NRT

NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY

CLIMATE PROSPERITY

A CANADIAN INITIATIVE

PAYING THE PRICE: THE ECONOMIC IMPACTS OF CLIMATE CHANGE FOR CANADA

// REPORT 04

Canada

NRT
NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY

THIS IS NOT JUST ABOUT COPING WITH CLIMATE CHANGE, BUT PROSPERING THROUGH IT.

A CANADIAN INITIATIVE

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NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY
TABLE RONDE NATIONALE SUR L'ENVIRONNEMENT ET L'ÉCONOMIE

ACKNOWLEDGEMENTS

The National Round Table on the Environment and the Economy (NRTEE) is grateful to the generous contributions of expertise from many individuals and organizations. We are particularly grateful to the members of our Advisory Committee who provided invaluable advice and direction as we developed and analyzed the research for this report, and to the many expert stakeholders who participated in our scoping and outreach sessions.

This type of work is necessarily interdisciplinary, in our case requiring an integration of climate, ecological, health, geographic, and economic information. We drew on expertise from many disciplines to inform our research and peer review our findings. These contributions helped us to improve the quality of our report. The final product is that of the NRTEE.

The NRTEE would also like to acknowledge the contributions from key consultancies involved in the research underpinning this report: Metroeconomica Limited, Paul Watkiss Associates, Burton Dickinson Consulting Limited, Marbek Resource Consultants, Van Lantz, David Anthoff, Patrick Kinney, Stockholm Environment Institute – U.S. Center, Industrial Economics Ltd., Paul Chinowsky, ArborVitae Environmental Services Ltd., and Chris Hope.

Finally, thanks to the NRTEE Secretariat staff for their contributions to developing the report. Nadra Meigag and Denise Edwards coordinated numerous stakeholder sessions. Marie-Josée Lapointe, Tony Bégin, Tania Tremblay, Edwin Smith, and Richard Pilon managed the design and production of the report. Will McDowell contributed to scoping the report and establishing a research framework and James Wellstead and Joëlle Boutin provided research support and editorial assistance. Suzanne Loney and Jimena Eyzaguirre steered the research underpinning this report, analyzed findings, convened stakeholders across the country, and prepared drafts. As project lead, Suzanne's contribution was instrumental in producing this fourth report of the *Climate Prosperity* series.

MESSAGE FROM THE VICE-CHAIR

Paying the Price: The Economic Impacts of Climate Change for Canada is the latest report in the *Climate Prosperity* series by the National Round Table on the Environment and the Economy. It complements *Degrees of Change: Climate Warming and the Stakes for Canada*, published in 2010, which shows a vast range of physical impacts of a warming climate on Canada. With these reports, we can better understand the growing economic impacts of climate change to Canada and assess both the costs we could face and the adaptation choices we can make.

Degrees of Change showed what the physical impacts of climate warming could be for Canada; *Paying the Price* shows what the economic impacts could be for Canada. Many of these impacts will be negative and many will carry a cost. Together, these two NRTEE reports will help Canadians know more about what some of those impacts could be and how much they could cost.

Paying the Price sets out to help all of us -- governments, business and communities -- make climate-wise investment choices now, and in the future. The economic information we provide in this report will further help us understand what is at stake if we fail to respond and global greenhouse gas emissions continue to rise.

R.W. SLATER, CM, PH.D.
NRTEE Vice-Chair

MESSAGE FROM THE PRESIDENT AND CEO

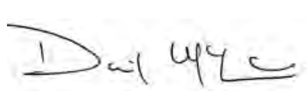
Climate change has a price tag and it could be expensive. But few Canadians know what that could be.

To date, focus has mostly been on what it would cost to reduce greenhouse gas emissions by industry and consumers. Little attention has been paid to the cost of inaction, to what economic damages could accrue to Canada and Canadians as global emissions rise and climate change plays out.

Paying the Price: The Economic Impacts of Climate Change for Canada sets out for the first time ever in Canada what those costs could be. This report makes clear that while there is an environmental cost to climate change, there is an economic cost too: of simply letting climate impacts occur. Those costs are high and could get higher.

Our report also shows that adapting to climate change makes economic sense. It can lower the costs of climate impacts by preventing damage, saving money and lives.

The Round Table's report now makes clear that getting global emissions down is both in Canada's economic and environmental interest.



DAVID McLAUGHLIN
NRTEE President and Chief Executive Officer

ABOUT US

Emerging from the famous Brundtland Report, *Our Common Future*, the National Round Table on the Environment and the Economy (NRTEE or Round Table) has become a model for convening diverse and competing interests around one table to create consensus ideas and viable suggestions for sustainable development. The NRTEE focuses on sustaining Canada's prosperity without borrowing resources from future generations or compromising their ability to live securely.

The NRTEE is in the unique position of being an independent policy advisory agency that advises the federal government on sustainable development solutions. We raise awareness among Canadians and their governments about the challenges of sustainable development. We advocate for positive change. We strive to promote credible and impartial policy solutions that are in the best interest of all Canadians.

We accomplish that mission by fostering sound, well-researched reports on priority issues and by offering advice to governments on how best to reconcile and integrate the often divergent challenges of economic prosperity and environmental conservation.

The NRTEE brings together a group of distinguished sustainability leaders active in businesses, universities, environmentalism, labour, public policy, and community life from across Canada. Our members are appointed by the federal government for a mandate of up to three years. They meet in a round table format that offers a safe haven for discussion and encourages the unfettered exchange of ideas leading to consensus.

We also reach out to expert organizations, industries, and individuals to assist us in conducting our work on behalf of Canadians.

The *NRTEE Act* underlines the independent nature of the Round Table and its work. The NRTEE reports, at this time, to the Government of Canada and Parliament through the Minister of the Environment. The NRTEE maintains a secretariat, which commissions and analyzes the research required by its members in their work.

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NRTEE PRESIDENT AND CEO

David McLaughlin

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0.0 EXECUTIVE SUMMARY

Climate change will be expensive for Canada and Canadians. Increasing greenhouse gas emissions worldwide will exert a growing economic impact on our own country, exacting a rising price from Canadians as climate change impacts occur here at home.

This report by the National Round Table on the Environment and the Economy (NRTEE) — the fourth in our *Climate Prosperity* series — sets out what those costs could be. It makes clear that while there is an environmental cost to climate change, there is an economic cost too: a cost of letting climate impacts occur and a cost to adapting to protect ourselves from these impacts.

Having highlighted some of the likely physical impacts of warming temperatures and changing precipitation patterns from climate change in Canada in our second report, *Degrees of Change*, we undertook new analysis to assess the economic costs in this companion report, *Paying the Price*.

This report represents the first time a national analysis of this kind, using various climate and growth scenarios, has been conducted to calculate how the economic costs of climate change stack up over time. This is necessary research that allows Canadians to appreciate just how pervasive and pernicious climate change can be. It shows the uncertainty of estimating economic impacts of climate change and increases our understanding of how to assess climate risk and our own willingness to accept — or not — the probability of more damages for future generations. It then identifies how adaptation measures can reduce those costs, saving money and lives.

THE NATIONAL COST OF CLIMATE CHANGE

Climate change costs for Canada could escalate from roughly $5 billion per year in 2020 — less than 10 years away — to between $21 billion and $43 billion per year by the 2050s. The magnitude of costs depends upon a combination of two factors: global emissions growth and Canadian economic and population growth. Our study generated four separate scenarios combining these factors to understand the potential costs of climate change under different futures.

As the speed and scale of climate change is uncertain, we need to consider the probability of both higher and lower costs. The NRTEE's research sheds new light on how to assess national economic risks. Our modelling shows not just the average results listed above, but what those economic costs could be as climate change plays out under a range of assumptions for key scientific and economic variables. It shows there is a risk those costs could be not just higher, but much higher. In the 2050s, where costs are estimated at $21 billion in the low climate change–slow growth scenario, there is a 5% chance that the costs could be at least $44 billion per year, and where costs are estimated at $43 billion in the high climate change–rapid growth scenario, there is a 5% chance that the costs could be at least $91 billion per year.

How do we get costs down? Global mitigation leading to a low climate change future reduces costs to Canada in the long term. This reinforces the argument that Canada would benefit environmentally and economically from a post-2012 international climate arrangement that systematically reduced emissions from all emitters — including Canada — over time.

CLIMATE IMPACTS ON PEOPLE, PLACES, AND PROSPERITY

Because climate change impacts will manifest themselves sectorally and regionally in different ways across our enormous country, the NRTEE conducted specific "bottom-up" studies to assess the costs of climate change on three representative aspects of Canada: its prosperity (timber supply), places (coastal areas), and people (human health).

In each of these three areas, climate change will impose costs for Canada. By the 2050s, the impacts of climate change on the timber supply through changes in pests, fires, and forest growth are expected to cost the Canadian economy between $2 billion and $17 billion per year. The coastal land area exposed to climate change–induced flooding from sea-level rise and increased storminess across Canada by the 2050s is roughly equivalent to the size of the Greater Toronto Area. The costs of flooding from climate change could be between $1 billion and $8 billion per year by the 2050s. Climate change will lead to warmer summers and poorer air quality, resulting in increased deaths and illnesses in the four cities studied — Montréal, Toronto, Calgary, and Vancouver. Illnesses associated with climate change impacts on air quality in turn will impose costs on the health care system; in Toronto these costs could be between $3 million and $11 million per year by the 2050s.

Our analysis shows that the costs of climate change on people, places, and prosperity will vary and be uneven across the country. Timber supply in Western Canada will be more affected than in the East. British Columbia's forest-reliant economy will suffer more than many others while Ontario's economy — due to its size — will see the largest absolute economic impact. Coastal regions across Canada are also affected differently by climate change. Relative to the total land area of each province and territory, Prince Edward Island's coastal areas are most at risk. Many dwellings in the Lower Mainland of British Columbia are likely to be impacted given

that the area is low-lying and has a high housing density, and the per capita costs of dwelling damage will be highest in British Columbia and Nunavut. Human health impacts and increased health system costs from climate change vary across the four cities we studied, with cities that experience the greatest increases in temperature — Toronto and Vancouver — experiencing the greatest impacts.

ADAPTATION SAVES MONEY

Adapting to climate change is both possible and cost-effective. Halting emissions growth tomorrow will do nothing to arrest the impacts of GHGs already in the atmosphere. So, some form of climate change impacts due to global warming can be expected, requiring adaptation measures in response. Our study examined five different adaptation strategies to assess their costs and benefits. All but one was found to be cost-effective, with the costs of the strategies being far lower than the savings they would yield through reducing the economic impacts of climate change.

Enhancing forest fire prevention, controlling pests, and planting climate-resilient tree species together reduced the impacts of climate change on timber supply across the country. Under a high climate change–rapid growth scenario, the benefit to cost ratio was 38:1 while it was 9:1 under a low climate change–slow growth scenario. In coastal areas, prohibiting new construction in areas at risk of flooding as well as undertaking "strategic retreat" by gradually abandoning dwellings once flooded reduces the costs of climate change to only 3–4% of what the costs would have been without adaptation. Adaptation strategies can reduce prospective health impacts of heat exposure and lower air quality. Replacing conventional roofs with green roofs helped reduce the urban heat-island effect across our four cities, but the costs of this strategy exceeded the benefits. In contrast, installing pollution control technologies to limit ozone formation was found to be cost-effective.

ECOSYSTEMS

Ecosystems provide us with a range of services critical to our health, economy, and overall well-being, but climate change is altering the quality and health of Canada's ecosystems. Our report illustrates some possible economic implications of climate change on ecosystem services: climate change could increase visitor spending in and around Canada's national parks due to warmer temperatures, and reduced availability of lake trout could lead to losses in recreational fishing expenditures. While ecosystem services, and the impact that climate change will have on them, can be very difficult to express in economic terms, a failure to do so underestimates the costs of climate inaction. At the same time, it is important to recognize that non-monetary indicators may matter more to people when it comes to preserving ecosystems —their "value" is often intrinsic and personal. Ecosystem losses can simply be irreplaceable.

TWO FUTURES

Examining long-term economic costs of climate change to Canada raises the spectre of two futures: one where the world acts — and keeps global warming to 2°C by 2050 as world leaders have pledged — and one where it doesn't and climate change impacts grow and accelerate beyond targets. At slightly under 2°C of global warming, the economic costs of climate change to Canada in 2050 would be between $21 billion and $43 billion with no adaptive action taken; costs could be at the lower end of range if economic growth slowed as part of domestic mitigation or for other reasons. If the world acts to limit warming to 2°C, future costs could stabilize around this 2050 level since emissions growth would have been dampened and plateaued to reach this new global reality.

WHAT DO WE RECOMMEND?

Canadians can and should use economic information to decide how to best prepare for, and respond to, the impacts of climate change. Our recommendations are as follows:

1 // The Government of Canada invest in growing our country's expertise in the economics of climate change impacts and adaptation so we have our own Canadian-focused, relevant data and analysis for public and private-sector decision makers.

2 // The Government of Canada cost out and model climate impacts to inform internal decisions about adapting policies and operations to climate change and allocating scarce resources to programs that help Canadians adapt.

3 // Governments at all levels continue investing in generating and disseminating research to inform adaptation decision making at the sectoral, regional, and community level. This research should, as a matter of routine, incorporate economic analysis of the costs and benefits of options to adapt to climate impacts because the current data is insufficient for decision makers and is not readily or consistently available.

