the Human Capital approach). As with the shades, living roofs are not installed on dwellings in the territories in either 2055 or 2085 since there are no heat-related deaths under the Reference Case. Installing living roofs in this case only generates private and public co-benefits. **In 2085, annual net benefits associated with 100% of available residential, commercial and institutional roof space in Canada adopting living roofs is estimated at positive \$10,621 million (based on the VSL) and \$9,739 million** (based on the Human Capital approach). Similar to 2055, however, **in the absence of the co-benefits the net annual benefits in 2085 would be negative**; about negative \$15,390 million when deaths avoided are valued using the VSL.

Figure 8-3 provides a tornado chart showing the sensitivity of the results for 2085 to our central case assumptions (with the valuation of deaths based on the VSL). Again, given the significant contribution of co--benefits to estimated net annual benefits, it is no surprise **the results are most sensitive to assumptions about the magnitude of these co-benefits**. Nonetheless, **even under pessimistic assumptions for co-benefits the net annual benefits remain positive**. A high discount rate actually exerts greater downward pressure of estimated net annual benefits.

Table 8-1: Estimated deaths avoided, costs, benefits and net benefits from the use of internal and external shading technologies on residential properties to mitigate heat-related mortality impacts in 2055 under RCP 8.5 [CCSM4], by province and territory [25% of homes adopt shading technologies] [central case] [avoided deaths valued using the VSL and Human Capital approach]

	2055									
				Annual benefits of avoided deaths		**Co-benefits**		**Annual net benefits of shading adoption**		
	Adapted homes	Excess deaths avoided	Annualized investment costs	VSL	Human Capital	Total energy savings		VSL	Human Capital	Census Divisions with +ve net annual benefits (VSL)
	(number)	(deaths)	($ 2015 million)	($ 2015 million)	($ 2015 million)	(PJ)	($ 2015 million)	($ 2015 million)	($ 2015 million)	(number)
Newfoundland and Labrador	25,153	0	1.2	1.6	0.2	0.08	3.6	4.0	2.6	1
Prince Edward Island	12,724	0	0.6	0.6	0.1	0.04	1.8	1.8	1.3	1
Nova Scotia	50,210	0	2.4	2.9	0.3	0.16	7.1	7.6	5.0	1
New Brunswick	30,085	0	1.4	1.6	0.2	0.10	4.1	4.3	2.9	2
Quebec	805,835	4	34.3	32.5	3.4	2.31	100.0	98.2	69.1	22
Ontario	1,837,363	9	95.1	80.3	8.5	6.42	277.1	262.3	190.5	35
Manitoba	125,358	1	5.8	5.0	0.5	0.39	16.8	16.1	11.5	3
Saskatchewan	104,682	1	5.0	4.6	0.5	0.34	14.5	14.1	10.0	3
Alberta	565,080	3	26.6	22.8	2.4	1.80	77.6	73.8	53.4	6
British Columbia	519,518	3	26.7	30.8	3.2	1.80	77.7	81.8	54.3	5
Yukon	0	0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
Northwest Territories	0	0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
Nunavut	0	0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
Canada	**4,076,008**	**21**	**199.1**	**182.7**	**19.3**	**13.44**	**580.3**	**563.9**	**400.5**	**79**

Table 8-2: Estimated deaths avoided, costs, benefits and net benefits from the use of internal and external shading technologies on residential properties to mitigate heat-related mortality impacts in 2085 under RCP 8.5 [CCSM4], by province and territory [50% of homes adopt shading technologies] [central case] [avoided deaths valued using the VSL and Human Capital approach]

	2085									
				Annual benefits of avoided deaths		**Co-benefits**		**Annual net benefits of shading adoption**		
	Adapted homes	Excess deaths avoided	Annualized investment costs	VSL	Human Capital	Total energy savings		VSL	Human Capital	Census Divisions with +ve net annual benefits (VSL)
	(number)	(deaths)	($ 2015 million)	($ 2015 million)	($ 2015 million)	(PJ)	($ 2015 million)	($ 2015 million)	($ 2015 million)	(number)
Newfoundland and Labrador	46,330	0	2.1	3.6	0.4	0.09	5.1	6.6	3.4	1
Prince Edward Island	34,653	0	1.6	1.6	0.2	0.07	3.8	3.8	2.4	1
Nova Scotia	157,601	1	7.1	9.3	1.0	0.32	17.1	19.3	11.0	3
New Brunswick	125,864	1	5.6	6.6	0.7	0.25	13.3	14.3	8.5	5
Quebec	2,080,305	8	82.6	81.7	9.1	3.66	197.6	196.7	124.1	28
Ontario	5,147,484	21	248.6	212.4	23.6	11.01	594.5	558.4	369.6	41
Manitoba	378,278	2	16.2	15.1	1.7	0.72	38.7	37.7	24.2	5
Saskatchewan	346,634	1	15.3	14.0	1.6	0.68	36.7	35.4	22.9	5
Alberta	1,900,397	7	83.6	66.7	7.4	3.70	199.9	183.1	123.8	11
British Columbia	1,611,661	9	77.2	89.0	9.9	3.42	184.6	196.4	117.3	10
Yukon	0	0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
Northwest Territories	0	0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
Nunavut	0	0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0
Canada	**11,829,207**	**50**	**539.9**	**500.1**	**55.6**	**23.92**	**1,291.4**	**1,251.6**	**807.1**	**110**

Figure 8-2: Tornado chart showing sensitivity of central case assumptions: use of internal and external shading technologies on residential properties to mitigate heat-related mortality impacts in 2085 under RCP 8.5 [CCSM4] [50% of homes adopt shading technologies]