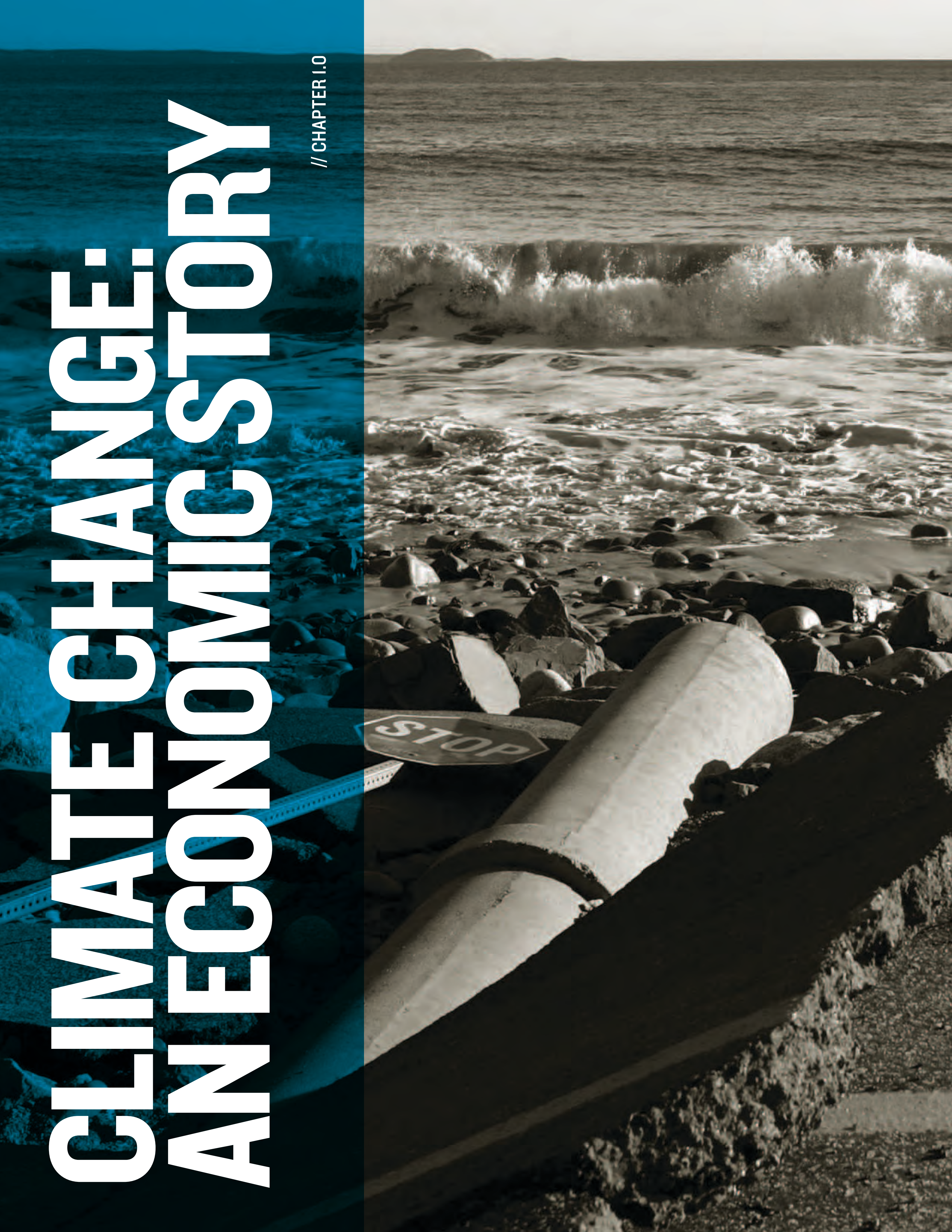
4 // The Government of Canada forge a new data- and analysis-sharing partnership with universities, the private sector, governments, and other expert bodies to leverage unique and available non-governmental resources for climate change adaptation.

WHAT'S NEXT?

Knowing the economic risks of climate change is one thing; acting to reduce them through adaptation is another. The NRTEE's fifth report in its *Climate Prosperity* series will examine the state of readiness of Canada's private sector to manage the impacts of climate change and what the private sector can and should do to reduce its own risk and exposure to climate change. We will analyze various risk management practices to build business resilience to climate change and barriers to putting them in place. And we will consider how government can cost-effectively promote private-sector adaptation, what businesses need from government to plan and adapt, and how government can most usefully contribute to this growing, long-term, shared challenge facing our country.

// CHAPTER 1.0

CLIMATE CHANGE: AN ECONOMIC STORY



1.0 // CLIMATE CHANGE: AN ECONOMIC STORY

1.1 WHAT'S AT STAKE

Climate change has a price tag.

But few Canadians know what that could be. To date, focus has mostly been on what it would cost to reduce greenhouse gas emissions by industry and consumers. Little attention has been paid to the cost of inaction, to what economic damages could accrue to Canada and Canadians as climate change plays out.

This matters. For one, we have a clear interest in reducing the negative economic consequences of climate change by adapting to impacts in cost-effective ways. So it's important to understand what the "cost of climate change" from increasing global emissions could amount to and what the implications of taking action to avoid these costs could be. For another, understanding what the scale of the costs of climate change could be makes us realize that we have a clear economic stake in reducing global greenhouse gas emissions. Both the physical impacts on our environment and the economic damages on our prosperity from climate change will only increase in the decades ahead. Canada's limited but real contribution to global greenhouse gas emissions masks the growing negative economic impact of overall world emissions on us. Reducing those emissions is not just in our environmental interest but, as our report shows, in our economic interest as well.

1.2 OUR CONTRIBUTION

Paying the Price: the Economic Impacts of Climate Change for Canada is the fourth report in the *Climate Prosperity* series by the National Round Table on the Environment and the Economy. It complements *Degrees of Change: Climate Warming and the Stakes for Canada*, published in 2010, which shows a vast range of physical impacts of a warming climate on Canada. With these reports, we can better understand the growing economic impacts of climate change to Canada and assess both the costs we could face and the adaptation choices we can make.

A growing body of research on the economic costs of climate change is amassing internationally, but less so in Canada. Canada has conducted remarkably little economic analysis to date on climate change impacts and the costs and benefits of adaptation. Much of the economic analysis undertaken in this country to date has focused on the costs of reducing greenhouse gases here in Canada, rather than the costs of climate change impacts themselves from rising global emissions. This needs to change.

The NRTEE believes that to both cope and prosper through climate change, we need better information on the costs of climate change impacts. We need to improve our understanding of the risks and opportunities we could face, including the opportunity to reduce costs by adapting to climate change impacts. So far, the amount of adaptation to future changes in climate taking place in Canada is small relative to what will likely be needed.[1] Public- and private-sector decision makers more readily see the costs of adapting to climate change as a key barrier to moving forward; less obvious is the cost of *not* adapting.

This report helps fill this knowledge gap by exploring, for the first time, the costs of climate change for the country as a whole, together with the costs of climate change with and without planned adaptation for three important impact areas: timber supply, coastal areas, and human health. We also discuss the economic implications of ecosystem impacts of climate change.

WE UNDERTOOK THIS RESEARCH AND ANALYSIS WITH THREE GOALS IN MIND:

FIRST, increase awareness of the costs we can expect from climate change. Climate change will impose costs on Canada. We need to prepare to face these costs and invest in actions that reduce costs to the extent possible. But what might those costs be? Our report explores this question.

SECOND, demonstrate that both domestic adaptation and global mitigation can reduce the costs of the impacts of climate change. We compare the costs and benefits of adaptation to the costs of some impacts of climate change to show that adaptation can save us money. Our analysis also shows the difference in costs Canadians could face with higher and lower levels of global greenhouse gas emissions, demonstrating that actions that curb global emissions can reduce the costs of impacts for us in the long run.

THIRD, encourage further exploration of the costs of climate change at the sectoral and regional level. Our analysis is one contribution to this field. By necessity, our coverage of climate change impacts and sectors assessed in this report is limited. Most decisions taken to adapt to climate change impacts are context and site-specific, requiring a more detailed analysis than what is possible at a national level. Our intention is that by documenting our approaches to developing these cost estimates we will inspire others.

1.3 OUR APPROACH

TO ACHIEVE THESE GOALS, WE USED TWO COMPLEMENTARY RESEARCH APPROACHES:

FIRST, we conducted *top-down* economic analysis that estimates the potential costs of climate change for the country as a whole. These high-level estimates give a sense of the scale of the challenge and the difference in costs that could be faced depending on future global greenhouse gas emissions under various scenarios. We also used this analysis to highlight the large degree of uncertainty and risk that underlies this type of costing work.

SECOND, we conducted *bottom-up* analysis that estimates the economic consequences of climate change for three specific impact areas — timber supply, coastal areas, and human health — and the relative costs and benefits of adaptation. Bottom-up studies are most helpful for informing decision making on adaptation because they connect the costs of climate change to particular sectors and regions where they will be felt most. Where possible our analyses are national in their scope. We used a common analytical framework to ensure a consistent approach to the research and, where possible, a consistent presentation of results across these studies (see **Appendix 8.1**). We also explore how climate change could impose costs through impacts on Canada's ecosystems.

With both our top-down and bottom-up analysis, we explore the costs that climate change could impose on Canada. Where there may be benefits in specific impact areas, we draw attention to these also. Studies of other impact areas such as energy demand or agriculture may identify other economic benefits from climate change.

OUR APPROACH TO CONSIDERING THIS ISSUE IS BASED ON WELL-UNDERSTOOD LIMITATIONS:

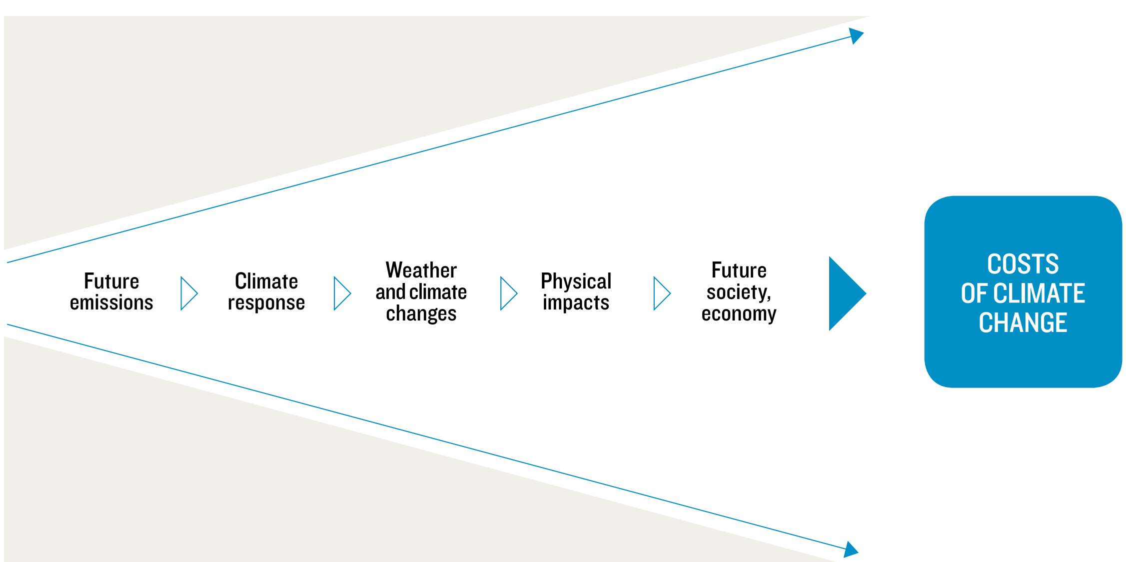
FIRST, economics is not a perfect tool for understanding the impacts of climate change or for deciding how to respond. When it comes to impacts on health, ecosystems, and culture (among other areas), expressing the impacts of climate change in dollar values is not always meaningful to people. Also, most of our costing methods consider incremental costs resulting from small changes in climate change impacts, but these methods are not appropriate when applied to major shifts in components of the earth's system, such as the global climate. In spite of these limitations, economics — combined with other information — is essential to appreciating the scope of what climate change portends and to help make societal choices on how to deal with it.

SECOND, there are many types of "costs" of climate change, some of which are more readily monetized than others. Economic value can be broken up between "use values" and "non-use values."[2] Use values are, for the most part, familiar to us and to our pocketbooks. Within this wide category of costs, we include goods and services with a market price like replacement costs of dwellings damaged from a flood or timber losses from wildfires. Also within this category of costs, we include ecosystem services like air purification by trees or clean water. We are familiar with these ecosystem benefits but their worth is hard to capture in economic terms because they typically lack market prices. Non-use values are, by comparison, intangible. They refer to our willingness to pay to maintain some service in existence despite no actual, planned or possible use, such as the value we derive from simply knowing that polar bears will be protected from extinction. Our analysis focuses primarily on traditional market values, which is a partial accounting.

THIRD, forecasting the economic impacts of a changing climate is no exact task. Uncertainty pervades every step in any such analysis: we don't know precisely what global greenhouse gas emissions will be in the future, how much or how fast the climate will change, how significant the impacts of climate change will be, how our economy and population will grow and respond to these impacts, or how these impacts will be felt in economic terms. Our analysis relies on the current scientific and economic understanding of climate change, which is incomplete and always being updated. **Figure 1** shows how uncertainty in this sort of analysis can accumulate. But uncertainty is part and parcel of all climate change policy planning. Following the precautionary principle and prioritizing "no-regrets" strategies can help decision makers navigate through the uncertainty, assess degrees of risk, and make sound, cost-effective investment and adaptation decisions.

FIGURE 1

WIDENING UNCERTAINTY IN COSTING THE IMPACTS OF CLIMATE CHANGE



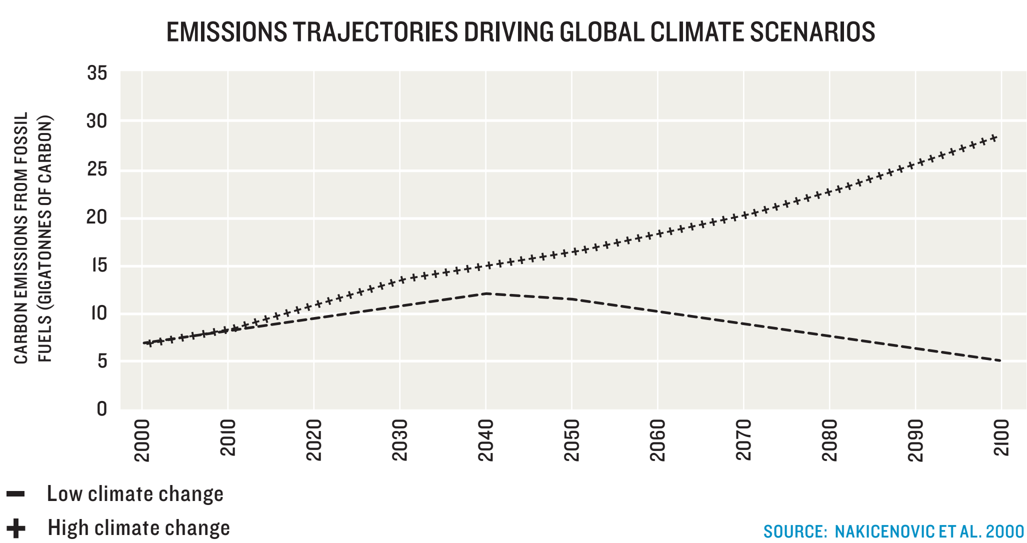
SOURCE: ADAPTED FROM MENNE AND EBI 2006

ASSESSING CLIMATE CHANGE IMPACTS AND STRATEGIES BASED ON A RANGE OF SCENARIOS AND POSSIBLE FUTURES IS CONSIDERED SOUND POLICY PRACTICE.

Knowing this, the NRTEE adopted a consistent, comparable scenario approach throughout our analysis and in this report. Instead of estimating the costs of climate change for only one possible future, we applied scenarios representing four possible futures to our analysis to highlight uncertainty and illustrate a range of future economic outcomes. These scenarios combine two key drivers of change: (1) extent of climate change resulting from global GHG emissions and (2) national rate of population and economic growth in Canada. A brief explanation of our scenario framework follows.