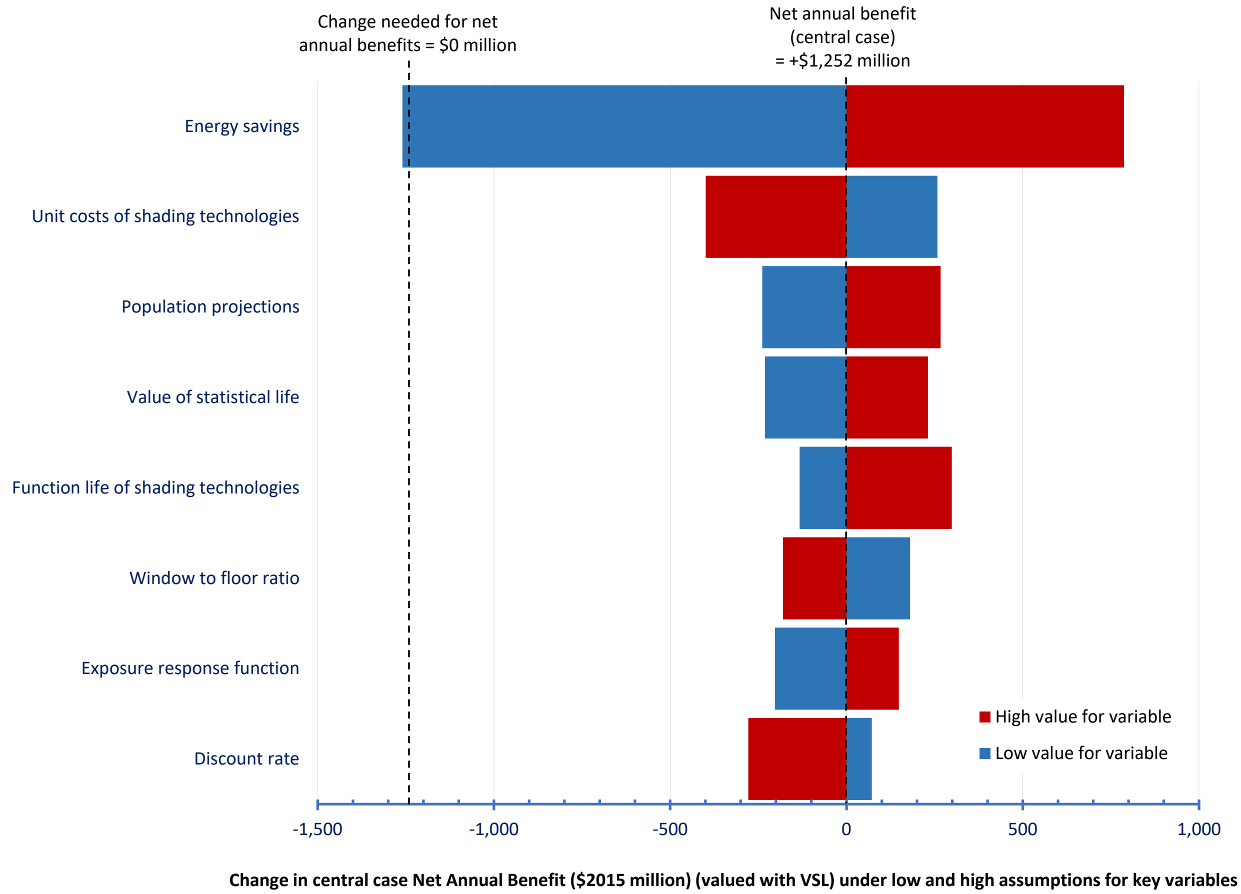


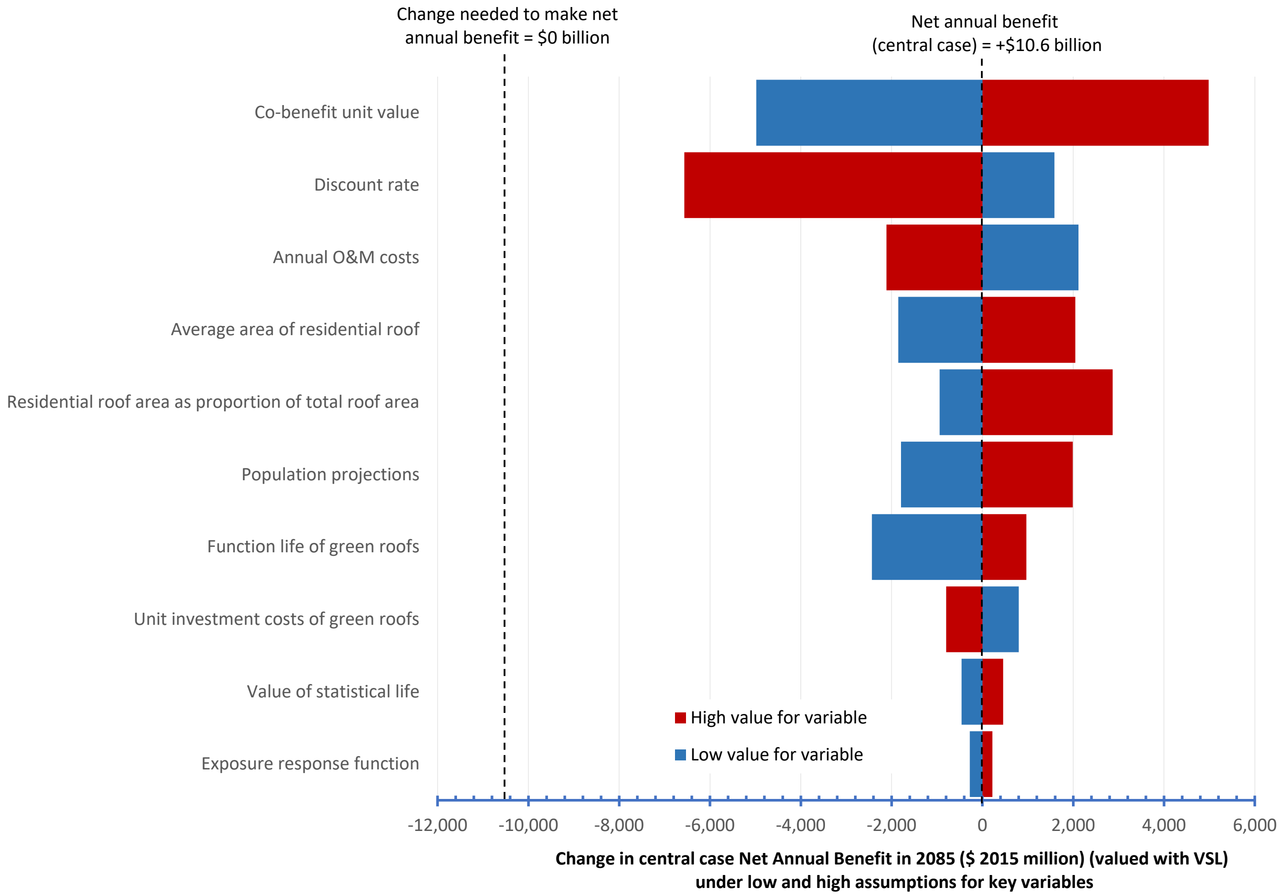
Table 8-3: Estimated deaths avoided, costs, benefits and net benefits from installation of living roofs to mitigate heat-related mortality impacts in 2055 under RCP 8.5 [CCSM4], by province and territory [50% of all available residential, commercial and institutional roof space] [central case] [avoided deaths valued using the VSL and Human Capital approach]

	2055									
				Annual benefits of avoided deaths		Co-benefits		Annual net benefits of living roofs		
	Adapted roof area	Excess deaths avoided	Annualized lifecycle costs	VSL	Human Capital	Private	Pubilc	Based on VSL	Based on Human Capital	Census Divisions with +ve net annual benefits (VSL)
	(million m2)	(deaths)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	(number)
Newfoundland and Labrador	6.8	0	47.7	3.7	0.4	5.6	60.8	22.4	19.1	11
Prince Edward Island	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Nova Scotia	16.1	1	112.2	9.0	0.9	13.2	143.2	53.1	45.1	18
New Brunswick	10.7	1	74.7	5.7	0.6	8.8	95.3	35.1	30.0	15
Quebec	219.4	9	1,532.2	83.6	8.8	180.0	1,954.6	686.0	611.2	98
Ontario	400.4	19	2,796.0	165.1	17.4	328.4	3,566.9	1,264.4	1,116.7	49
Manitoba	32.1	1	224.4	12.6	1.3	26.4	286.3	100.9	89.6	23
Saskatchewan	28.3	1	197.7	12.0	1.3	23.2	252.2	89.7	79.0	18
Alberta	133.6	6	932.7	49.7	5.2	109.6	1,189.8	416.4	371.9	19
British Columbia	146.4	8	1,022.3	72.8	7.7	120.1	1,304.2	474.7	409.6	29
Yukon	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Northwest Territories	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Nunavut	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Canada	**993.8**	**46**	**6,939.9**	**414.1**	**43.7**	**815.2**	**8,853.3**	**3,142.7**	**2,772.3**	**280**

Table 8-4: Estimated deaths avoided, costs, benefits and net benefits from installation of living roofs to mitigate heat-related mortality impacts in 2085 under RCP 8.5 [CCSM4], by province and territory [100% of all available residential, commercial and institutional roof space] [central case] [avoided deaths valued using the VSL and Human Capital approach]

	2085									
				Annual benefits of avoided deaths		Co-benefits		Annual net benefits of living roofs		
	Adapted roof area	Excess deaths avoided	Annualized lifecycle costs	VSL	Human Capital	Private	Pubilc	Based on VSL	Based on Human Capital	Census Divisions with +ve net annual benefits (VSL)
	(million m2)	(deaths)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	($ 2015 million)	(number)
Newfoundland and Labrador	12.6	1	77.1	7.6	0.8	10.3	112.1	52.9	46.2	11
Prince Edward Island	6.6	0	40.3	2.6	0.3	5.4	58.6	26.3	24.0	3
Nova Scotia	36.1	2	221.3	18.7	2.1	29.6	321.7	148.8	132.1	18
New Brunswick	23.7	1	145.0	10.8	1.2	19.4	210.8	96.0	86.4	15
Quebec	532.3	18	3,261.8	185.2	20.6	436.7	4,742.2	2,102.2	1,937.7	98
Ontario	1,088.2	39	6,667.9	393.6	43.8	892.7	9,694.1	4,312.6	3,962.7	49
Manitoba	87.3	3	535.0	31.7	3.5	71.6	777.8	346.1	318.0	23
Saskatchewan	82.1	3	502.8	29.4	3.3	67.3	731.0	324.9	298.8	18
Alberta	406.3	12	2,489.6	125.4	13.9	333.3	3,619.5	1,588.6	1,477.1	19
British Columbia	398.5	19	2,441.8	187.5	20.8	326.9	3,550.0	1,622.6	1,456.0	29
Yukon	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Northwest Territories	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Nunavut	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Canada	**2,673.6**	**99**	**16,382.5**	**992.5**	**110.3**	**2,193.2**	**23,817.8**	**10,621.0**	**9,738.9**	**283**

Figure 8-3: Tornado chart showing sensitivity of central case assumptions: installation of living roofs to mitigate heat-related mortality impacts in 2085 under RCP 8.5 [CCSM4] [installed on 100% of all available residential, commercial and institutional roof space]



8.3 Labour

Workplace exposure to temperature extremes is influenced by many factors—in addition to ambient air temperature, humidity and wind speed—including: exposure to direct sunlight, clothing worn at work, the time when tasks are performed, the intensity of those tasks, and the experience of individuals working at high temperatures (i.e., their acclimatization).[118] Most of these socioeconomic and environmental contextual factors can be influenced through private (individuals and businesses) and public decisions. In other words, negative impacts on labour productivity because of higher temperatures under climate change can be reduced through adaptation actions.

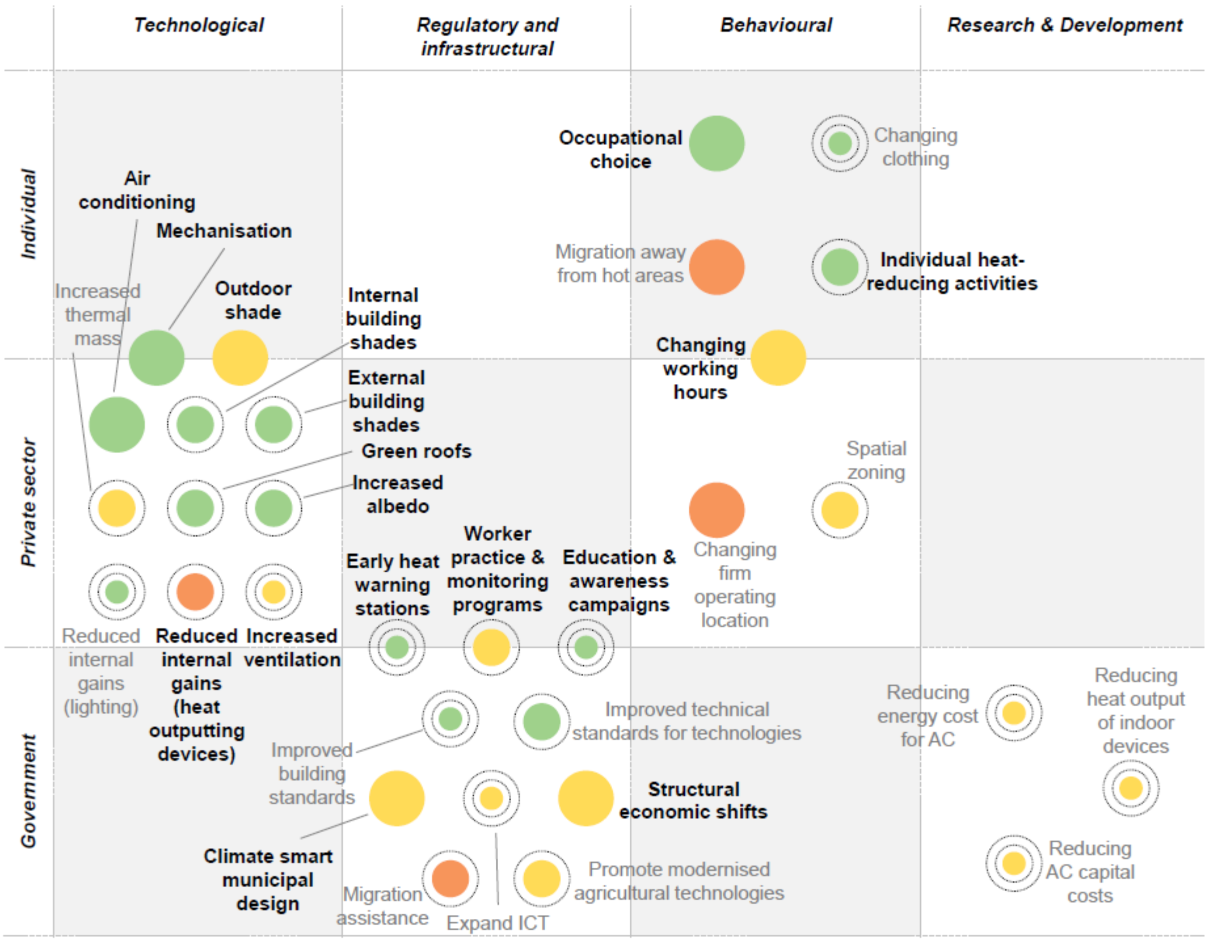
Day et al. (2019), Vivid Economics (2017) and the ILO (2019) have investigated options to reduce temperature-related labour supply and productivity losses. A wide range of adaptation options have been identified, categorized by type of response (i.e., technological, regulatory and infrastructural, behavioural and research & development) and by the primary agent of change (i.e., the individual worker, businesses, or government). The identified adaptation options are presented in Figure 8-4, which also shows the results of a qualitative assessment of each option's feasibility for implementation (orange, yellow and green coloured bubbles indicate low, medium and high feasibility for implementation, respectively) and potential scale of impact (larger coloured areas indicate larger potential impacts).

Guided by these results and what was practically feasible as part of this study, we developed and appraised the following "what-if" proactive adaptation scenario for labour supply: **25% and 50% of manufacturing facilities have installed internal and external shading technologies in 2055 and 2085, respectively**. As the results in Section 7.5 show, the manufacturing sector is impacted most (in both absolute and relative terms) by climate change, in terms of lost labour hours. Furthermore, fixed shading technologies are largely not applicable as a heat mitigation measures for the other "high-risk" sectors considered in this study (e.g., agriculture, forestry and fisheries, construction, etc.).

Key assumptions underpinning the analysis, in addition to those used in the cost of inaction calculations, include:

- Shades reduce internal temperatures during daylight hours by 2-3°C (we modelled a reduction of 2.5°C) (Vivid Economics, 2017; Kjellstrom et al., 2014 and 2016).
- Average floor space per employee in the manufacturing sector is 85 m^2 [53-142 m^2] (US EIA, 2014).
- Average window-to-floor ratio is 15% [10%-20%] (US DOE, 2013).
- Shades are applied to 50% of windows (south and west walls).
- Average installed costs of 12 different internal and external shading technologies in 2015 are $154 per m^2 [$56-$420 per m^2] (2015 dollars) (Consortium for Building Energy Conservation, 2016).
- Unit investment costs are reduced by 33% and 50% by 2055 and 2085, respectively, due to learning effects (Karali, Park and McNeil, 2015).
- The functional life of the shading technologies is 20 years [15-25 years] (Consortium for Building Energy Conservation, 2016).
- Real annual discount rate is 3% [1.5%-8.0%].
- Average energy savings from shading technologies is 4.6% [0.1%-7.4%] reduction in baseline consumption (US DOE, 2013 and Dakleel and Aoul, 2017).
- Average total energy (electricity and natural gas) consumption for HVAC is 0.67 GJ per m^2 in 2014 and assumed to fall to 0.36 GJ per m^2 and 0.22 GJ per m^2 by 2055 and 2085, respectively (based on US DOE, 2020).
- Average total energy costs (electricity and natural gas) in 2055 and 2085 is $14.6 per GJ and $20.6 per GJ (2015 dollars), respectively (based on CER, 2019).

Figure 8-4: Adaptation solution space for temperature-related impacts on labour supply and productivity. Feasibility for implementation is denoted in orange, yellow and green coloured bubbles (low, medium and high feasibility, respectively) and the potential scale of impact is denoted by the size of the bubbles (larger coloured areas indicate larger potential impacts) (Source: Vivid Economics (2017))



Modelled results for 2055 and 2085 and presented in Table 8-5 and Table 8-6, respectively. Relative to the cost of inaction Reference Case, if 25% of manufacturing facilities in Canada had shading technologies installed in 2055, about 4.1 million labour hours would be saved. The corresponding annual costs avoided amount to $197 million (payroll compensation) and $347 million (labour productivity). Annual co-benefits associated with energy savings are about $11 million. Annualized investment costs are about $33 million, resulting in net annual benefits of positive $176 million (based on payroll compensation). In this case, **net annual benefits are positive—and the adaptation investment is justified on economic efficiency grounds—based solely on labour hours saved (i.e., without the inclusion of co-benefits)**. In 2085, annual net benefits associated with 50% of manufacturing facilities in Canada adopting shades are estimated at $180 million.

Figure 8-5 provides a tornado chart showing the sensitivity of the results for 2085 to our central case assumptions. The results are most sensitive to exposure response function coefficients and the unit costs of the shading technologies. However, **even under pessimistic assumptions net annual benefits remain positive**; though with high unit costs for shades, net annual benefits are substantially reduced to $41 million.

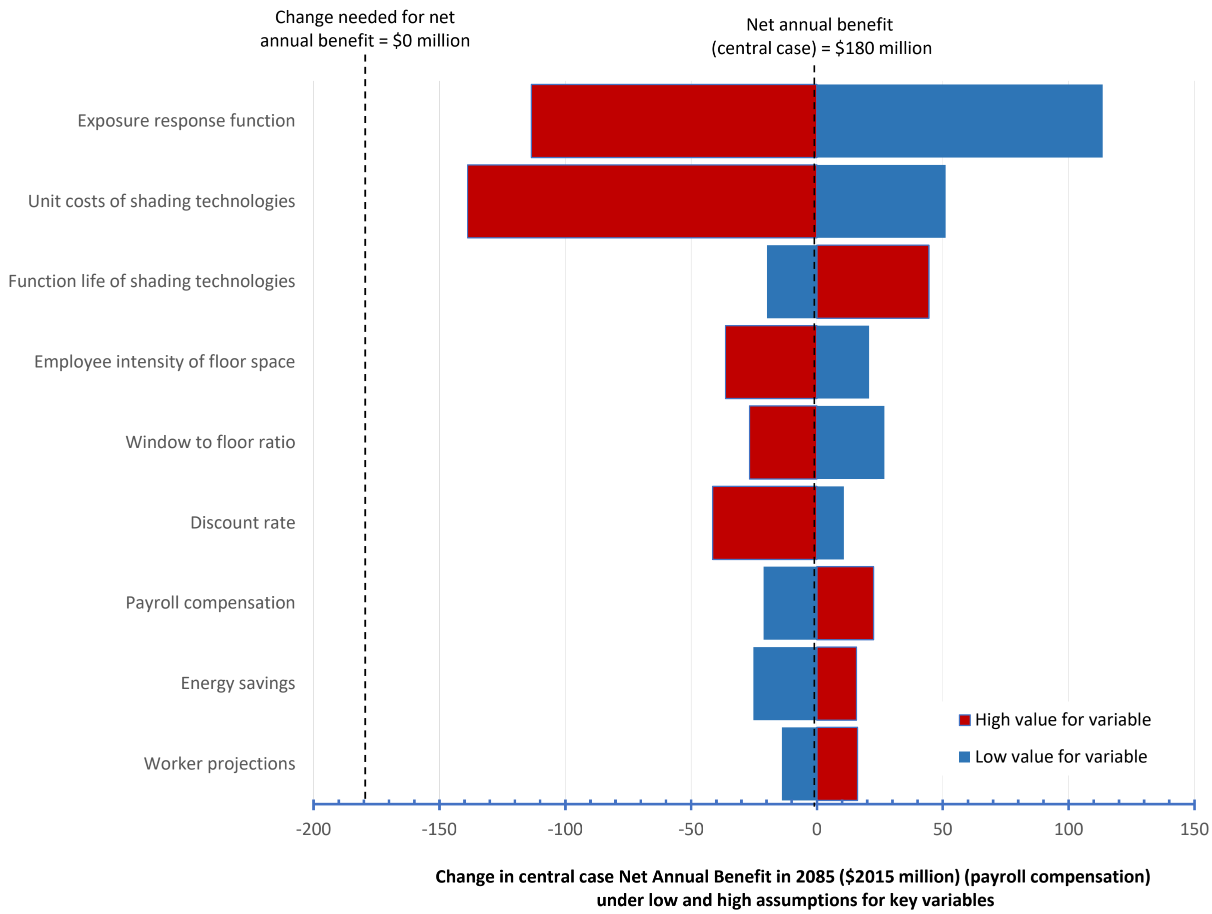
Table 8-5: Estimated labour hours saved, costs, benefits and net benefits from the use of internal and external shading technologies on manufacturing buildings to mitigate occupational heat stress impacts in 2055 under RCP 8.5 [MIROC-ESM-CHEM], by province and territory [25% of manufacturing buildings adopt shading technologies] [central case] [labour hours saved valued using payroll compensation payments and labour productivity]