// **EXTENT OF CLIMATE CHANGE:** Our assumptions about global GHG emissions trajectories relied on well-established scenarios of the Intergovernmental Panel on Climate Change (IPCC), representing possible climate futures in the absence of climate mitigation policy.[a,3] The low climate change scenario results from a convergent low-emissions world with a heightened environmental consciousness, a population that peaks by mid-century, accelerated technological advances, service-focused economies, and equitable economic development. The high climate change scenario results from a high emissions world of less economically integrated regions, continued population growth, slow-paced technological change, and slow growth in per-capita incomes. **Figure 2** presents the two hypothetical trajectories of global GHG emissions. In the low climate change scenario, annual emissions start to decline around 2040, but global greenhouse gas concentrations in the atmosphere continue to rise.

FIGURE 2

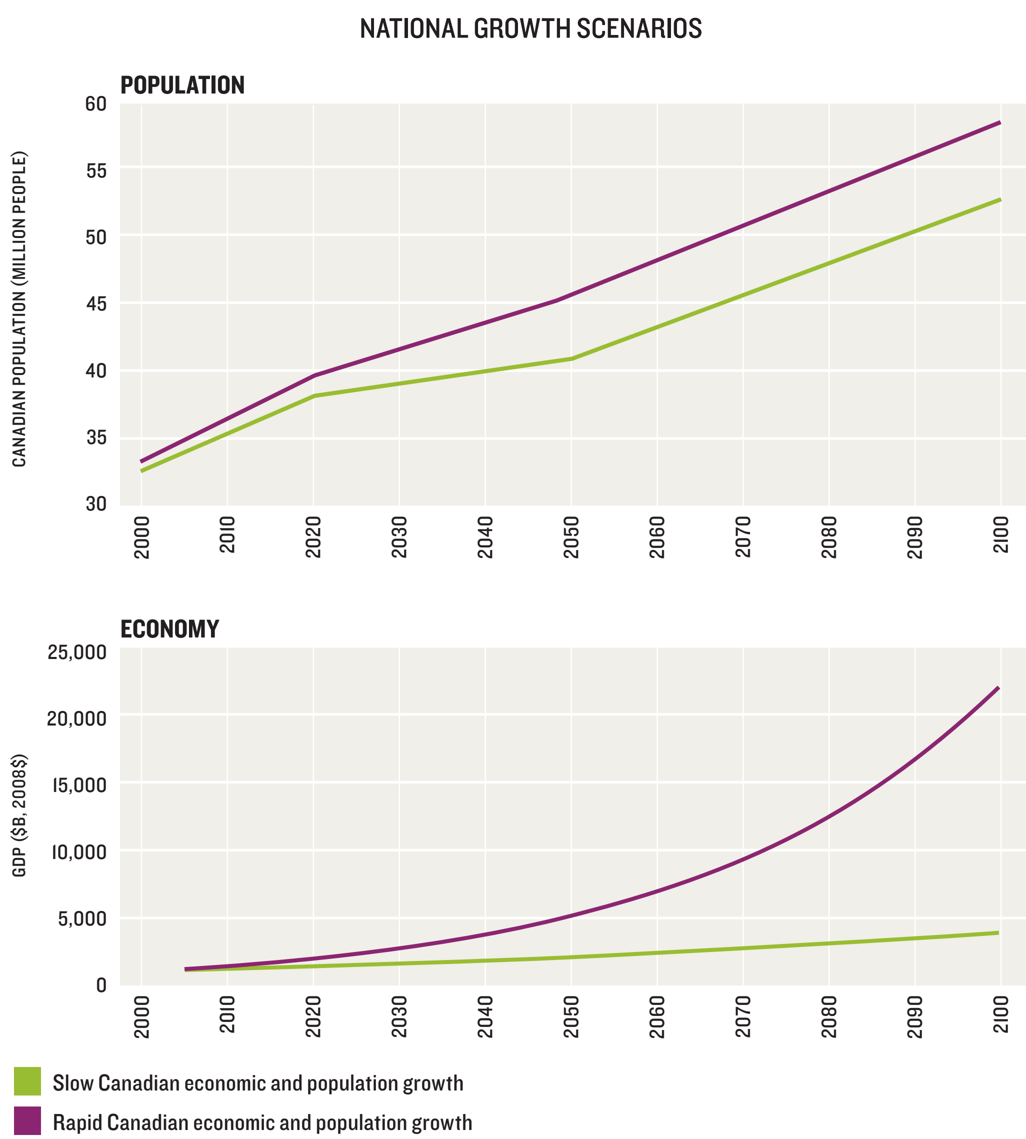


SOURCE: NAKICENOVIC ET AL. 2000

a We used the IPCC "A2" scenario for our high climate change scenario and the "B1" scenario for our low climate change scenario.

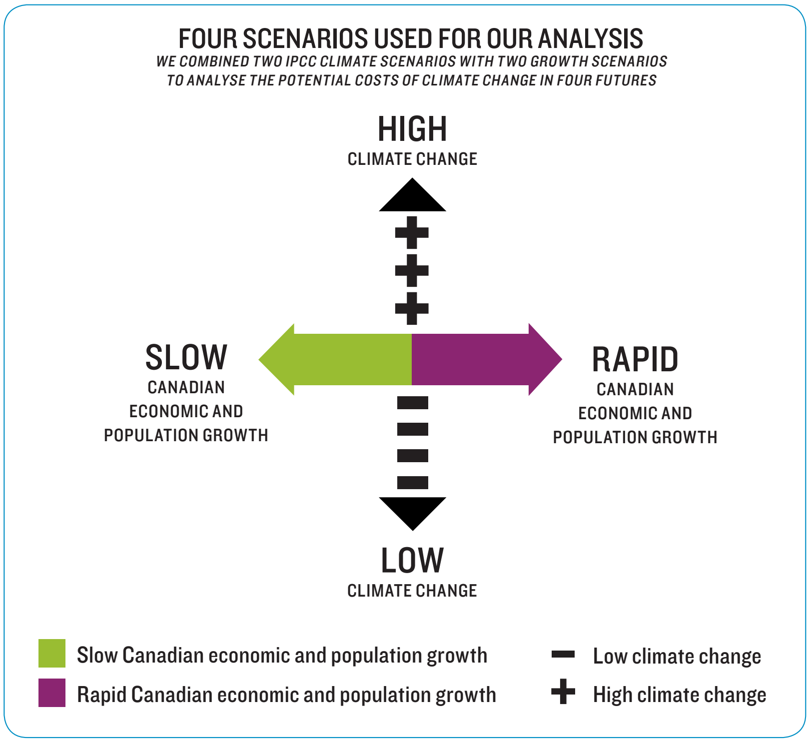
// **RATE OF POPULATION AND ECONOMIC GROWTH IN CANADA:** To our assumptions of global climate futures, we overlay a distinct set of assumptions about Canada's future population and economic growth. We use "slow growth" and "rapid growth" scenarios adapted from the United Kingdom Climate Impacts Program's "local stewardship" and "world markets" scenarios, respectively.[4] Our slow-growth scenario represents a Canada characterized by slow population and economic growth, and our rapid-growth scenario represents the opposite — a Canada with both rapid population and economic growth. **Figure 3** shows our assumptions on population and economic growth for these two scenarios. Annual growth in gross domestic product (GDP) is 1.3% in the slow-growth scenario and 3% in the rapid-growth scenario. When these growth scenarios are overlaid on the climate scenarios, we have four possible futures as shown in **Figure 4**.

FIGURE 3



SOURCE: NRTEE ESTIMATES BASED ON DATA FROM INFORMETRICA AND STATISTICS CANADA

FIGURE 4



Implicit in our selection of population and economic growth assumptions for Canada is the notion that Canada could evolve differently than the rest of the world. So, although global growth patterns determine aggregate emissions levels, we are assuming that Canada's own growth could follow a separate path. The four scenarios allow us to explore the relationship between domestic development, global emission trajectories, and climate change impacts in Canada.

For each scenario, we present results in the near term (next 10 to 20 years), medium term (mid-century) and long term (late century). We present both annual costs and cumulative costs over time. Throughout the report annual costs are not adjusted to present-day terms using a discount rate. They are instead the costs that will be experienced at the future time (in C$(2008)). However, when we present cumulative costs aggregated over the century we use present-value terms, employing a 3% discount rate as recommended by the Government of Canada for this type of analysis.[5]

RESEARCH AND CONVENING: The NRTEE conducted extensive research and convening, bringing together experts, advisers, and stakeholders to augment our understanding of the modelling and research data and analysis produced. This type of work is necessarily interdisciplinary, in our case requiring an integration of climate, ecological, health, geographic, and economic information. No one expert can speak to all the components of this report, so we engaged a wide cross-section of experts and adaptation practitioners to offer advice, input, and commentary as we went along. Their feedback helped identify the best information available for our analysis, the limits of the existing knowledge base, and where we could usefully contribute.

WE EMPLOYED SEVERAL ENGAGEMENT VEHICLES:

1 // **EXPERT SCOPING WORKSHOP:** A group of experts comprising academics and adaptation experts in government and the private sector participated in a workshop in July 2009 to help narrow down topics for sectoral analysis.

2 // **ADVISORY COMMITTEE:** An advisory committee comprising representatives from government, academia, and the private sector provided advice throughout the process.

3 // **EXPERT REVIEW PROCESS:** Individuals from government, academia, research organizations, and professional associations knowledgeable in the issues and this type of analysis reviewed our commissioned studies and this final report.

4 // **STAKEHOLDER ENGAGEMENT SESSIONS:** We discussed preliminary findings, particularly those with regional significance, with expert stakeholders in five cities in October 2010, to assess their validity and salience.

OUR REPORT HAS THE FOLLOWING STRUCTURE:

CHAPTER 2 presents the estimated costs of climate change for Canada from now to 2075. We show the costs in absolute dollars and relative to the future GDP. We then critically assess the uncertainty underlying these estimates, including the possibility that costs could be much higher than expected.

CHAPTER 3 presents an analysis of the impacts of climate change on the timber supply and the economic consequences of timber supply changes for the Canadian economy. It shows economic consequences with and without planned adaptation.

CHAPTER 4 presents an analysis of the number and value of dwellings that could be flooded across the country's marine coasts due to sea-level rise and increased storminess in a changing climate. It shows economic consequences with and without planned adaptation.

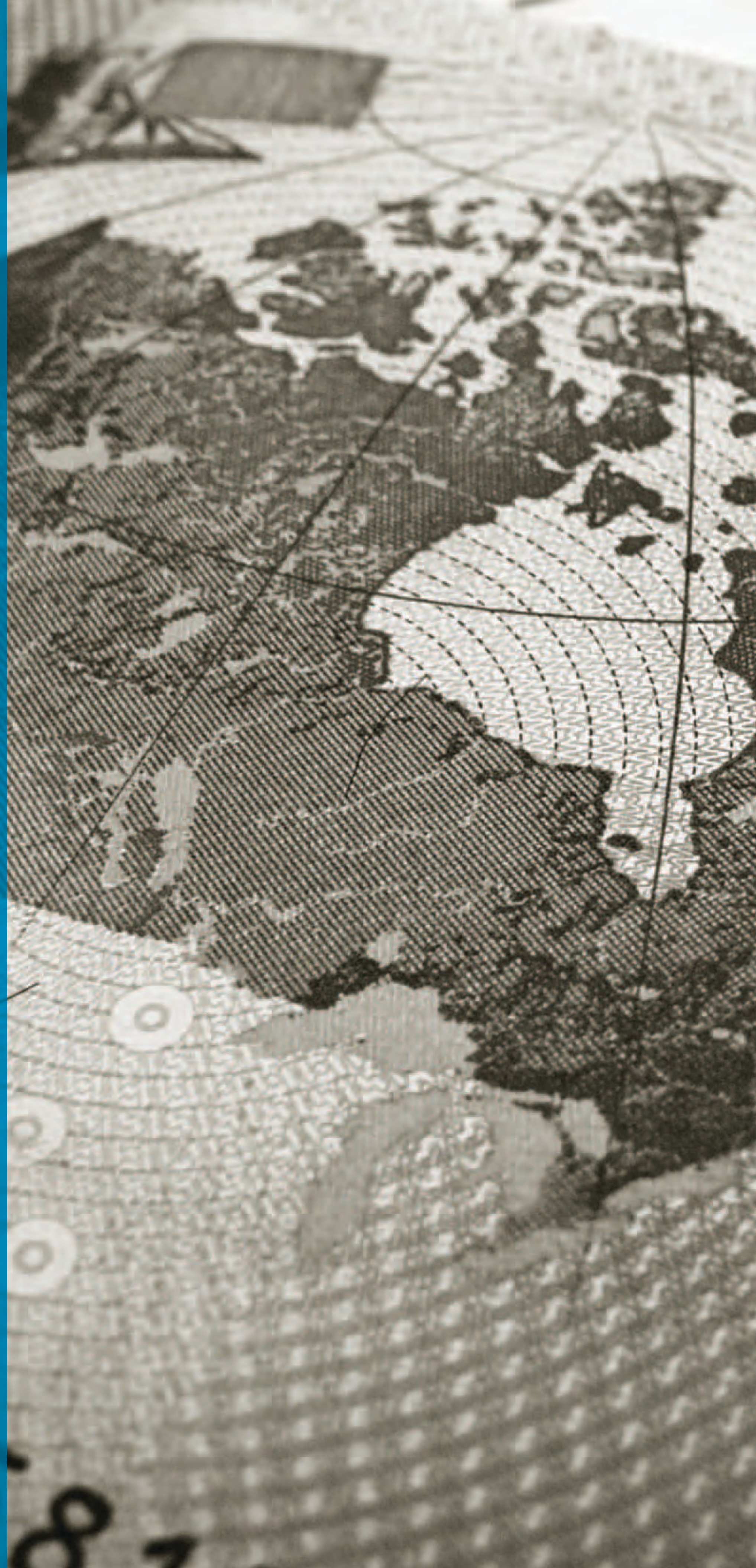
CHAPTER 5 presents an analysis of the social costs and costs to the health care system of illnesses and deaths in four of Canada's cities due to warmer summers and poorer air quality from climate change. It considers how planned adaptation could reduce the incidence of illness and death and lead to welfare savings.

CHAPTER 6 discusses the costs of ecosystem impacts of climate change by way of examples. It explains the limits of economics in shaping our response to climate change.

CHAPTER 7 concludes with the key messages stemming from our analysis, introduces the future work planned at the NRTEE exploring policy pathways to adaptation, and provides recommendations.

CANADA-WIDE COSTS OF CLIMATE CHANGE

// CHAPTER 2.0




CANADA

2.0 // CANADA-WIDE COSTS OF CLIMATE CHANGE

2.1 HOW IS CANADA AFFECTED?

Climate change leads to costs and benefits arising from impacts of gradual changes in temperature, precipitation, and sea levels, as well as from changing patterns of extreme weather and climate events. Could we see economic benefits? How is Canada affected? What will climate change cost Canada?