	2055								
				Annual benefits of labour hours saved		Co-benefits		Annual net benefits of shading adoption	
	Affected workers	Labour hours saved	Annualized investment costs	Payroll compensation	Labour productivity	Total energy savings		Payroll compensation (PC)	Census Divisions with +ve net annual benefits (PC)
	(number)	(hours)	($ 2015 million)	($ 2015 million)	($ 2015 GDP million)	(PJ)	($ 2015 million)	($ 2015 million)	(number)
Newfoundland and Labrador	3,751	15,111	0.2	1.0	1.8	0.01	0.1	0.8	11
Prince Edward Island	2,266	11,718	0.1	0.3	0.7	0.00	0.0	0.2	3
Nova Scotia	10,638	34,940	0.6	1.4	1.9	0.01	0.2	0.9	15
New Brunswick	9,957	56,996	0.6	1.8	3.4	0.01	0.2	1.4	14
Quebec	146,883	1,095,344	8.8	49.3	79.5	0.21	3.0	43.5	98
Ontario	231,583	2,026,319	13.8	102.4	172.0	0.32	4.7	93.3	49
Manitoba	20,507	233,892	1.2	10.3	16.8	0.03	0.4	9.5	23
Saskatchewan	12,277	109,356	0.7	5.0	11.1	0.02	0.3	4.6	18
Alberta	63,568	442,742	3.8	22.8	55.7	0.09	1.3	20.3	19
British Columbia	54,086	68,553	3.2	3.0	4.6	0.08	1.1	0.9	24
Yukon	149	409	0.0	0.0	0.0	0.00	0.0	0.0	1
Northwest Territories	109	274	0.0	0.0	0.0	0.00	0.0	0.0	5
Nunavut	64	123	0.0	0.0	0.0	0.00	0.0	0.0	3
Canada	**555,837**	**4,095,777**	**33.1**	**197.4**	**347.5**	**0.78**	**11.4**	**175.6**	**283**

Table 8-6: Estimated labour hours saved, costs, benefits and net benefits from the use of internal and external shading technologies on manufacturing buildings to mitigate occupational heat stress impacts in 2085 under RCP 8.5 [MIROC-ESM-CHEM], by province and territory [50% of manufacturing buildings adopt shading technologies] [central case] [labour hours saved valued using payroll compensation payments and labour productivity]

	2085								
				Annual benefits of labour hours saved		Co-benefits		Annual net benefits of shading adoption	
	Affected workers	Labour hours saved	Annualized investment costs	Payroll compensation	Labour productivity	Total energy savings		Payroll compensation (PC)	Census Divisions with +ve net annual benefits (PC)
	(number)	(hours)	($ 2015 million)	($ 2015 million)	($ 2015 GDP million)	(PJ)	($ 2015 million)	($ 2015 million)	(number)
Newfoundland and Labrador	6,903	33,824	0.4	1.2	2.2	0.01	0.1	1.0	11
Prince Edward Island	6,011	52,097	0.3	0.3	0.6	0.01	0.1	0.1	3
Nova Scotia	26,139	210,465	1.5	1.5	2.2	0.02	0.5	0.6	15
New Brunswick	23,277	227,586	1.3	2.0	3.8	0.02	0.4	1.1	14
Quebec	354,354	4,256,614	19.7	57.6	92.8	0.31	6.3	44.2	98
Ontario	582,591	7,018,020	32.4	123.3	207.1	0.51	10.4	101.4	49
Manitoba	55,670	783,061	3.1	12.7	20.6	0.05	1.0	10.6	23
Saskatchewan	38,745	421,226	2.2	6.0	13.2	0.03	0.7	4.5	18
Alberta	212,942	1,931,374	11.8	26.5	64.7	0.19	3.8	18.5	19
British Columbia	137,369	11,523	7.6	3.3	5.1	0.12	2.5	-1.9	22
Yukon	456	2,061	0.0	0.0	0.0	0.00	0.0	0.0	1
Northwest Territories	334	1,173	0.0	0.0	0.0	0.00	0.0	0.0	5
Nunavut	197	392	0.0	0.0	0.0	0.00	0.0	0.0	0
Canada	**1,444,987**	**14,949,418**	**80.4**	**234.5**	**412.3**	**1.26**	**25.9**	**180.0**	**278**

Figure 8-5: Tornado chart showing sensitivity of central case assumptions: installation of internal and external shading technologies on manufacturing buildings to mitigate occupational heat stress impacts in 2085 under RCP 8.5 [MIROC-ESM-CHEM [50% of manufacturing buildings adopt shading technologies] [labour hours saved valued using payroll compensation payments]



9. Discussion

This study contributes to the Canadian evidence base on the human health and labour supply costs of climate change. Using a bottom-up modelling approach similar to health impact assessments in comparable European and U.S. studies we quantified and monetized the impacts of future climate change on various temperature-sensitive health outcomes and labour supply. We coupled exposure-response functions (ERFs) from published research with projected socioeconomic and climate data to calculate climate-related mortality, morbidity and labour outcomes for the 2050s (2041-2070) and 2080s (2071-2100), using climate data from seven global climate models under two future emissions concentration scenarios (RCP 4.5 and RCP 8.5). Our approach allowed us to estimate incremental health / labour outcomes as 30-year annual averages attributable to climate change compared to a socioeconomic future with and without climate change; we, therefore, present results in terms of changes to total risk (i.e., attributable to both socioeconomic and climate change relative to a 2016 baseline under current climate conditions) as well as due to climate change alone.

Much of the quantitative research on human health effects of climate change and related economic costs in Canada has focused on direct effects, such as those related to heat and cold. The national scope of this study, encompassing all 293 Census Divisions, the coverage of new impact areas (Lyme disease and occupational heat stress) and the consistent adoption of a societal perspective for the economic valuation of estimate outcomes are key attributes of this study, yielding new information to advance climate action in Canada. Access to enhanced computational power via use of cloud-based servers and automation using the R software environment has greatly improved the analytical possibilities since the NRTEE's Paying the Price (2011), which constrained health analyses to four major urban centres in Canada.

Our results reinforce findings from previous work drawing attention to the high and growing costs of human health impacts as climate change intensifies. Projected annual average costs from both socioeconomic and climate change across all impact areas analyzed (heat-related mortality and morbidity; mortality and morbidity from ozone air pollution, Lyme disease cases and labour productivity) for RCP 4.5 in 2050s and 2080s amount to $87 billion and $148 billion, respectively (central estimates, 2015$, undiscounted). For RCP 8.5, annual average costs reach $101 billion and $214 billion in 2050s and 2080s, respectively (central estimates, 2015$, undiscounted). To put projected costs attributable to both socioeconomic growth and climate change under RCP 8.5 into context, $101 billion and $214 billion amount to, respectively, about 3.1% and 4.4% of Canada's projected GDP in 2055 and 2085 (in the absence of climate change).

A high-level breakdown of estimated human health costs attributable to both climate change and socioeconomic change appears in Figure 9-1 . Panels A and B show annual average costs related to mortality from exposure to heat and from temperature-driven increases in ozone air pollution. Under both RCPs and across both impacts, costs are higher toward the end of the century. As noted in Section 7, where costs attributable to climate change are presented separately from those due to socioeconomic changes, climate change becomes a more influential driver of cost further into the future. As expected, different global emissions trajectories imply different levels of climate change and are therefore linked to different economic consequences. For both heat mortality and mortality from exposure to ozone air pollution a high-emissions concentration future leads to higher welfare losses (costs) than under a lower emissions future.

Annual average morbidity costs from heat-related exposures, exposure to ozone air pollution and new incident cases of Lyme disease appear in Panels C and D of Figure 9-1. These projected costs are at least two orders of magnitude lower than mortality impacts. Noteworthy is the pattern of economic costs for Lyme disease, where costs associated with a lower climate change future are higher than under a climate change future. Further, under a high emissions future, projected costs are lower toward the end of the century than toward mid-century. These counterintuitive results are driven by the inverted U-shaped relationship assumed for Lyme disease incidence and annual average temperatures. The hypothesis by researchers (Dumic and Severnini) who developed the U.S-based model we used in our calculations is that at higher temperatures tick activity and survival peak and then decline; however, as discussed in Section 7.3 the U.S. model does not pick up shifting abundance and distribution of tick vectors, which will become more pronounced under future climate change. Therefore, Lyme disease costs should be interpreted and used with caution. Not shown in Figure 9-1 are projected labour productivity losses due to individuals in high risk occupations being exposed to warmer temperatures at work. The project annual average costs, from both socioeconomic and climate change, under RCP 4.5 amount to $6.1 billion and $10.8 billion in 2050s and 2080s, respectively. The corresponding annual average costs for RCP 8.5 are $7.5 billion and $18.4 billion in 2050s and 2080s, respectively.

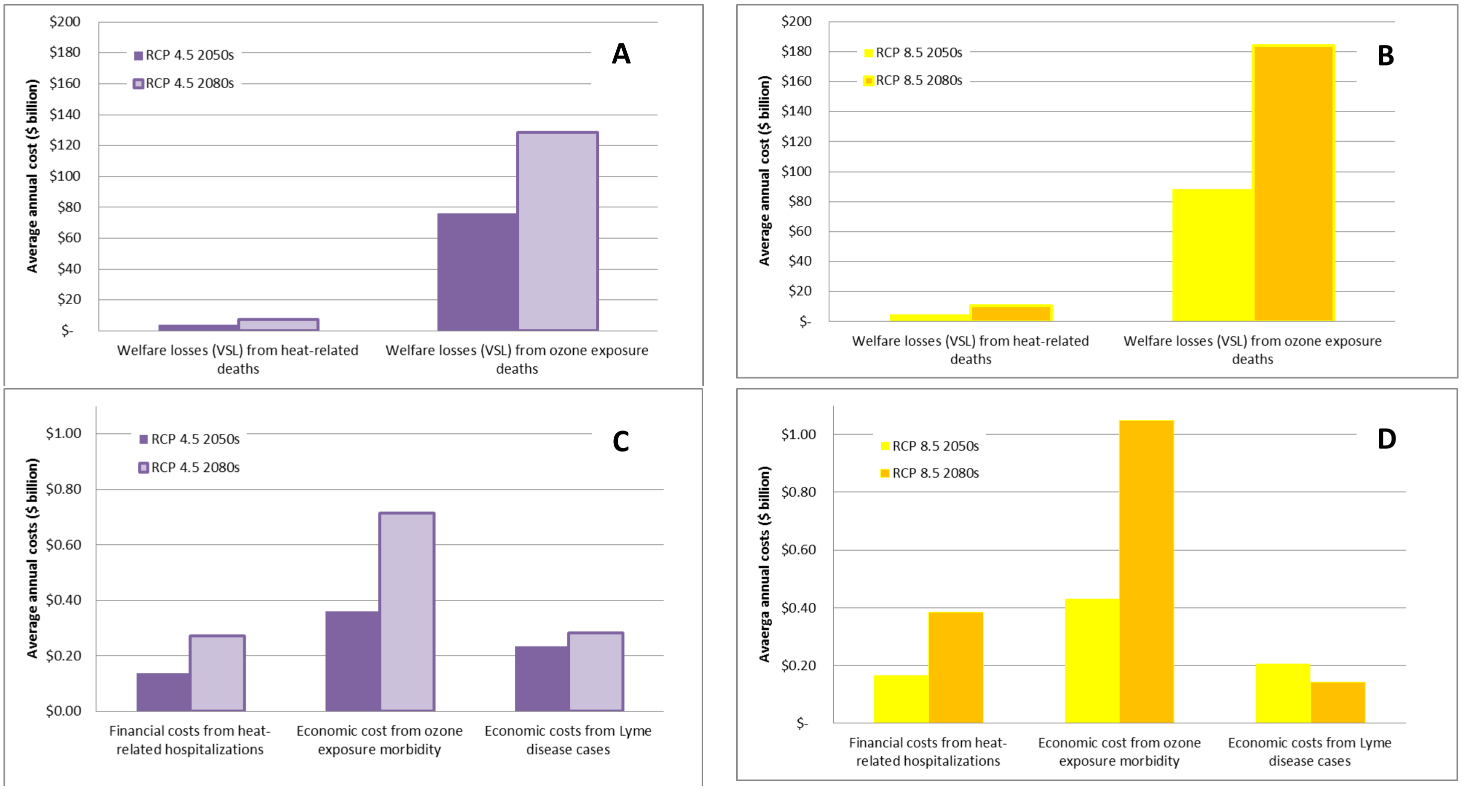


Figure 9-1: Average annual health costs of climate change and socioeconomic change estimated in this study ($2015, undiscounted). Panels (A) and (B) show annual average costs or welfare losses related to mortality impacts in 2050s and 2080s for RCP 4.5 and RCP 8.5, respectively. Panels (C) and (D) show annual average costs or welfare losses related to morbidity impacts and costs of new incident cases of Lyme disease in 2050s and 2080s for RCP 4.5 and RCP 8.5, respectively.

The geographic distribution of projected human health and labour supply costs of climate change generally track population density, with greatest physical impacts and costs for Ontario, then Quebec and Alberta. Analysis of mortality and morbidity impacts from climate-induced rise in ozone air pollution was the only impact area for which we took into account specific population groups per health outcome analyzed (e.g., asthma symptom days only apply to asthmatic children aged five to 19 years or age). This was only possible because we were able to build on the age-specific ERFs and baseline occurrence rates in Health Canada's Air Quality Benefits Assessment Tool. With respect to labour supply and labour productivity, Ontario and Quebec are projected to experience the largest losses both in absolute and relative terms. All three territories are projected to experience small financial benefits in 2050s and 2080s in the lower climate change future. Out of the six "high risk" sectors analyzed[24], projected losses in labour supply and productivity are greatest for manufacturing (in both absolute and relative terms).

There are cost-efficient ways to reduce the health and labour impacts and costs of climate change estimated in this study. To explore the economic case for adaptation we modelled three national-level proactive adaptation scenarios, focused on technological and nature-based solutions. Our analyses centred on two snapshots in time (2055 and 2085) and compared the projected costs of inaction against the incremental costs and benefits of specific adaptation interventions. The three proactive adaptation scenarios investigated were as follows (these are of course only a small sample of the adaptation interventions that could have been examined):

[24] The six sectors are as follows: Agriculture, Forestry, Fishing, and Hunting; Mining, Quarrying, and Oil and Gas Extraction; Utilities; Construction; Manufacturing; and Transportation and Warehousing.

Installing internal and external shading technologies on the residential housing stock to reduce the health effects of heat stress on households;

- Installing living (green) roofs on residential, commercial and institutional buildings in urban areas to reduce the health effects of heat stress on the general population; and,
- Installing internal and external shading technologies on manufacturing facilities to reduce the effects of heat exposures on workers in "high risk" occupations.

Installing shading technologies in 25% and 50% of private dwellings across Canada to reduce exposure to high temperatures avoids premature deaths and yields net annual benefits in 2055 and in 2085, but only with the inclusion of energy savings co-benefits. Installing living roofs in 50% and 100% of available residential, commercial and institutional roof space in Canadian urban areas to reduce exposure to urban heat island effects avoids 50 to 100 heat-related deaths in 2055 and 2085, respectively. As with the installation of shading technologies, installing living roofs yields net annual benefits, but only with the inclusion of multiple co-benefits, including energy savings. Indeed, the contribution of co-benefits to estimated net annual benefits is significant making the results highly sensitive to assumptions about the magnitude of these co-benefits.

Installing shading technologies in 25% and 50% of manufacturing facilities to reduce workers' heat exposure (and related productivity losses) results in net annual benefits based solely on labour hours saved. In other words, these adaptation investments are justified on economic efficiency grounds without needing to account for energy savings co-benefits. These results are most sensitive to the ERF coefficients adopted and to unit costs of shading technologies.

Study limitations

In an effort to be transparent and support replication of the approaches, input and output data used in this study we have documented assumptions and methodological choices extensively throughout this report. In addition, we report central estimates for the "costs of inaction" bounded by an interval to reflect uncertainty across ERFs, socioeconomic projections and economic unit values and also show the spread of our central estimates across the seven GCMs. We provide readers sufficient information to assess levels of confidence in our results. Limitations worth emphasizing, such that future research efforts can address these shortcomings and gaps, are as follows:

- ERFs for heat-related mortality were derived from a study that estimated excess deaths attributable to heat for 384 locations globally, including for 21 Canadian cities. We applied these urban-specific ERFs to the entire population of each Census Division—thereby treating urban and rural populations alike. However, heat tends to impact people living in urban centres more so than populations in rural areas. A sensitivity test in which rural populations were excluded from the analysis reduced projected heat-related deaths in Canada in both the 2050s and 2080s by about 19% under RCP 8.5. Removing the rural population of course results in an underestimate of total heat-related deaths and costs, as these populations are still sensitive to heat exposures. To reduce uncertainty in results such as ours, there is a need for estimated relationships between ambient temperature and mortality (and morbidity) for rural, remote and northern populations. Despite treating urban and rural populations alike, comparisons with results from previous studies actually suggest that our projected excess deaths from heat exposures are conservative in magnitude.

- ERFs for temperature-related morbidity rely on a relationship between ambient air temperatures and hospitalizations in Ontario between 1996 and 2013 (focusing on coronary heart disease, stroke, hypertensive diseases and diabetes). We applied relationships developed from Ontario data to the rest of the country. Although this is a better alternative than relying on estimated relationships from outside of Canada, the applicability of the Ontario-based ERF to, for example, northern Canada is a first approximation. It's worth noting, though, that the Bai et al. (2016 and 2017) studies (on which our ERFs are based) used 14 Health Regions as a random effect, so there would be some adjustment for northern rural areas. Further research on temperature-related morbidity would be helpful to increase understanding of the health impacts of extreme heat in other regions in Canada, particularly again for rural, remote and northern communities.

- Interactions between climate change and air quality are increasingly studied (e.g., Lanzi and Dellink, 2019). This study only focused on increases in ground-level ozone resulting from a rise in ambient air temperatures and used a constant relationship between temperature and ozone that we applied across the country. Other important factors in altering ozone concentrations that are of relevance but were unfeasible to include were long-range transport of ozone precursor emissions, including changes in traffic and vehicle type (motor vehicle km traveled, vehicle emissions standards, more electric vehicles are on the road) and reduced ozone absorption by plants during extreme heat episodes.

- Because of the paucity of Canadian studies directly linking Lyme disease incidence in human populations to climate, we turned to a US study. The ERF accounted for changes in average annual temperatures only (i.e., did not include other climate variables like precipitation or seasonality). To build on Canadian research on projected changes in vector distribution across eastern Canada we provide an alternative analysis that applies a static Lyme disease incidence rate to areas considered "high risk" of exposure to ticks. Quantitative modelling studies directly examining the climate link to human cases of Lyme disease and the economic impacts in Canada are research gaps that merit addressing.
- The ERF for the labour supply analysis relies on a temperature-labour model used in US studies (Rhodium Group, 2014 and US EPA 2015 and 2017). Using this relationship is an important improvement over the characterization of labour supply impacts of climate change for Canada described in global studies. Still, future efforts should endeavor to account for relative humidity, air quality, the presence of aeroallergens, and various forms of extreme weather events, all of which are affected by climate change, and in a direction that reduces labour supply.