Many global and country-specific studies assessing climate change impacts and adaptation have been undertaken since the early 1990s, including detailed scientific assessments conducted by the Government of Canada,[6] but economic evidence for Canada is limited. No national-level analysis of this kind has been published until now. Yet, the need for such information is growing. Canada has already warmed more than the global average with warming to date estimated at over 1°C.[7] Physical impacts of warmer temperatures and shifts in precipitation in our country are increasingly well documented, from shrinking polar sea ice to drier conditions in the Prairies and interior of British Columbia. Canada's own geography and hemispheric location are key determinants of just how much we will be impacted.

All countries face some, but unequal, economic risk from the impacts of climate change. The magnitude of those risks is also contingent on capacity to adapt. The IPCC's Fourth Assessment Report concluded that low-latitude and less-developed areas are particularly vulnerable to the impacts of climate change. For example, agricultural yields are expected to decline in seasonally dry and tropical regions, increasing hunger and malnutrition particularly in areas most susceptible to food insecurity, while developing countries are expected to be more vulnerable to sea-level rise due to their limited adaptive capacity.[8] In this context, and considering the capacities we have available to adapt, many of the risks facing Canada may seem minor. What's more, impacts that could be negative in warm countries could be more positive in a colder country like Canada, leading to reduced heating costs in winter and improved agricultural productivity in parts of the country. Studies on the global impacts of climate change have tended to portray Canada at low risk from climate change, and, in some cases, even seeing modest benefits.[9]

Our own assessment shows a different story. The NRTEE analysis suggests that climate change will hit us economically. In a changing climate, temperatures will rise more quickly in polar regions so, on average, we will experience more warming than most countries. We are currently well adapted to cold temperatures: our houses are well insulated and in some parts of the country we have built homes and infrastructure on permafrost. Prairie farmers are accustomed to variability in moisture levels from one growing season to the next, but recent research suggests the potential for more severe and frequent drought and unusually wet years,[10] with implications for future yields. The costs we could incur from climate change are the costs of continuously adjusting to changing conditions. Although harder to calculate and less immediately apparent, they are real and significant and bear understanding.

This chapter provides estimates of the costs that Canada could expect over this century in a changing climate.[b] We show that there is a clear economic link between rising global emissions and how Canada is impacted. These are the costs of *inaction* — possible costs of climate change without concerted global action on mitigation and without significant adaptation domestically. We do not provide an assessment of the relative costs and benefits of mitigation action and inaction as was conducted in earlier international studies like the Stern Review or Garnaut Report.[11] Nor do we compare the costs and benefits of mitigation with the costs and benefits of adaptation. Climate change is real and requires concerted international action involving both mitigation — here and elsewhere — to reduce future emissions and adaptation to live with the climate impact results of past emissions.

Some readers may be inclined to make comparisons between the costs of action and inaction drawing from earlier NRTEE work on the costs of mitigation, or the work of others, and this report on the costs of impacts. These were different reports for different purposes with different modelling and analysis. Such a comparison would not be reliable due to significant technical differences between reports (e.g., time horizon, economic modelling forecasts). Nor would it be meaningful, since climate change is a global problem and any assessment of the economically "optimal" response to climate change should occur at the global level, factoring in all the costs of climate change impacts and mitigation in Canada and abroad as well. Also, choices about the balance of approaches and timing of actions will need to consider adaptive capacity, rigidity of our economies and societies to accommodate change, and our willingness to tolerate irreversible losses like the extinction of iconic wildlife, considerations that are not economic in their nature.

Our estimates are not the last word, but even partial estimates of the costs of climate change for Canada such as these can help shape how Canada and Canadians should respond to climate change. Our estimates demonstrate the potential scale of the economic challenge facing Canada from climate change. They highlight the importance of investing in strategies to adapt to the damages we are likely to incur over the next few decades due to greenhouse gases that have already been emitted, and show the long-term cost implications of future global emissions pathways on Canada.

2.2 MODELLING THE COSTS OF CLIMATE CHANGE

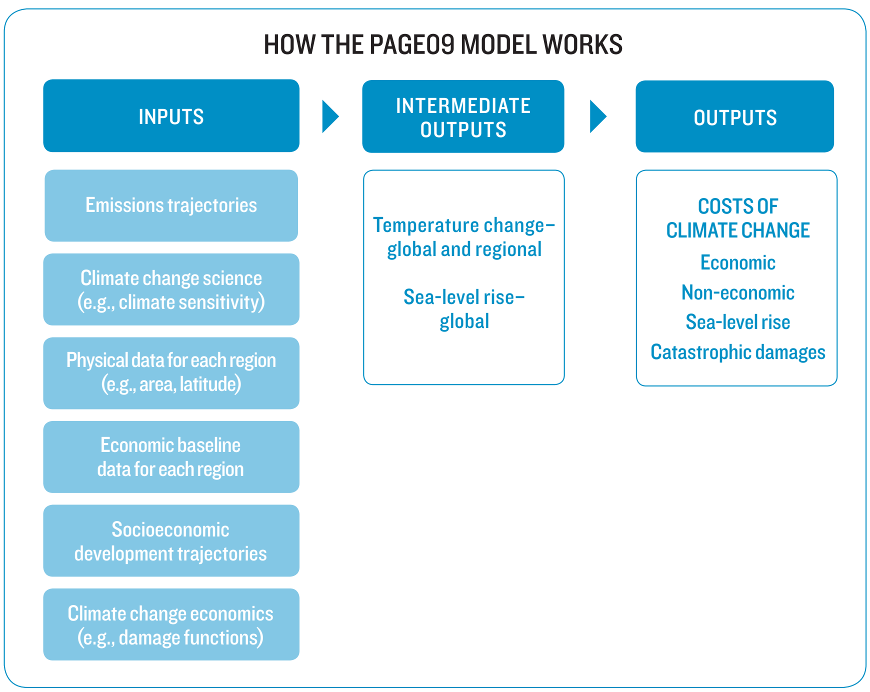
We used the well-established model PAGE (Policy Analysis of the Greenhouse Effect) to explore the costs of climate change for Canada. Initially developed in the early 1990s, the PAGE model has undergone periodic upgrades in line with advancements in the scientific and economic understanding of climate change. Our modelling employs the version completed in summer 2010, PAGE09.[12] We adapted PAGE09 to include Canada as a distinct region in the model.

b A technical report underpinning this chapter was prepared by the NRTEE Secretariat and is available upon request (National Round Table on the Environment and the Economy 2011). It includes more on the PAGE09 model, the results generated, and sensitivity analysis.

SEE CHAPTER I FOR A REMINDER OF OUR SCENARIOS

PAGE09 is a simple representation of a complex problem. It estimates the costs of climate change by integrating forecasts of global emissions, population, and economic growth with climate change science and economics (see **Figure 5**). To be consistent with our sectoral analysis and to focus on the costs for Canada, we isolated Canada as one of the eight world regions in the model and fed in forecasts of the future global emissions and Canadian growth pathways that correspond to each of our SCENARIOS. PAGE09 estimates the extent of warming and sea-level rise resulting from global emissions and monetizes these impacts for four categories: (1) costs to traditional economic sectors; (2) "non-economic" costs, such as those related to health and ecosystem impacts; (3) costs from sea-level rise; and (4) costs from catastrophic damages such a sea-level rise of several metres due to rapid melting of Greenland and West Antarctic ice sheets. Given that PAGE09 uses such broad categories, it is not a tool to identify specific costs and benefits of particular impacts of climate change, but instead to identify the broad costs that climate change could impose.

FIGURE 5



MODELLING THE ECONOMIC IMPACTS OF CLIMATE CHANGE REQUIRES SEVERAL KEY ASSUMPTIONS ABOUT THE SCIENCE AND ECONOMICS OF CLIMATE CHANGE AND THE FUTURE STATE OF THE WORLD:

// **CLIMATE SENSITIVITY:** Scientific research has not pinpointed the precise amount of global warming corresponding to given levels of greenhouse gases in the atmosphere. The majority of estimates of the temperature rise resulting from a doubling of carbon dioxide levels in the atmosphere relative to pre-industrial times are in the range of 2°C to 5°C. PAGE09 allows us to capture this type of uncertainty in our analysis, forecasting a range of possible temperatures.

// **GLOBAL COSTS:** Building on a research report prepared for the Stern Review, which assessed damages from several integrated assessment models,[13] PAGE09 is structured to estimate costs in most regions equivalent to slightly under 2% of GDP per year in response to 3°C of warming. This assumption fundamentally determines the scale of global economic impact that PAGE09 can generate. The model varies the costs among world regions based on wealth, population, forecast temperature change, and relative vulnerability to climate change.

// **CANADA'S VULNERABILITY:** On average, Canada will experience more warming than world regions further from the poles, but exposure to warming doesn't directly translate into impacts or costs. For a host of reasons, heat-related deaths will likely be lower here than in regions with warmer baseline temperatures; damages from sea-level rise are likely to be more acute in regions with more densely populated, low-lying coastlines; and agricultural production in some parts of Canada may fare better in a warmer world than in some other regions. The costs estimated by the model reflect these differences in vulnerability, based on an up-to-date body of evidence that includes our own sectoral analyses presented in the next few chapters. As the evidence base grows, further refinements to our characterization of vulnerability are possible.

// **COSTS OF NON-MARKET IMPACTS:** PAGE09 conceptually captures non-market impacts of climate change such as species extinctions and losses in ecosystem services. Research that monetizes these types of non-market impacts is sparse and incomplete. For example, what would a credible economic value be of "widespread coral mortality" possible at 2.5°C global temperatures above pre-industrial levels?[14] Since humanity's well-being — economic and otherwise — relies on healthy functioning ecosystems, the economic significance of ecosystem impacts of climate change could well dwarf global GDP. By necessity, the coverage of important non-market impacts in the model is limited, and so we could be understating the costs estimated. However, the extent to which a more comprehensive inclusion of non-market impacts would increase costs is unclear.[15] Chapter 6 of our report includes further information on the economics of climate change impacts on ecosystems within Canada.

// **COSTS OF CATASTROPHIC CLIMATE CHANGE:** Scientific understanding of the risks of catastrophic climate change is limited and the corresponding costs even more so. Such rapid climate change and resulting impacts are beyond humanity's collective experience. Not only that, these impacts will likely never be fully anticipated, with surprises likely looming on the horizon. In our modelling we assumed that we only face a chance of catastrophe after a temperature threshold has been crossed (between 2°C and 4°C of global warming) and then the chance of catastrophe grows with every further degree of warming. If catastrophe occurs, then between 5% and 25% of GDP is expected to be lost.

// **ADAPTATION:** To illustrate the economic impacts of climate change itself, our analysis focuses on the cost of *inaction* and therefore assumes that no adaptation takes place. Some degree of adaptation to future climate change will undoubtedly occur without policy intervention but its extent and associated costs were too unclear to formulate defensible assumptions. In this sense our estimates could be overstating what we could expect in terms of costs.

A strength of PAGE09 is its built-in capability to undertake uncertainty analysis. It provides both the average (mean) result and a range of possible results for temperature change, sea-level rise and costs (see **Box 1**). Presenting this range of possible results is essential. It underscores the uncertainty underpinning this type of analysis and helps illuminate the implications of differences in our perception and tolerance of risk. An outcome with an estimated 1 in 20 chance of occurring based on the available information, might be unacceptable to some but not others, due to the magnitude of impacts we could face in that 1 in 20 chance.

BOX 1

CAPTURING UNCERTAINTY IN MODELLING THE COSTS OF CLIMATE CHANGE

Costing the future impacts of climate change requires working with incomplete and uncertain information. Two alternative approaches exist to deal with this inevitable situation:

We can ignore uncertainty and solely rely on best guesses of all model inputs in our costing work, following a "**deterministic**" approach. *This approach combines our best guesses into a single result.* For example, if we think that a rise in global temperatures over pre-industrial times of 3°C would occur at a doubling of carbon dioxide levels in the atmosphere, and that each degree of warming would cost us $1 million, then a doubling of carbon dioxide levels in the atmosphere would cost $3 million. This cost estimate would only hold true if we turned out to be right about our best guesses.

Or, we can explicitly factor in the uncertainty that underlies our best guesses in our costing work, following a "**probabilistic**" approach. *This approach produces a distribution of possible results and provides a range of possible outcomes.* It involves inputting our best guesses along with a range of values we think are possible for each model input. We can use the distributions associated with each model input to generate a distribution of results. Applying the probabilistic approach to the same example, we could assume that the most likely rise in global temperatures at a doubling of carbon dioxide in the atmosphere is 3°C, but it could be anywhere between 2°C and 5°C, and that the most likely cost of each degree of warming is $1 million, but it could be anywhere between $0.5 million and $2 million. Then, if we wanted to know the costs of a doubling of carbon dioxide levels we could say that these costs have a central estimate of $3 million but could be anywhere between $1 million and $10 million.

The probabilistic approach yields richer results than the deterministic approach because they let us know about a range of possible futures rather than one outcome. But, these results are still only as accurate as the information we include in the model. We could introduce bias in the distribution of results we generate and in central estimates by, for example, using too narrow a range of values for a given model input. In time, and with more research, we could find out that the costs of each degree of warming are nowhere near $0.5 million to $2 million, but much higher (or much lower).

We take a probabilistic approach in our modelling for this chapter. For uncertain model inputs, the PAGE09 model includes distributions like the ones described above, with outer limits and a most likely value. Each time we hit "go," the model runs 10,000 times, each time randomly selecting a value from a different point along each uncertain distribution. The model generates a set of results for each of the 10,000 runs and when all these results are combined, we can see the full distribution of possible outcomes — what outcomes are possible and how likely each one is relative to the other possible outcomes.

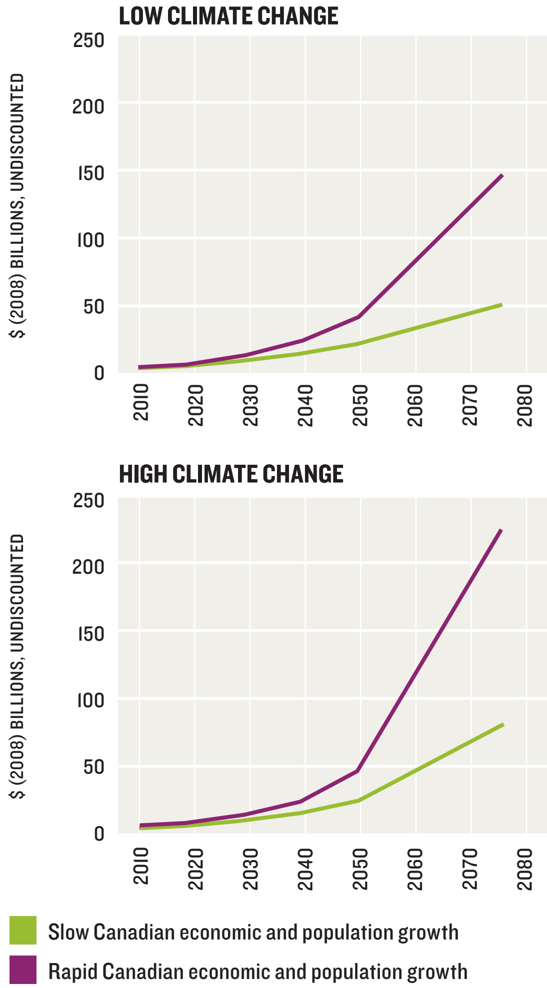
Against this backdrop of assumptions and uncertainties, the PAGE09 model is a powerful tool that highlights the potential scale of the issue to Canada and Canadians, shows trends over time, shows how our future choices can influence future outcomes, and incorporates uncertainty and risk in cost forecasts.

2.3 ECONOMIC CONSEQUENCES OF CLIMATE CHANGE FOR CANADA

In all scenarios, climate change is expected to impose accelerating costs, rising from an average value of $5 billion per year in 2020 to an average value of between $21 billion and $43 billion per year by 2050. **Figure 6** shows the costs out to 2075 in each scenario. The emissions levels in our high and low climate change scenarios start to diverge around 2010 (see **Figure 2**), but the impact of these future emissions on temperatures does not become very large until after 2050, due to the lag time between emissions and warming and inertia among components of the Earth system — climate, ocean, and terrestrial biosphere.[16] Costs are higher with more climate change. On a dollar basis, a richer Canada would face higher costs than in the alternate case, since the value and number of assets exposed to damages from climate change is higher. The combination of high climate change and rapid growth leads to the highest economic cost impacts.

FIGURE 6

AVERAGE ANNUAL COSTS OF CLIMATE CHANGE FOR CANADA



LOW CLIMATE CHANGE

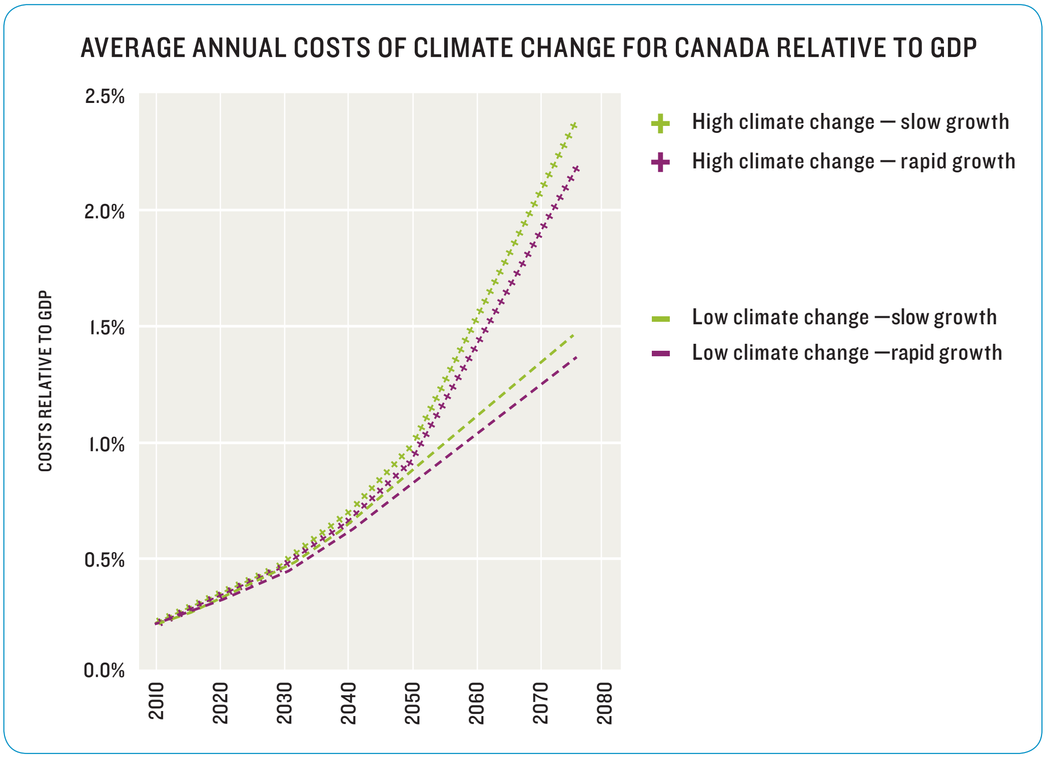
	CANADIAN TEMPERATURE CHANGE	GLOBAL SEA-LEVEL RISE
2020	1.8°C	18cm
2050	3.4°C	28cm
2075	4.3°C	41cm

HIGH CLIMATE CHANGE

	CANADIAN TEMPERATURE CHANGE	GLOBAL SEA-LEVEL RISE
2020	1.8°C	18cm
2050	3.6°C	29cm
2075	5.3°C	44cm

Climate change presents a growing, long-term economic burden for Canada. Changes in future global emissions have little effect on the costs in Canada in the next three or four decades but have a major effect later in the century. **Figure 7** shows the average annual costs of climate change relative to the forecast GDP between now and 2075. Presenting costs this way shows the variation of costs of climate change relative to our overall wealth, and gives a different perspective than the results shown in **Figure 6**. We can expect average costs to amount to roughly 0.8% to 1% of GDP by 2050. The economic burden will be much greater on future generations with higher future emissions. The model assumes that richer societies are somewhat less vulnerable than poorer societies, so the relative burden of the costs in the slow growth scenarios for Canada is higher than in the rapid growth scenarios.

FIGURE 7



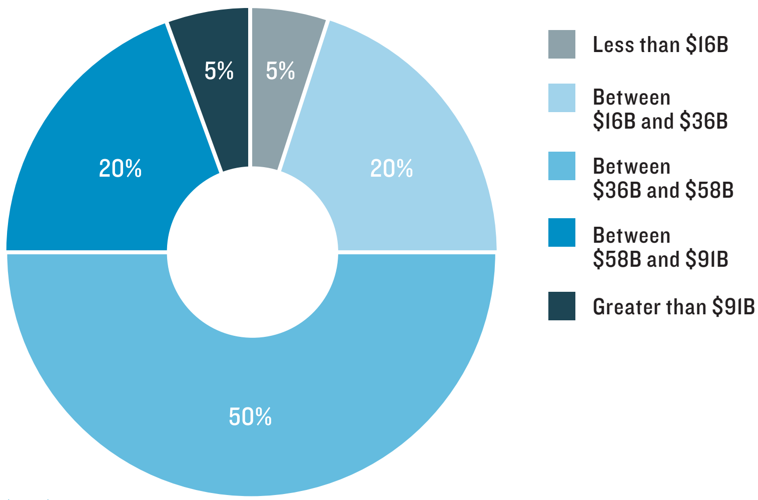
Uncertainty about the science and economics of climate change suggests that a wide range of outcomes is possible. Figure 8 shows the range of possible costs in 2050 for a high climate change–rapid growth scenario estimated from 10,000 model runs. The central average value for the cost of climate change in this scenario is $43 billion per year in 2050; yet, a closer look at the range of possible costs indicates a 5% chance of costs being *less* than $16 billion and a 5% chance of costs being *greater* than $91 billion. Typically, there is more certainty in estimates for earlier time periods since we have more confidence in the information built into immediate forecasts of emissions levels, economic performance and population trends. We also have a better idea of the costs of smaller amounts of warming than of larger amounts of warming. Though the model provides results out to 2200, we focus on estimates out to 2075 and have most confidence in results for the early periods.

The costs could be far higher than the average. A small but not impossible chance of costs reaching over $150 billion per year in 2050 exists. This highlights the precautionary principle: the costs at the upper end of the distribution spectrum are so high, they merit consideration even though the chance of them occurring appears small. There is a similar degree of uncertainty underlying each of the four scenarios, but the magnitude of costs varies among them (see Appendix 8.2 for histograms showing cost distributions for each of the four scenarios in 2050).

FIGURE 8

DISTRIBUTION OF COSTS OF CLIMATE CHANGE IN HIGH CLIMATE CHANGE–RAPID GROWTH SCENARIO, 2050

PERCENTAGE LIKELIHOOD OF DIFFERENT ANNUAL COSTS OF CLIMATE CHANGE



$ (2008), UNDISCOUNTED

A lower emissions future would remove the possibility of very costly outcomes that would be possible in a high emissions future. Table 1 shows that by 2075, when differences in impacts between the low and high climate change scenario start to become more pronounced, the annual costs at the upper end of the range of possibilities are substantially lower in the low climate change future than in the high climate change future. Comparing the results of the two rapid growth scenarios, with high climate change there would be a 5% chance of costs exceeding $546 billion and a 1% chance of costs exceeding $820 billion, but with low climate change the magnitude of the low risk–high impact possibilities is much lower — a 5% chance of costs exceeding $350 billion and a 1% chance of costs exceeding $525 billion.

TABLE 1

ANNUAL COSTS OF CLIMATE CHANGE, 2075

	− LOW CLIMATE CHANGE		+ HIGH CLIMATE CHANGE	
	SLOW GROWTH	RAPID GROWTH	SLOW GROWTH	RAPID GROWTH
AVERAGE ANNUAL COST	$51B	$149B	$80B	$221B
5% CHANCE OF ANNUAL COSTS REACHING AT LEAST	$119B	$350B	$198B	$546B
1% CHANCE OF ANNUAL COSTS REACHING AT LEAST	$180B	$525B	$300B	$820B

$ (2008), UNDISCOUNTED

The pattern of possible results illustrates the nature of risk and uncertainty in forecasting climate change outcomes. Our modelling shows not just expected or average costs but the prospect or risk of either lower or higher costs. And it shows what the magnitude of those different costs could be. By examining the distribution of possible results through this kind of modelling we can assess Canada's risks of acting or not acting in the face of uncertain economic outcomes. For while all results show there is a chance the costs could be somewhat lower under each scenario at one end of the scale, they also demonstrate that the same chance — 1% or 2% or even 5% — leads to demonstrably higher costs at the other end of the scale.

These findings show that lower global emissions levels would greatly reduce the costs of climate change in absolute and relative terms or put another way, they show that higher global emission levels mean correspondingly greater economic costs. They also show that lower global emissions levels reduce the risks of extremely high costs of climate change. By implication, worldwide efforts, including ours, to rein in and cut emissions can be seen as an insurance strategy to reduce these risks. Canadians make regular investments to reduce or manage the risks of small probability events like car accidents and house fires. We spend money on winter tires and smoke alarms to reduce risks and impacts, and we spend money on insurance so that if that small probability event occurs despite our efforts to avoid it, we take less of a financial hit. We should therefore assess not just the societal and economic acceptability of the higher likelihood impacts of climate change and their costs, but also consider the acceptability of a lower likelihood outcome of climate change with more costly impacts.[c]

2.4 CANADA AND THE WORLD AT 2°C WARMING

The results of the PAGE09 modelling can be used to explore the scale of costs we may face from climate change under different policy futures. Under the 2009 Copenhagen Accord, Canada is working in concert with other governments to limit the global temperature increase to 2°C above pre-industrial levels.[17] Being a northern country, a 2°C rise in global average temperature could mean a temperature increase of over 3°C on average for Canada. Although we do not explore this specific scenario in our analysis, we can extract from results presented in this chapter to think about what that global target could mean for Canada. The four scenarios we modelled would lead to a global temperature increase of 1.7°C to 1.8°C by 2050.

Even if we succeed in achieving the 2°C temperature limit established in the Copenhagen Accord, our analysis shows that climate change would still be expensive for Canada: the average costs of a 1.7°C to 1.8°C increase in global temperatures are estimated at $21 billion to $43 billion per year for Canada in 2050 if we do nothing to adapt and try to reduce those impacts. Costs would more likely be at the lower end of this range if domestic mitigation slowed economic growth. However, in sharp contrast to the growing costs of *inaction* presented in this report, under the Copenhagen Accord costs would not continue to increase in later time periods as emissions continue to grow, as shown in our results, but instead stabilize at the 2050 levels (at least in relative terms) and perhaps decline over time as we adjusted to a new reality.[d]

c See section 3.3 of the NRTEE's recent report *Degrees of Change: Climate Warming and the Stakes for Canada* for a discussion on 'navigating uncertain climate futures' (National Round Table on the Environment and the Economy 2010).

d However due to lags and feedback mechanisms related to greenhouse gases already in the atmosphere, temperatures may rise well-above 2050 levels until they reach long-term ('equilibrium') levels.

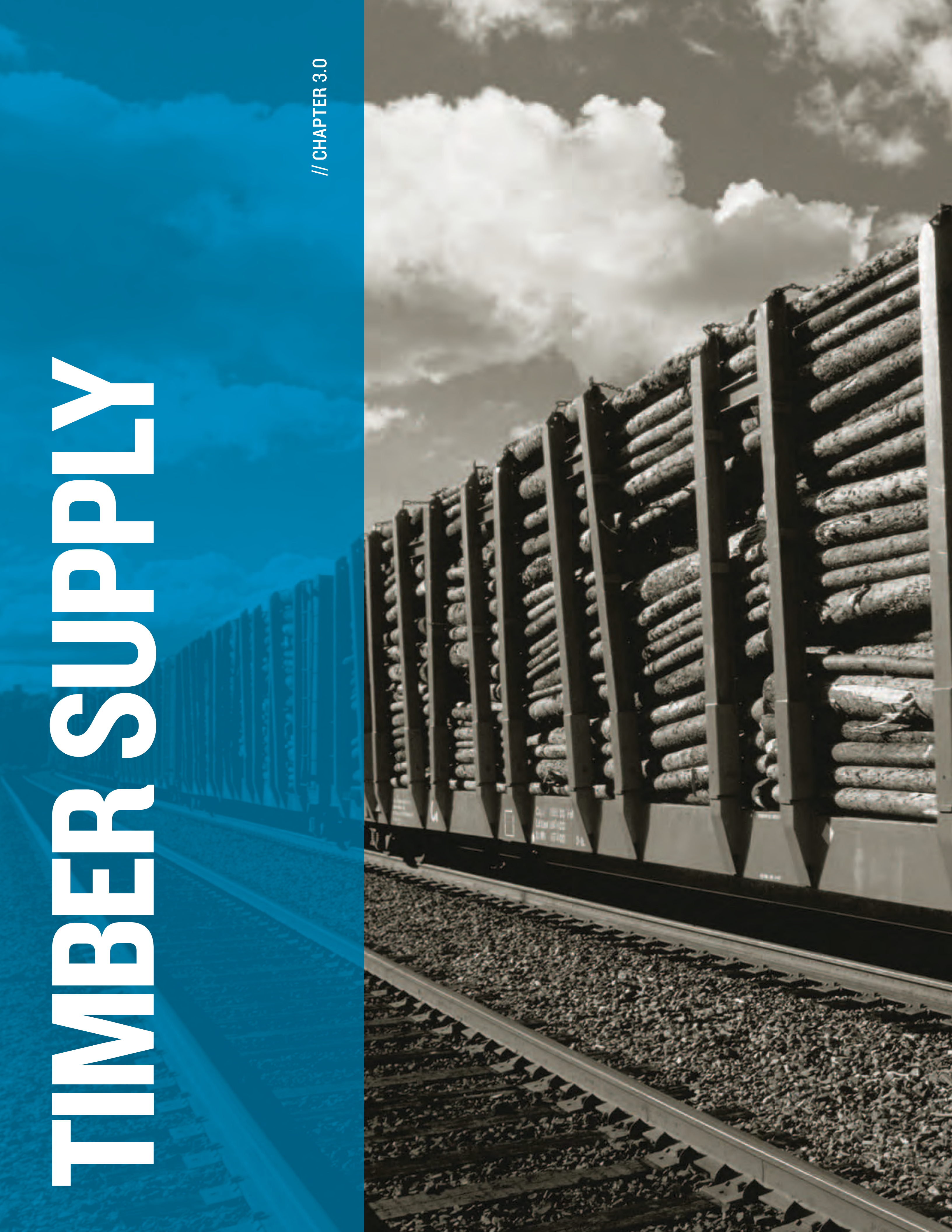
2.5 CONCLUSION

Climate change has a price tag for Canada, and it could be big. Our research and analysis shows it could range from $21 billion to $43 billion per year by 2050, equivalent to 0.8% to 1% of GDP, depending upon what future global emissions occur and how Canada grows in the meantime. There are also risks of costs being far higher and these risks merit consideration.