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Appendix I

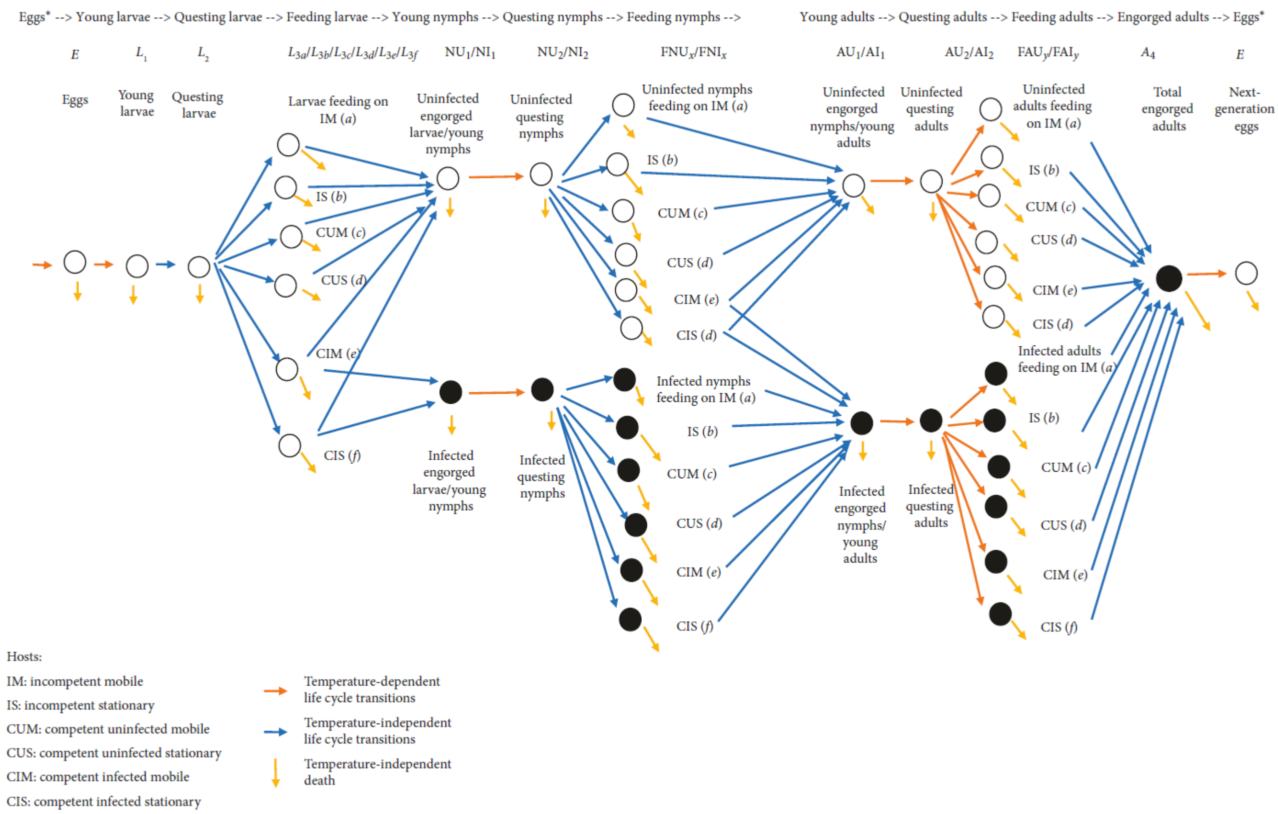


Figure 10-1: Conceptual model describing *I. scapularis* biology and host population and Lyme disease dynamics, emphasizing pathways that are temperature-dependent (Source: Wallace et al. 2019)

Appendix II

Qualitative assessment of bias in the primary study for our Lyme disease analysis

Authors	Study design	Statistical analyses	Sample size	Sample selection	Exposure measurement	Sensitivity analyses	Missing data	Assumptions	Confounding adjustment	Selective reporting of outcomes	Other biases	Risk of bias
Dumic and Severnini 2018	Panel study	Panel regression model	Population	US	Average temperature ranges and total precipitation ranges	No	No	Yes	Yes	No	Residual confounding	L

Risk of bias: L=low; LM=low to moderate, M=moderate, S=serious, C=critical, NI=no information

Appendix III

Prior to finalizing our approach to estimating climate change-driven cases of Lyme Disease (LD) in Canada we were asked to explore alternative options grounded in Canadian research. The approach we proposed in our Methodology Report (April 2020) relied on a relationship between temperature and LD incidence (cases/100,000) derived from reported LD cases in the U.S. (Dumic and Severnini, 2018). Based on feedback from peer reviewers (Dr. Sherilee Harper and Dr. Katie Clow) and the client (Dylan Clark, Canadian Institute for Climate Choices, INSTITUTE) we endeavoured to develop a different approach, within the scope of the study (an $80k study in which LD is one of five impact areas covered). Key concerns about using the U.S. (LD-climate) relationship in Canada include how long the tick populations have been in ecosystems of the Northeastern U.S., the populations of deer and mouse populations in Canada and the surveillance and control mechanisms that differ across the border. To scope potential alternate approaches we set out to (1) interview Canadian LD researchers and (2) undertake exploratory analysis of reported LD cases and climate covariates. What follows is a brief description of these two efforts and their outcomes.

Interviews with Canadian experts

Facilitated by the INSTITUTE, we scheduled interviews with Dr. Jianhong Wu (University Distinguished Research Professor, Canada Research Chair in Industrial and Applied Mathematics, York University) and Dr. Dr. Dongmei Chen (Associate Head, Geography Graduate Programs, Queen's University). Prior to arranging to meet with these experts we developed the following questions to explore with them:

1. Do you know of any literature or approaches to estimate exposure-response functions for Lyme disease (in Canada)?

2. When reviewers argued potential bias when using U.S. data, what would be most important to consider differences in surveillance or ecological systems?

2a. In what contexts could the U.S. model be applicable?

3. Could methods that estimate the equivalent of an Entomological Inoculation Rate be a reasonable approach?

4. In estimating future projections of Lyme disease incidence, a number of assumptions need to be made. Would it be reasonable to extrapolate disease trends from Eastern Canada/U.S. to other parts of Canada if data were lacking for other locations?

5. What would be a reasonable number of assumptions and which (e.g., tick behaviour representing disease; similar US/Canada ecosystems; similar ecosystems across Canada)?

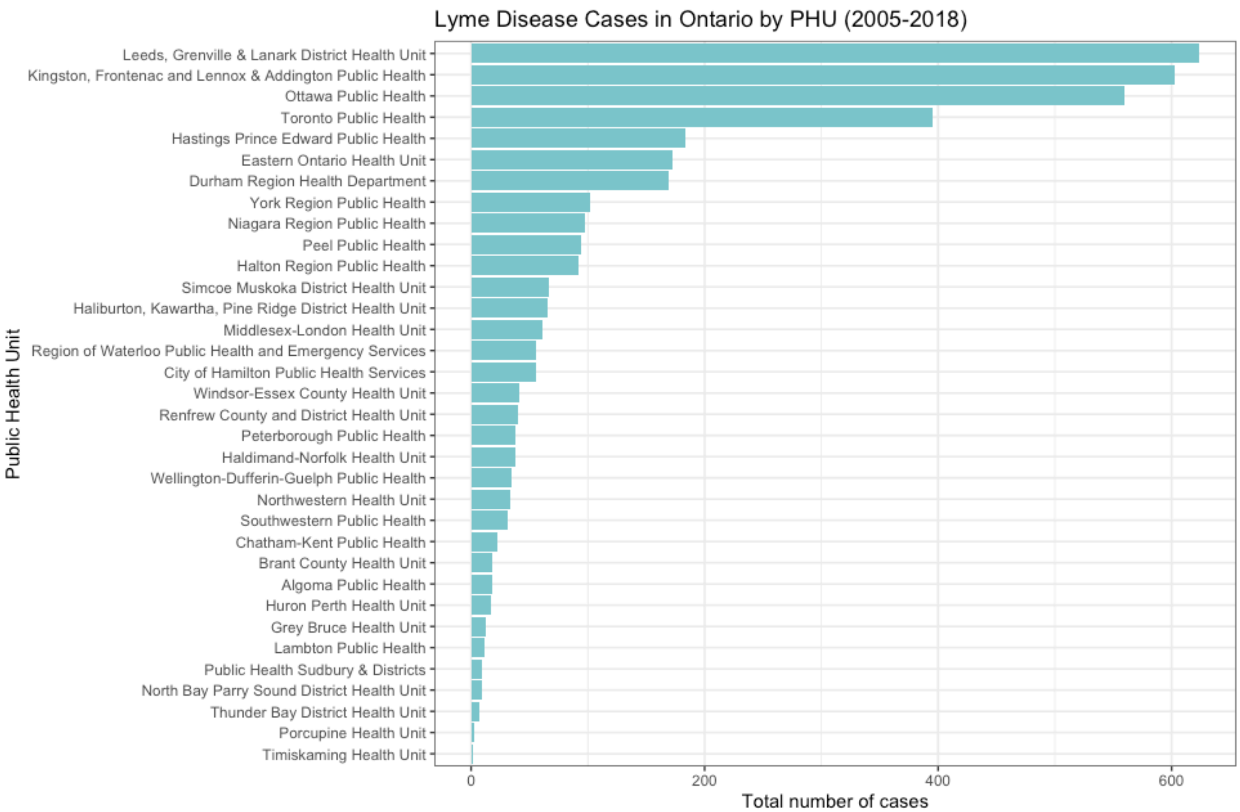
Unfortunately, we were unable to meet with Dr. Wu, as he had a family emergency. Key findings from the meeting with Dr. Chen are as follows:

- Focused on Eastern Ontario, the last decade has seen increasing cases of LD. Her research explores whether increase is due to (1) tick spread (movement of hosts and other things) or (2) climate change. Modelling-based research does show correlations between temperature and LD but they do not have enough field data to validate what they found so they are focused on this fieldwork now.
- Her sense is that LD cases are under-reported. When field sampling, a high percentage of collected ticks is positive for the disease (up to 18%). Frequency of tick surveillance is insufficient and should be more closely tied to tick reproductive cycle.
- Dr. Chen was not able to advise on a credible model or set of assumptions to use to estimate the risk of human exposure at the scale of our study.

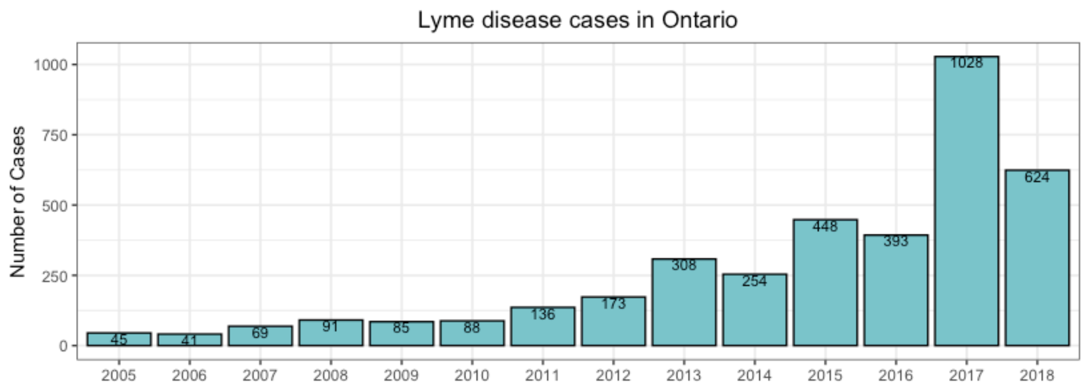
Analysis of Reported Lyme Disease in Ontario and Climate Variables

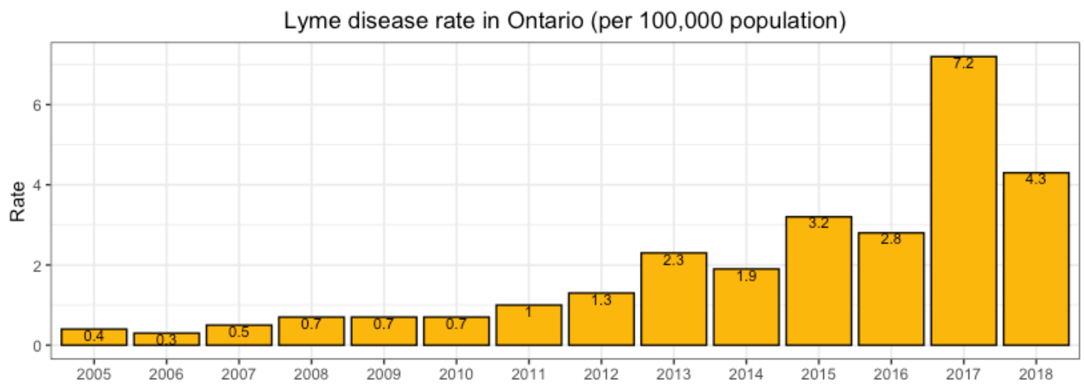
To analyze relationships between reported LD occurrence in Ontario (2005-2018) and climate covariates, the INSTITUTE facilitated access to daily temperature and precipitation data for weather stations in that province from Environment and Climate Change Canada. LD occurrence data come from Ontario Public Health.

Over 2005 to 2018, LD cases have been reported in almost all Ontario Public Health Units (PHU), although the number of cases is spatially variable.

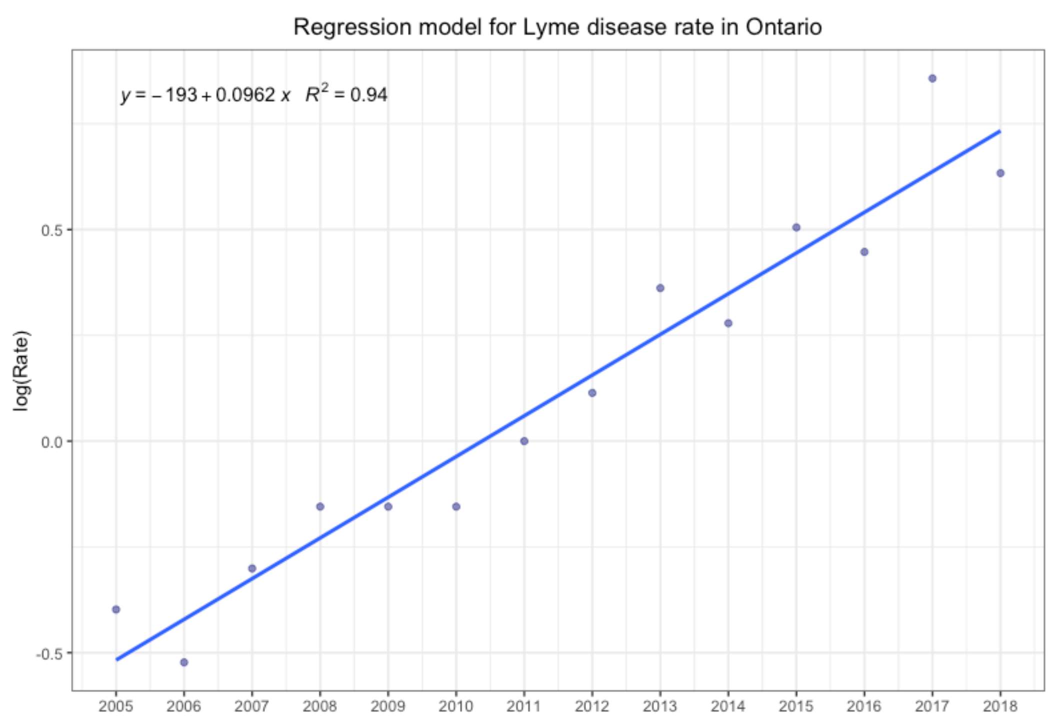


Province-wide, both number of reported cases and rate have increased between 2005 and 2018.





A regression model was fitted to understand the trend of LD rate over time. A good fit was achieved by log transforming the rate of reported LD, this means the growth is exponential (see Figure 1).



To analyze the relationship between climate and LD a regression model was developed with specific data for each region or Public Health Unit. We did not find clear trends in annual average temperature or total precipitation for the time period of interest, therefore, these variable were not included in the model, which instead focused on cumulative degree days above zero. The regression analysis by Public Health Unit included a time-fixed effect, resulting in the formula:

$$LymeRate_{it} = \beta_1 CumulativeDegreeDaysabove0C_{it} + TimeFixedEffects + u_{it}$$

The Cumulative Degree Days above 0°C appears statistically significant at the 95% confidence interval in 14 out of the 33 Public Health Units that were analyzed (Brant County Health Unit was excluded because of uncertainties in the weather station data provided). The tables below show the summaries of the regression model for each of these Public Health Units:

Chatham-Kent Public Health

MODEL FIT:

$F(2,12) = 8.30470$, $p = 0.00545$

$R^2 = 0.58056$

Adj. $R^2 = 0.51065$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00044	0.00015	-2.96985	0.01170*
Year	0.00079	0.00060	1.31984	0.21151

City of Hamilton Public Health Services

MODEL FIT:

$F(2,12) = 8.81545$, $p = 0.00441$

$R^2 = 0.59502$

Adj. $R^2 = 0.52752$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00004	0.00001	-2.53684	0.02609*
Year	0.00004	0.00008	0.53085	0.60521

Grey Bruce Health Unit

MODEL FIT:

$F(2,12) = 13.73172$, $p = 0.00079$

$R^2 = 0.69592$

Adj. $R^2 = 0.64524$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00010	0.00003	-2.79717	0.01613*
Year	0.00004	0.00054	0.07918	0.93820

Haliburton, Kawartha, Pine Ridge District Health Unit

MODEL FIT:

$F(2,12) = 3.74810$, $p = 0.05437$

$R^2 = 0.38450$

Adj. $R^2 = 0.28191$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00013	0.00005	-2.45293	0.03043*
Year	0.00066	0.00044	1.51143	0.15656

Huron Perth Health Unit

MODEL FIT:

$F(2,12) = 11.70739$, $p = 0.00151$

$R^2 = 0.66116$

Adj. $R^2 = 0.60468$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00031	0.00012	-2.66659	0.02054*
Year	0.00007	0.00056	0.11733	0.90854

Kingston, Frontenac and Lennox & Addington Public Health

MODEL FIT:

$F(2,12) = 45.57340$, $p = 0.00000$

$R^2 = 0.88366$

Adj. $R^2 = 0.86427$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00009	0.00002	-4.92850	0.00035***
Year	0.00123	0.00017	7.37984	0.00001***

Leeds, Grenville & Lanark District Health Unit

MODEL FIT:

$F(2,12) = 17.79258$, $p = 0.00026$

$R^2 = 0.74782$

Adj. $R^2 = 0.70579$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00029	0.00006	-5.28095	0.00019***
Year	0.00285	0.00049	5.83087	0.00008***

Niagara Region Public Health

MODEL FIT:

$F(2,12) = 35.26630$, $p = 0.00001$

$R^2 = 0.85460$

Adj. $R^2 = 0.83037$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00004	0.00000	-8.33767	2.46e-06***
Year	0.00053	0.00006	8.19587	2.93e-06***

Ottawa Public Health

MODEL FIT:

$F(2,12) = 8.45841$, $p = 0.00511$

$R^2 = 0.58502$

Adj. $R^2 = 0.51585$

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00013	0.00004	-3.39458	0.00532**
Year	0.00085	0.00022	3.89226	0.00214**

Peterborough Public Health

MODEL FIT:

```
F(2,12) = 8.14749, p = 0.00582
R² = 0.57590
Adj. R² = 0.50521

Standard errors: OLS
--------------------------------------------------------------
                            Est.       S.E.     t val.          p
------------------- ---------- --------- ---------- ---------
cumulative_dd         -0.00035   0.00012   -2.97169   0.01166*
Year                   0.00088   0.00062    1.41039   0.18382
--------------------------------------------------------------
```