These Canada-wide results frame some of the issues for us. So far we have shown that we expect to face costs and that we need to adapt to that reality. But, as our *Degrees of Change* report illustrated, the impacts of climate change will be felt differently in different parts of the economy and different parts of the country. Given the local or regional impacts of climate change, solutions and responses to managing its costs are most readily identified by analyzing the impacts on different sectors. To gain a better understanding of the economic impacts of climate change and possible adaptation measures for Canada's prosperity, places, and people, the following three chapters explore three important and representative areas that will all be affected by climate change: timber supply, coastal areas, and human health.

TIMBER SUPPLY

// CHAPTER 3.0



3.0 // TIMBER SUPPLY

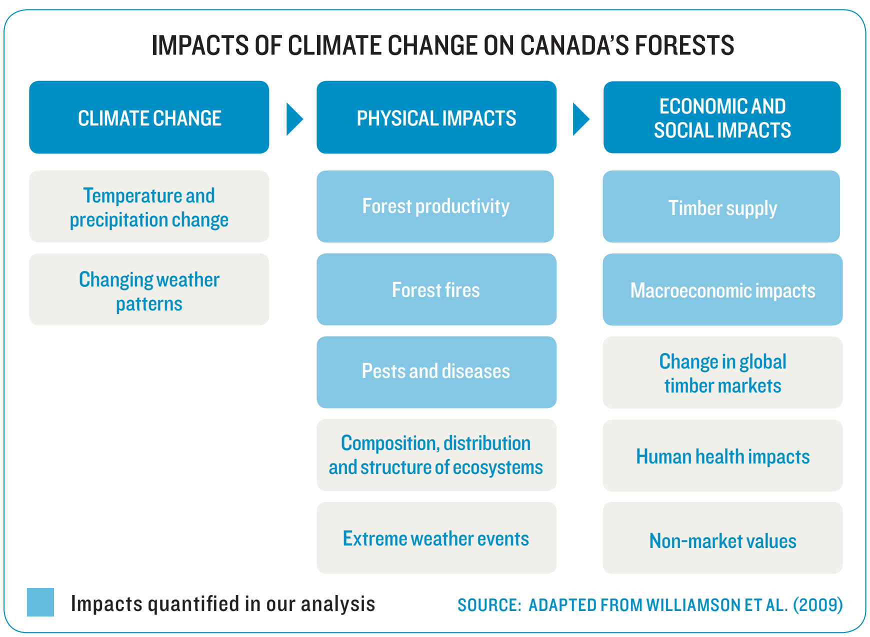
3.1 THE CLIMATE CONNECTION

Climate change adds a new threat to Canadian timber supply.

Canada is home to almost 3.5 million square kilometres of forests, representing 10% of global forest cover and 30% of the boreal forest.[18] These forests clean our water and our air, shelter many species, provide us with recreation values, absorb and store carbon, and support a forest industry[e] that drives 1.7% of our GDP.[19] Climate change will have real consequences for Canada's forest industry and cascading effects will impact other sectors. GDP could fall by 0.1% to 0.3% by mid-century.

Forests are sensitive to changes in weather and climate. Canadian researchers, including in the Canadian Forest Service at Natural Resources Canada, are studying the potential impacts of climate change on Canada's forests (**Figure 9**).[20] In a changing climate, forest fire activity is expected to increase, affecting timber supplies and leading to higher fire management and control costs. An increase in pest disturbance is likely over the next few decades, and more frequent and intense extreme weather events including wind and ice storms could damage trees and industrial operations. Warmer temperatures and higher levels of carbon dioxide in the atmosphere may accelerate productivity under certain conditions. The distribution and composition of ecosystems — including forests — is shifting, with some species gaining suitable habitat and others losing it. In a global economy, impacts of climate change on forests outside of Canada could have cascading effects on our forest industry.

FIGURE 9



e The forest industry includes forestry and logging, pulp and paper manufacturing, and wood product manufacturing. We use "forestry" to refer to the forestry and logging sector that includes timber production, harvesting, reforestation, and gathering of forest products (Industry Canada 2010a).

A changing climate is one driver of economic change, among many others. **Box 2** highlights the steps underway to transform Canada's forest industry and draws connections between this transformation and climate change.

BOX 2

TRANSFORMATION OF CANADA'S FOREST INDUSTRY

Canada's forest industry is vulnerable to global dynamics including international labour and wood costs, the strength of the U.S. dollar, and U.S. housing starts. Total exports have fallen by nearly 50% between 2004 and 2009 partly because of the recent economic downturn.[21] In order to tackle increased international competition and maximize the value extracted from timber, work is underway to transform Canada's forest sector by diversifying the use of forest products through the development of new bioproducts (e.g., biodegradable plastics) and by enhancing penetration of wood products as building materials.[22] A recent study has identified a roughly $200 billion global market opportunity for bioproducts from the forest industry.[23]

The Canadian Council of Forest Ministers has set out a vision for sustainable forest management in Canada underpinned by forest sector transformation and climate change. These two themes go hand in hand.[24] The emergence of carbon markets and carbon-pricing policy with mechanisms to allow offsets from forest carbon projects could create economic opportunities for the sector. Adapting forest management practices to account for future impacts of climate change could help advance industrial transformation and the objectives of climate change mitigation, for example, by increasing our forests' capacity to absorb carbon and industry's capacity to produce a reliable supply of sustainable biofuels. Transforming the economic trajectory of the sector toward diversified and highly valued products is also a strategy to buffer the forest industry and the communities it supports from adverse impacts of climate change.

But just how much economic impact could climate change have for Canada's forest industry and for Canada as a whole? This chapter explores the relationship between climate change impacts on timber supply and the economic repercussions for Canada's economy that flow from these impacts.[f] As highlighted in **Figure 9**, we concentrate on shifts in timber quantities resulting from changes to forest fire regimes, forest productivity, and pest disturbance in a changing climate and then estimate the economic costs or benefits of these impacts. Finally, we consider whether adapting to climate change could improve our economic welfare.

f *A technical report* underpinning this chapter is available upon request: *Costing Climate Impacts and Adaptation: A Canadian Study on the Forest Sector* (Marbek and Lantz 2010).

3.2 AN OVERVIEW OF OUR METHODS

This section provides highlights of the methods used to guide our analysis. Additional information on the methods and limitations is available in **Appendix 8.3**.

PHYSICAL IMPACTS: Our analysis of physical impacts covers shifts in timber quantities from forest fires, forest productivity, and pest disturbance in a changing climate. We focus on these impacts for two reasons: (1) they most directly affect the quantity of timber supply[g] that will be available in the future and (2) there is already a sufficient evidence base upon which to build. Geographically, our analysis covers forest areas assigned for timber production across six regions: British Columbia; Alberta; Manitoba, Saskatchewan and the Territories[h]; Ontario; Québec; and Atlantic Canada.

SEE CHAPTER 1 FOR A REMINDER OF OUR SCENARIOS

We developed estimates of the expected changes to timber supply for each region and climate change **SCENARIO** (both high climate change and low climate change). These estimates were drawn primarily from research conducted by the Canadian Forest Service at Natural Resources Canada, including qualitative or quantitative estimates of the impacts of climate change on fires, forest productivity, and pests in Canada's various forest regions.

ECONOMIC IMPACTS: The economic consequences of changes in timber extend beyond forestry, affecting industries such as manufacturing and construction. We used computable general equilibrium (CGE) modelling to explore the costs and benefits to Canada's broader economy of changes in timber quantities due to climate change. Generally speaking, CGE models forecast macroeconomic trends, using simplifying assumptions to represent regional economies and their complex interactions. CGE models integrate consumer demand, labour and capital supply, and markets for production inputs and outputs. We ran CGE models for each region under both rapid and slow growth scenarios. We then changed the forest sector output based on the estimated changes in timber supply from climate change and reran the models. Comparing the economic indicators across model runs with and without climate change lets us explore the economy-wide impacts of different climate futures.

g Our focus is on timber quantity but we recognize that climate change also affects timber quality and the timing of planting and harvesting.

h Yukon and the Northwest Territories have far more forested land than Nunavut.

3.3 TIMBER IMPACTS DUE TO CLIMATE CHANGE

The effect of climate change on timber quantities intensifies over time and varies regionally with western parts of the country faring worse than eastern parts. The analysis shows that timber quantities decrease in all regions as climate change heightens over time. These decreases range from 1-5% in the 2020s to 2-23% in the 2080s. But these impacts are more noticeable for western Canada than for eastern Canada. For example, according to the analysis, timber quantities could fall by between 9% and 14% in Alberta, between 7% and 11% in Manitoba, Saskatchewan, and the Territories, and between 5% and 8% for British Columbia by the 2050s. In Québec, timber quantities could fall by 1% to 2% by the 2050s. Our estimates reflect expectations of broad trends rather than specific events. Recent experience with the mountain pine beetle in British Columbia, projected to result in an estimated loss of 23% of provincial timber volume by 2015,[25] suggests that our results are conservative for British Columbia. **Table 2** summarizes our estimated range of reductions in timber quantities relative to current levels from the combined effects of climate change on fire, forest productivity, and pests, under both the low and high climate change scenarios.

TABLE 2

TIMBER QUANTITY REDUCTIONS DUE TO CLIMATE CHANGE

	BRITISH COLUMBIA	ALBERTA	MANITOBA, SASKATCHEWAN, TERRITORIES	ONTARIO	QUÉBEC	ATLANTIC CANADA
2020s	3 to 4%	3 to 5%	4 to 5%	2%	1%	1%
2050s	5 to 8%	9 to 14%	7 to 11%	2 to 4%	1 to 2%	2 to 4%
2080s	8 to 14%	13 to 22%	13 to 23%	4 to 8%	2 to 4%	2 to 5%

Forest fires have the largest impact on timber quantities in most regions. The influence of forest productivity on timber quantities is positive in eastern Canada while negative in the west. All regions are expected to be negatively similarly affected by pests in the future.

3.4 ECONOMIC IMPACTS

Changes to timber quantities due to climate change in the 2050s could reduce national GDP by up to 0.3% — or about $17 billion — compared to a case with no climate change. The costs of climate change are a function of the rate of change of timber supply impacts and the evolving structure of the economy as a whole. **Table 3** presents the impacts of climate change to Canada's economy, as measured by changes in GDP. We show results for all four scenarios. In each scenario, the relative GDP changes are higher in the 2050s than the 2020s but then subside somewhat by the 2080s as GDP growth outpaces the growth in the costs of climate change.

TABLE 3

ANNUAL CHANGES IN GDP RELATIVE TO "NO CLIMATE CHANGE" BASELINES

	LOW CLIMATE CHANGE		HIGH CLIMATE CHANGE	
	SLOW GROWTH	RAPID GROWTH	SLOW GROWTH	RAPID GROWTH
2020s	-0.10%	-0.12%	-0.15%	-0.18%
2050s	-0.12%	-0.18%	-0.21%	-0.33%
2080s	-0.11%	-0.08%	-0.19%	-0.15%

Climate change dampens economic activity and productivity, with GDP impacts most pronounced for Manitoba, Saskatchewan and the Territories, and for British Columbia. Table 4 shows the range of expected GDP impacts over time for two of our future scenarios compared to "no climate change" baselines. GDP in British Columbia could fall by roughly 0.2% to 0.4% by the 2050s. In the most adversely impacted region — Manitoba, Saskatchewan, and the Territories — our modelling shows that GDP could fall by roughly 0.3% to 0.9% by the 2050s.

TABLE 4

ANNUAL CHANGES IN GDP RELATIVE TO "NO CLIMATE CHANGE" BASELINES BY REGION, 2050s

	LOW CLIMATE CHANGE		HIGH CLIMATE CHANGE	
REGION	SLOW GROWTH		RAPID GROWTH	
BRITISH COLUMBIA	-$0.5B	-0.18%	-$3.1B	-0.44%
ALBERTA	-$0.2B	-0.06%	-$1.0B	-0.14%
MANITOBA, SASKATCHEWAN AND TERRITORIES[i]	-$0.5B	-0.33%	-$3.3B	-0.85%
ONTARIO	-$1.0B	-0.11%	-$7.4B	-0.31%
QUÉBEC	-$0.3B	-0.08%	-$2.1B	-0.23%
ATLANTIC CANADA	-$0.1B	-0.07%	-$0.5B	-0.21%
CANADA	**-$2.4B**	**-0.12%**	**-$17.4B**	**-0.33%**

$(2008), UNDISCOUNTED

i This region represents an aggregation of five distinct regional economies with varying characteristics, making it difficult to explain the significance of our estimated impact on GDP. There are two possible contributors: size of the aggregate forest industry relative to the aggregate regional economy and the extent of interconnections between the forest industry and other industries of the regional economy. Within the aggregate region modelled, the forest industries in Manitoba and Saskatchewan are the largest of the five. Their respective GDP contribution to each provincial economy is about the same as in Alberta. Therefore, the more likely explanation relates to the many cascading effects that changes in the forest industry produce, which may be an artifact of the model.