Public Health Sudbury & Districts

```
MODEL FIT:
F(2,12) = 18.79030, p = 0.00020
R² = 0.75797
Adj. R² = 0.71763

Standard errors: OLS
--------------------------------------------------------------
                            Est.       S.E.     t val.          p
------------------- ---------- --------- ---------- ---------
cumulative_dd         -0.00021   0.00009   -2.27616   0.04197*
Year                   0.00091   0.00114    0.79758   0.44061
--------------------------------------------------------------
```

Renfrew County and District Health Unit

```
MODEL FIT:
F(2,12) = 2.83415, p = 0.09816
R² = 0.32082
Adj. R² = 0.20762

Standard errors: OLS
--------------------------------------------------------------
                            Est.       S.E.     t val.          p
------------------- ---------- --------- ---------- ---------
cumulative_dd         -0.00020   0.00009   -2.26200   0.04306*
Year                   0.00119   0.00065    1.84871   0.08928
--------------------------------------------------------------
```

Toronto Public Health

```
MODEL FIT:
F(2,12) = 11.12984, p = 0.00185
R² = 0.64973
```

Adj. R^2 = 0.59136

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00009	0.00002	-4.49101	0.00074***
Year	0.00035	0.00009	4.03006	0.00167**

York Region Public Health

MODEL FIT:

$F(2,12)$ = 10.43725, p = 0.00237

R^2 = 0.63498

Adj. R^2 = 0.57414

Standard errors: OLS

	Est.	S.E.	t val.	p
cumulative_dd	-0.00037	0.00010	-3.81589	0.00246**
Year	0.00097	0.00036	2.72732	0.01836*

Signif. codes: 0 '*' 0.001 '**' 0.01 '***

Although in these Public Health Units the cumulative degree days variable is statistically significant, the adjusted R^2 in most cases is < 0.7. Therefore, other variables or factors are necessary to more fully explain the variation in the dependent variable (LD rate). Additionally, there are limits in using such a short time period to examine LD and climatic relationships.

Appendix IV

Projected expected (undiscounted) life-time costs for valuation of new incident cases of Lyme disease diagnosed in 2016, 2055 and 2085 (chronic effects included)

	Low ($ 2015 per case)	Central ($ 2015 per case)	High ($ 2015 per case)
2016	60,280	*204,040	501,860
2050s	63,675	**214,875	527,725
2080s	66,830	***225,280	553,300

Note: * 5% are resource costs, 7% are opportunity costs and 88% are disutility costs; ** 8% are resource costs, 6% are opportunity costs and 86% are disutility costs; *** 9% are resource costs, 7% are opportunity costs and 84% are disutility costs.

Endnotes

[1] Warren and Lemmen (2014); Watts et al. (2019); Watts et al. (2018).

[2] Seguin (2008); Watts et al. (2019); Watts et al. (2018).

[3] Hong et al. (2012); Leighton et al. (2012); Ogden et al. (2006); IPCC (2014).

[4] Warren and Lemmen (2014); Watts et al. (2018); Austin et al. (2015); Kinney (2008).

[5] Warren and Lemmen (2014); Arnfield (2003).

[6] Smith et al. (2014); Wesche and Chan (2010); Guyot et al. 2006.

[7] Beaumier and Ford (2010).

[8] Gregory et al. (2005).

[9] Dellink et al. (2014); OECD (2015); Kompas et al. (2018).

[10] Ciscar et al. (2011); Ciscar et al. (2014); Szewczyk et al. (2018).

[11] EPA (2017); Steininger et al. (2016).

[12] Larrivée et al. (2015).

[13] COACCH (2018); Roson and Sartori (2016).

[14] See Dell et al. (2014); Kjellstrom et al. (2015); Heal and Park (2016); or Newell et al. (2018) for a review).

[15] Kjellstrom et al. (2009); Kjellstrom et al. (2013); Dunne et al. (2013); Zivin and Neidell (2014).

[16] Zivin and Neidell (2014).

[17] See, for example, Kahn et al. (2019).

[18] PESETA refers to Projections of Economic impacts of climate change in Sectors of the EU based on bottom-up Analysis.

[19] Horricks (2006); Paci (2014).

[20] Kovats et al. (2011).

[21] OECD (2020, 2020a).

[22] Judek et al. (2019).

[23] Basu and Samet (2002); Turner et al. (2012); and Ye et al. (2012)

[24] Michelozzi et al. (2009); Bayentin et al. (2010); Vida et al. (2012); Lian et al. (2015); and Bai et al. (2016, 2017)

[25] Paci (2014).

[26] Kovats et al. (2011).

[27] Saha et al. (2014)

[28] Hajat et al. (2005); and Saha et al. (2014)

[29] Health Canada (2019)

[30] WHO (2016).

[31] Health Canada (2019)

[32] Berry et al. (2014).

[33] Leung (2015).

[34] Brown-Steiner et al. (2015); Rasmussen et al. (2012).

[35] Pusede et al. (2015).

[36] Bloomer et al. (2009); Rasmussen et al. (2012).

[37] Sillman and Samson (1995).

[38] Pusede et al. (2015).

[39] Ito et al. (2009).

[40] Leung et al. (2015); Reuten et al. (2012)

[41] Dawson et al. (2008); Avise et al. (2012); Pfister et al. (2014); Fann et al. (2015); Brown-Steiner et al. (2015)

[42] Heald et al. (2008); Abel et al. (2017).

[43] Leung et al. (2012).

[44] Adam-Poupart et al. (2015).

[45] Cheng et al. (2008); Cheng et al. (2008a).

[46] Cheng et al. (2008a).

[47] EPA (2017).

[48] Marbek (2011).

[49] Judek et al. (2019).

[50] Judek et al. (2019).

[51] Greig et al. (2015)

[52] Gasmi et al. (2019)

[53] Greig et al. (2015)

[54] PHO (2016)

[55] PHAC (2015)

[56] Gasmi et al. (2017)

[57] IBIDEM

[58] Ogden et al. (2006), Leighton et al. (2012), Clow et al. (2017), Ebi et al. (2018)

[59] Ogden et al. (2014)

[60] Leighton et al. (2012)

[61] Wu et al. (2013)

[62] Greig et al. (2018)

[63] Wallace et al. (2019)

[64] Simon et al. (2014)

[65] Gasmi et al. (2019)

[66] McPherson et al. (2017)

[67] Wallace et al. (2019)

[68] USGRP (2018)

[69] Nelder et al. (2017)

[70] Statistics Canada - ftp.maps.canada.ca/pub/statcan_statcan/Census_Recensement/census-division-2016_division-recensement-2016

[71] Natural Earth (1:10 Million scale)

[72] Digital Elevation Model - Canada 3d - ftp.maps.canada.ca/pub/nrcan_rncan/elevation/canada3d

[73]Leighton et al. (2012) and see https://www.canada.ca/en/public-health/services/diseases/lyme-disease/risk-lyme-disease.html highlighting geographic areas of greatest risk of exposure.

[74] Kjellstrom et al. (2009); Dunne et al. (2013)

[75] ESDC (2018)

[76] Kjellstrom et al. (2008), Kjellstrom et al., 2015

[77] Heal and Park (2016)

[78] Dell et al. (2012)

[79] Metroeconomica (2006); Horricks (2006); Kovats et al. (2011); Paci (2014); US EPA (2015, 2017)

[80] Drummond et al. (2005)

[81] PHAC (2018)

[82] Drummond et al. (2005)

[83] WHO (2009)

[84] US EPA (2007); and PHAC (2018)

[85]Cropper and Sahin (2009); Hammitt and Robinson (2011); Boyd et al. (2013); Cropper and

Khanna (2014); US DOT (2015); and Robinson and Hammitt (2018).

[86] Kovats et al. (2011) and Paci (2014)

[87] NAS (2008)

[88]Cropper and Sahin (2009); Hammitt and Robinson (2011); Boyd et al. (2013); Cropper and Khanna (2014); US DOT (2015); and Robinson and Hammitt (2018).

[89] Mangen et al. (2013)

[90] See, for example, Zhang et al. (2006); Adrion et al. (2015); van der Wijngaard et al. (2017); and Shing et al. (2018).

[91] Feder et al. (2007); and Marzec et al. (2017).

[92] Feder et al. (2007).

[93] Kugeler et al. (2011).

[94] See OECD (2017).

[95] A Disability-adjusted life year (or DALY) is the product of disease severity and disease duration (in years). The severity of a disease is measured using health questionnaires to elicit disability weights on the interval 0 ('full health') to 1 ('death').

[96] The assumed DALYs for erythema migrans and disseminated Lyme disease (per case) are, respectively, 0.005 [0.002 – 0.008] and 0.113 [0.062 – 0.213]. DALYs for persisting symptoms are 1.663 [1.278 – 2.078].

[97] See Hammitt (2017) and Robinson and Hammitt (2018) for a discussion of the valuation of health-adjusted life years metrics, like DALYs.

[98] Most of the summary results tables provide in Section **Erreur! Source du renvoi introuvable.** adopt this format.

[99] Sheridan (2003); Michelozzi et al. (2007); and Gabriel and Endlicher (2011).

[100] Combined socioeconomic change and climate change.

[101] Combined socioeconomic change and climate change.

[102] Combined socioeconomic change and climate change.

[103] See Kovats et al. (2011).

[104] See Paci (2014).

[105] Combined socioeconomic change and climate change.

[106] Combined socioeconomic change and climate change.

[107] Combined socioeconomic change and climate change.

[108] Combined socioeconomic change and climate change.

[109] Combined socioeconomic change and climate change.

[110] Combined socioeconomic change and climate change.

[111] Combined socioeconomic change and climate change.

[112] Assuming an 8-hour work day, five days per week for 52 weeks per year.

[113] Due to both socioeconomic change and climate change.

[114] Due to both socioeconomic change and climate change.

[115] Due to both socioeconomic change and climate change.

[116] Boyd et al. (2013)

[117] Remember that the proactive adaptation scenario results are based on a single GCM whereas the costs of inaction estimates in Section 8 are based on the ensemble mean of seven GCMs.

[118] Heal and Park (2016)