We cannot predict the sensitivity of regional economies to climate change by looking at the extent of exposure to physical changes in timber quantities alone. Comparing **Table 2** with **Table 4** helps illustrate how the structures of regional economies influence regional vulnerability to the impacts of climate change. At least two factors come into play: the relative size of the forestry sector and the degree of reliance of other economic sectors on outputs from forestry. Our estimates in **Table 2** show that Alberta could experience greater percentage changes in timber quantities due to climate change than British Columbia. However, relative costs of these timber changes as shown in **Table 4** differ markedly. The forestry industry in British Columbia is a larger component of the provincial economy and is more important to the rest of the provincial economy than is the case in Alberta, so the cascading effects are more significant.

Costs aggregated at the regional level mask important differences within regions. Residents of communities that depend on the forest sector will be particularly susceptible to climate change. For example, forest fires are a particular threat to health and assets in forest-based communities. And, severe impacts like those seen in the case of the mountain pine beetle could limit the availability of the forest products that drive local economic growth.[26]

The cumulative costs of changes in timber supply over the next 70 years due to climate change range widely, from $25 billion to $176 billion for the country as a whole depending on the scenario. **Table 5** shows the cumulative costs of climate change from 2010 to 2080 by region and for Canada. Here we add up the costs for each year from 2010 to 2080 and apply a 3% discount rate to develop the cumulative costs. One observation is worth noting. Regional similarities in relative impacts on GDP as shown in **Table 4** do not translate into similar costs in absolute terms. While relative GDP changes in Ontario will be comparable to those in Québec and British Columbia in the high climate change–rapid growth scenario (as shown in **Table 4**), in absolute terms the costs are higher in Ontario (perhaps as high as $75 billion cumulatively between 2010 and 2080) due to the larger size of that province's economy. Costs vary widely between the two scenarios shown below, which reflects diverging climate futures and diverging socioeconomic futures.

TABLE 5

CUMULATIVE COSTS DUE TO CLIMATE CHANGE, 2010–2080

	– LOW CLIMATE CHANGE	+ HIGH CLIMATE CHANGE
REGION	SLOW GROWTH	RAPID GROWTH
BRITISH COLUMBIA	$5B	$32B
ALBERTA	$2B	$10B
MANITOBA, SASKATCHEWAN AND TERRITORIES	$5B	$33B
ONTARIO	$10B	$75B
QUÉBEC	$3B	$21B
ATLANTIC CANADA	$1B	$6B
CANADA	**$25B**	**$176B**

$(2008), 3% DISCOUNT RATE

3.5 ADAPTATION STRATEGIES

Several strategies exist to prepare for and offset the physical and economic impacts of climate change on forests.[27] They include operational and management changes, such as shortening rotation lengths and minimizing the spread of pests. They can also involve behavioural change, such as shifting forest management practices away from historical norms toward practices that embed principles of risk management, adaptive management, and ecosystem resilience. These examples are but a few of the potential options available. In practice, the choice of adaptation strategies will likely take into account the potential to achieve synergies among strategies and to derive co-benefits. For example, improved fire management strategies could also enhance forest carbon sequestration and reduce greenhouse gas emissions from forests, thus contributing to climate change mitigation efforts. Trade-offs between adaptation and mitigation can also arise. For example, shorter rotation lengths support adaptation but longer rotation lengths enhance carbon sequestration, which is important for climate change mitigation. If financial incentives are established to encourage sequestration or reduce emissions overall, then adaptive strategies that also achieve these objectives would likely be favoured.

Adapting to climate change in many cases involves improving upon existing activities.[28] Provincial and territorial governments are responsible for fire suppression and forest pest management and already devote considerable resources to these activities. Costs fluctuate from year to year depending on the frequency and severity of fires and pest infestations. Over the last decade, yearly firefighting costs ranged from $4 million to $73 million in Québec[29] and from $86 million to $417 million in British Columbia.[30] In Québec, 2010 spending on pest management and tree diseases totalled $6 million.[31]

TO EXPLORE COSTS AND BENEFITS OF ADAPTATION, WE INVESTIGATED THE COMBINED EFFECT OF THREE STRATEGIES:

// **ENHANCING FOREST FIRE PREVENTION, CONTROL, AND SUPPRESSION:** This short-term strategy could include prescribed burning, removing dead wood that could fuel fires, and enhanced fire fighting.

// **INCREASING PEST PREVENTION AND CONTROL:** This short-term strategy could include minimizing the risk of introducing new pest species into a forest, managing the forest in a way that discourages pest productivity, or spraying pesticides more aggressively.

// **PLANTING TREE SPECIES SUITABLE TO FUTURE CONDITIONS:** This long-term strategy takes future climate conditions into account in selecting tree species in re-planting efforts. Despite concerns regarding the potential for assisted migration to contribute to maladaptation and have unintended consequences, we still explore this option because of the scale of forest regeneration activities in Canada. Forestry companies are already subject to provincial/territorial forest regeneration requirements and decisions about the type of seedlings to plant could incorporate the prospect of changes in future conditions.

We chose these strategies because of their potential to cost-effectively reduce impacts of climate change on timber quantities and their national application. To estimate the economic impact of their implementation, we reran the six regional CGE models making adjustments to the expected changes in forest sector output to account for the effect of adaptation. We then compared economic indicators from this modelling with the costs of adaptation.

There are many uncertainties regarding the costs of potential adaptation options far into the future. Besides costs, the exact effects of adaptation in reducing physical climate change impacts on a regional basis are also largely unknown. For example, recent experience with the mountain pine beetle has shown that decisions about the timing and effort of response to pest outbreaks can affect outcomes in important ways (see **Box 3**). We do not consider the potential economic gains from developing Canadian technical and scientific expertise that could be exported to provide adaptation solutions abroad. We document our assumptions about the costs and effectiveness of adaptation in **Appendix 8.3**.

BOX 3

MOUNTAIN PINE BEETLE RESPONSES IN BRITISH COLUMBIA AND ALBERTA

Forest ecosystems are enormously complex, and although we can anticipate some of the gradual ecosystem impacts of climate change, others may happen with little warning. By spotting potentially damaging impacts early on and acting on this information we open up the range of adaptation strategies available to us. This allows us to choose to be proactive or reactive. But when the impacts of climate change come as a surprise, reactive adaptation may be the only option.

This was the case in British Columbia where the scale of the recent mountain pine beetle infestation took many by surprise.[32] By the time the scale of the problem was well understood, the infestation was already too widespread for pest containment measures in central British Columbia.[33] Instead, planners focused on recovering as much economic value as possible from damaged forests.[34] The B.C. government temporarily increased timber harvest levels so trees could be harvested before they lost their entire commercial value.[35] The government also invested roughly $160 million in forest regeneration to recover forest values in affected areas.[36] Despite these efforts, the mountain pine beetle infestation is expected to have long-term economic consequences for the province, and roughly 16 mills and production plants are expected to close by 2018 as timber supplies decline.[37]

Alberta learned from British Columbia's experience and prepared for the infestation in advance.[38] The scale of the impact in British Columbia encouraged Alberta to invest heavily in up-front containment of the infestation. Since 2006, Alberta has committed approximately $210 million and has concentrated its efforts on removing affected trees, implementing pest management strategies, and harvesting over-mature and vulnerable pines.[39]

According to our analysis, the benefits of adaptation outweigh the costs in every region and scenario. The results of our analysis appear in **Table 6**. The present value of the implementation costs is in the order of $2 billion to $4 billion for all three strategies combined between now and 2080, while the present value of these benefits ranges from $20 billion to $138 billion (applying a 3% discount rate). Even after adaptation, some impacts remain and their costs are estimated at $5 billion to $37 billion.[j] This adaptation strategy appears beneficial regardless of the future climate. This raises the following question: if these adaptation strategies have obvious payoffs, why is application limited? Part of the answer may lie with existing incentive structures, where the party responsible for investing in adaptation is different than the party that would reap the benefits. Also, as mentioned earlier, assumptions about the effectiveness and cost of adaptation are critical in estimating the returns expected from adaptation.[k] The effectiveness and cost estimates will vary between sites and adaptive strategies, making it difficult to identify a more credible set of national assumptions.

j We measure benefits as the reduction in consumer compensation that would be needed if these adaptation strategies were in place — in technical terms this is the "compensating variation." We calculate the remaining costs of impacts as consumer compensation that would be needed to return people to the level of welfare they had without climate change after adaptation.

k Some expert reviewers during the course of writing this report have suggested that our assumptions in this regard are perhaps too optimistic based on recent experience with the mountain pine beetle.

TABLE 6

SUMMARY OF TIMBER ADAPTATION STRATEGY

	ADAPTATION STRATEGY			
STRATEGY	• Enhance forest fire prevention, control, and suppression • Enhance pest control • Plant tree species suitable to future climate			
OBJECTIVE	Reduce the impacts of climate change on timber supply			
COSTS OF IMPLEMENTING STRATEGY (PRESENT VALUE, 2010-2080)	–		+	
	$2.3B		$3.6B	
BENEFITS OF IMPLEMENTING STRATEGY (PRESENT VALUE, 2010-2080)	–		+	
	SLOW	RAPID	SLOW	RAPID
	$19.9B	$77.2B	$34.4B	$137.9B
BENEFIT-COST RATIO	–		+	
	SLOW	RAPID	SLOW	RAPID
	9:1	34:1	10:1	38:1
REMAINING COSTS OF CLIMATE CHANGE AFTER ADAPTATION (PRESENT VALUE, 2010-2080)	–		+	
	SLOW	RAPID	SLOW	RAPID
	$4.6B	$24.4B	$8.1B	$37.1B
POTENTIAL CO-BENEFITS	• Enhanced greenhouse gas sequestration • Health benefits from reduced forest fires • Enhanced ability to achieve sustainable forest management objectives			
IMPLEMENTATION CHALLENGES	• Uncertainty on effectiveness • Ecological risks to planting alternative tree species			

Slow Canadian economic and population growth
Rapid Canadian economic and population growth
– Low climate change
+ High climate change

$(2008), 3% DISCOUNT RATE

Further research is necessary to assess the feasibility of implementing the adaptive strategies explored in this report on a wide scale. Some specific challenges are worth noting. The sheer vastness of Canada's forests makes comprehensive on-the-ground interventions cost-prohibitive, requiring targeted, staged interventions.[40] The gap in time between planting and harvesting trees — 50 to 100 years[41] — means that adjustments in management strategies to account for climate change will need to be made in the near term despite uncertainty about the extent of climate change expected in the future.[42] Governance challenges may also arise. Most forests that are harvested for timber are provincial crown land licenced out to timber companies. As landowners and regulators of the industry, provincial and territorial governments have a strong role in helping to create conditions for adaptation. Governments and industry will need

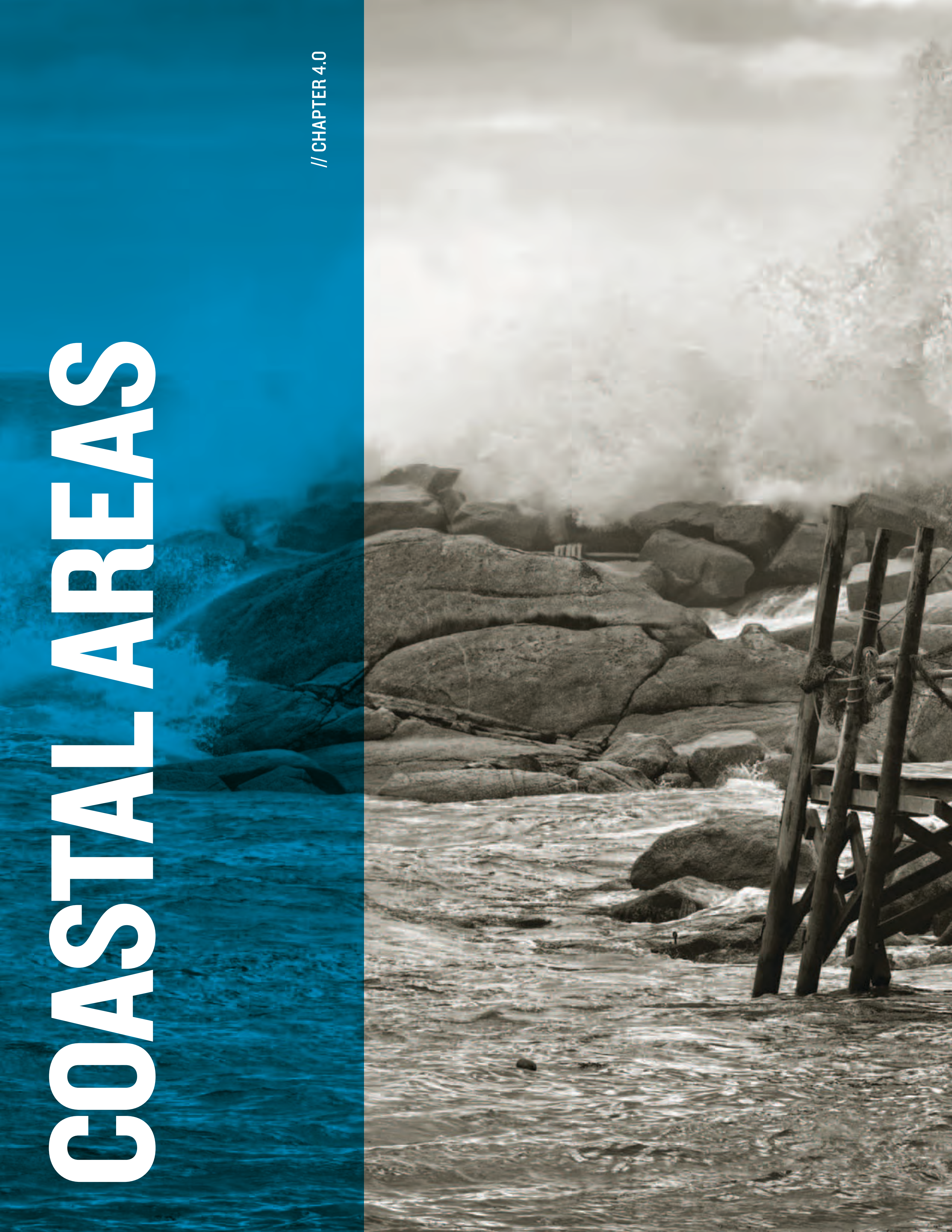
to work together to identify and implement the most suitable adaptation strategies. British Columbia's Future Forest Ecosystems Initiative is identifying ways that climate change could impact forest values and adapting the forest management framework to these changing conditions in collaboration with external partners including industry associations, First Nations, the Pacific Climate Impacts Consortium, and the federal government.[43]

3.6 CONCLUSION

Our analysis shows that climate change is expected to negatively impact the timber supply through changes in forest fires, pest outbreaks, and tree productivity. These impacts will be more severe in western parts of the country. Timber supply reductions will have consequences for the economy as a whole through cascading effects in other sectors. Overall, we could see GDP reductions of 0.12% to 0.33% by the 2050s and the cumulative costs between now and 2080 could be on the order of $25 billion to $176 billion. Implementing a variety of adaptive strategies to manage pests and fires and to plant trees suitable for future climate conditions could alleviate much of the negative impacts of climate change for the timber supply and yield benefits that far exceed the costs of adaptation.

COASTAL AREAS

// CHAPTER 4.0



4.0 // COASTAL AREAS

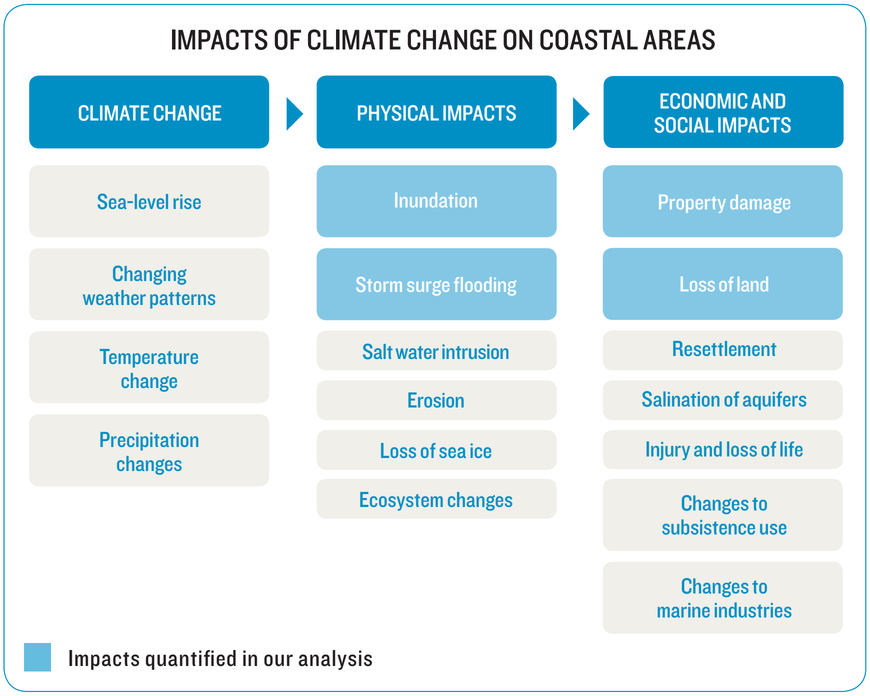
4.1 THE CLIMATE CONNECTION

Canadians living in coastal areas are accustomed to the hazards of shifting sea levels and storm surges. Climate change will exacerbate existing risks, exposing 3,000 to 13,000 more homes to flooding by mid-century.

Canada has a vast coastline stretching 243,000 kilometres along three marine coasts. One in six Canadians lives within 20 kilometres of a marine coast.[44] Coasts are an important source of recreation and livelihoods for many more. Coastal communities have a long history of contending with the hazards of flooding and erosion, but climate change is a new force that heightens risks to people, property, and the environment along coastal areas.

In a changing climate, the combined effects of accelerated coastal erosion, sea-level rise, and a greater frequency and intensity of storm surges could lead to permanent loss of land, temporary flooding, freshwater salination, damage to property, and disruption of key economic activities, among other impacts (see **Figure 10**). Our understanding of the way that climate change could impact the coasts has recently improved. A nationwide study assessed Canada's sensitivity to sea-level rise and found that one-third of our coastline is moderately or highly sensitive including 80% of the Nova Scotia, New Brunswick, and Prince Edward Island coasts.[45] The high concentration of people and expensive infrastructure in Metro Vancouver make this area particularly vulnerable. A few local and regional studies have assessed the impacts and costs of climate change for built infrastructure and homes, with most of them focusing on the East Coast.[46] Beyond this, little research exists estimating the likely costs of climate change for Canadian coastal areas; this study will begin to fill that gap.

FIGURE 10



In this study, we assessed the impact of sea-level rise and storm surge in terms of land at risk of flooding and destruction of dwellings, and estimated the costs of dwellings lost, as highlighted in **Figure 10**.[1] We then considered how two adaptation strategies — "climate-wise development planning" and "strategic retreat" — could reduce the costs. The economic impact of accelerated erosion is another important effect of climate change, potentially of commensurate damage, but was beyond the scope of our analysis because of its very local nature (**Box 4** explores this further).

1 A technical report underpinning this chapter is available upon request: *Costing Climate Impacts and Adaptation: A Canadian study on coastal zones* (Stanton, Davis, and Fencl 2010).

BOX 4

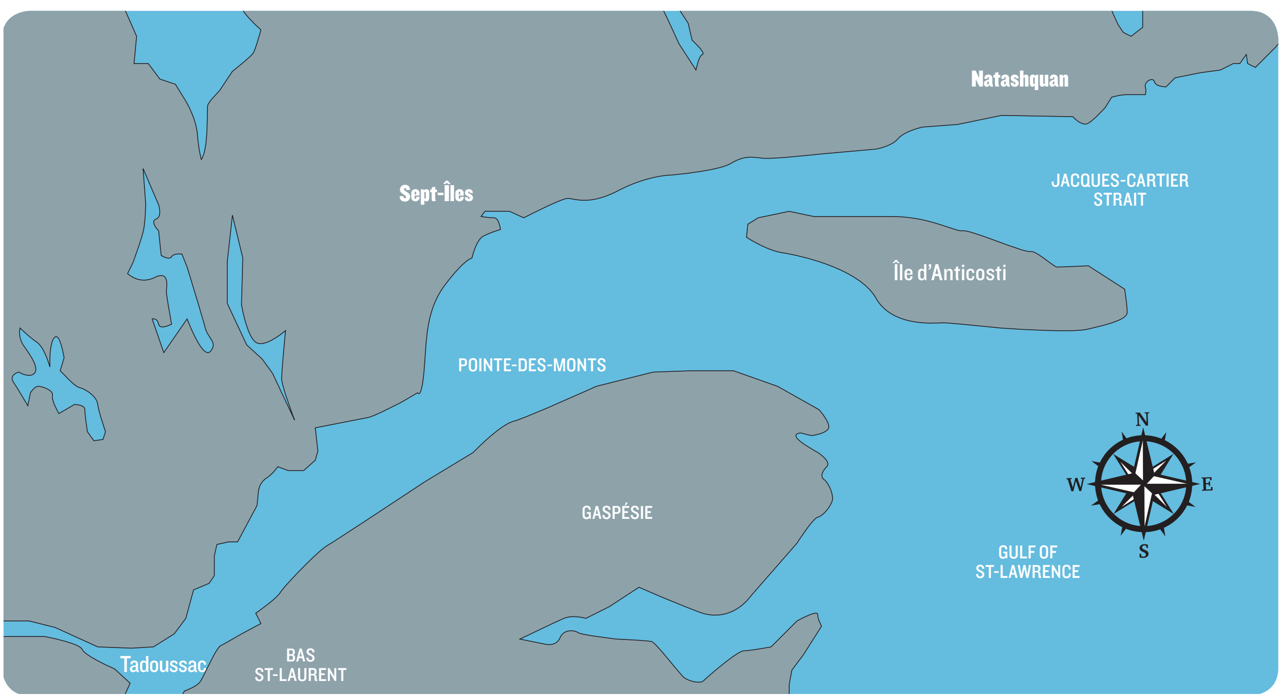
THE COST OF COASTAL EROSION

Erosion shapes and reshapes Canada's coastlines. Along the St. Lawrence River's Côte-Nord, the rate of erosion is expected to accelerate due to rising sea levels, increasing storm intensity, and shifting freeze-thaw cycles in a changing climate.

An assessment of the 1,600 kilometres of coastline between Tadoussac and Natashquan revealed that roughly 400 kilometres of sand and clay coastline along the Côte-Nord is eroding, and less than 100 kilometres of it is protected by adaptive defences or walls to reduce erosion. Furthermore, 62% of towns on the Côte-Nord are located at river mouths and coasts composed of a sand and clay base, and more than 50% of the Côte-Nord buildings are located within 500 metres of the coastline.[47]

Research on the community of Sept-Îles has found that 80% of the community's coastline comprises vulnerable unconsolidated sediment, a type of material highly susceptible to erosion by physical forces such as wind and waves. Erosion rates in some areas have reached as much as eight metres of coastline loss per year.[48] Today's erosion rates already pose risks to homeowners. As an example, in an eight-kilometre stretch between Monaghan beach and Routhier beach, an estimated $13.5 million in housing and $3.6 million in land is at risk from erosion.[49] By 2050, the low-lying sandy coastlines in the community are expected to have eroded by 54 metres on average and up to 139 metres in some areas.[50] In the "most likely" future climate scenario, an estimated $25 million in assets — primarily houses and roads — could be at risk in Sept-Îles by 2050.[51]

Detailed assessments are underway to further assess coastal sensitivity and community vulnerability. The Government of Québec has already invested more than $40 million to divert roads and build protective structures.[52] Incorporating projections of erosion from climate change into local planning processes and land use would go a long way to supporting sustainable development in the region.[53] Zoning amendments to limit construction in at-risk areas were among the favoured options by a committee of local stakeholders in Sept-Îles. This same committee recommended against engineered defences where possible and also suggested that relocating houses may be necessary in some cases.[54]



4.2 AN OVERVIEW OF OUR METHODS

This section provides highlights of the methods used to guide our analysis. Additional information on the methods and limitations is available in **Appendix 8.4**.

PHYSICAL IMPACTS: Our analysis considers two types of flooding: permanent flooding from sea-level rise and the risk of temporary flooding from storm surges. Even without climate change, both these types of flooding pose risks for Canadians. Sea levels along Canada's coasts are dynamic and depend on local physical properties. For example, land subsides or rises relative to the sea due to geological processes. Also, communities already experience flooding from storm surges.

Climate change exacerbates existing flood risk. As oceans warm, they expand, raising global sea levels. Melting ice caps, mountain glaciers, and blocks of ice from land-based ice sheets (e.g., Antarctica and Greenland) also contribute to rising sea levels. The prospect of more frequent and intense storms poses additional risk for flooding, particularly if storms occur during high tides.

Our analysis estimates the impacts from sea-level rise and storm surge with and without climate change for Canada in aggregate and for each province and territory with a marine coast. Relying on methods applicable for the country as a whole, we used geographic information system (GIS)-based modelling to map the elevation of Canada's coastal land in order to look at how much land would flood if water levels were to increase to different heights. The GIS modelling assumes that land can only be flooded if it is beside the ocean or another flooded area rather than assuming all land below a certain height would flood. We divided Canada's coastline into 20 segments and estimated sea-level change and baseline storm surge frequency and intensity unrelated to climate change along with increases in sea level and storm-surge intensity related to climate change for each coastal segment. We use this information about sea levels and storm-surge intensity to estimate the future land area at risk of flooding without climate change ("baseline") and under the two future climate **SCENARIOS**.

SEE CHAPTER I FOR A REMINDER OF OUR SCENARIOS

Using 2006 census data, we then estimated the number of dwellings at risk of sea-level rise and storm surge both in the baseline and due to climate change in each of the four futures. Rather than estimating absolute losses in land area and dwellings, land area and dwellings are characterized as "at risk" of flooding, which aggregates the portion of this flooding expected from sea-level rise and the risk-weighted portion from storm surges.

ECONOMIC IMPACTS: In our analysis, the economic consequences of climate change flow solely from flooding impacts on dwellings. Building on the approach used to estimate the number of dwellings at risk of flooding, we used 2006 census data to estimate the average dwelling value in the flooded areas. We scaled these values up over time based on the population/economic growth scenarios. The costs of dwellings flooded by sea-level rise only register once — in other words, these costs are the full value of dwellings incrementally lost to the sea. In contrast, storm-surge costs amount to the full value of dwellings flooded in each year — as if homes were rebuilt after each flood. Cost estimates for storm-surge damages are weighted by the risk of a

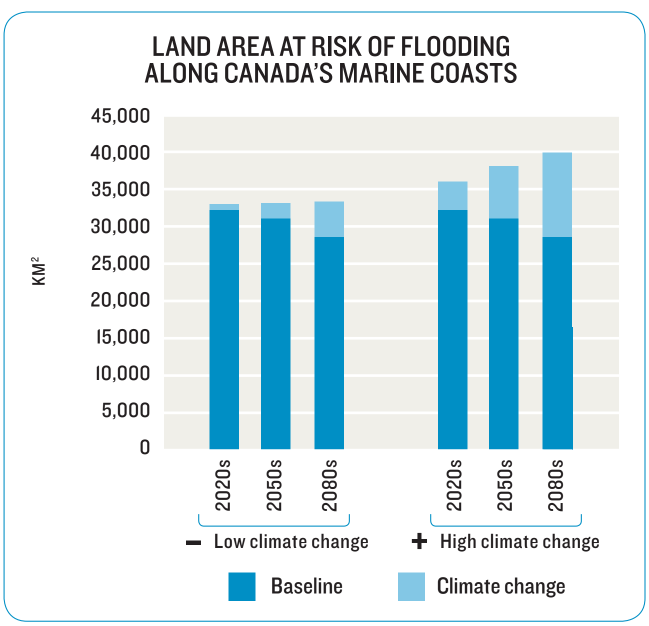
storm surge occurring, and we assume that complete rebuilding of homes due to storm-surge damage could not take place more than once per year. In reality, the relative destruction of homes and loss in value depends on the height of a storm surge. A mild surge may, for example, cause damage equivalent to less than half of the home value.[m] In this context, our damage estimates may overstate the costs of climate change.

4.3 COASTAL FLOODING IMPACTS

By the 2050s, in a given year, between 33,000 and 38,000 square kilometres (km^2) of land will be at risk of flooding, with between 2,000 and 7,000 km^2 of this area at risk due to climate change. Figure 11 shows the area of land that would be at risk without climate change (baseline) and due to climate change in any given year, for each time period. These results highlight the potential for loss of land to ocean flooding regardless of climate change. Baseline risks lessen over time for a couple of reasons: (1) in some regions, the land is rising relative to sea levels, reducing the flood risk, and (2) in cases where a gradually sloped coastline transitions to steeper slopes not far inland, early increases to sea level have a much bigger impact on the land areas inundated than do later increases (once the ocean has run up against a cliff, for example).

Climate change adds to the baseline risk. By the 2050s, 6% to 18% of land at risk of ocean flooding is due to climate change, but this grows to between 14% to 29% by the 2080s. To give a sense of scale, our results from the high climate change scenario in the 2050s show that, in total, the land at risk of flooding from climate change across Canada is about 25% larger than Prince Edward Island, or roughly the size of the Greater Toronto Area.

FIGURE 11

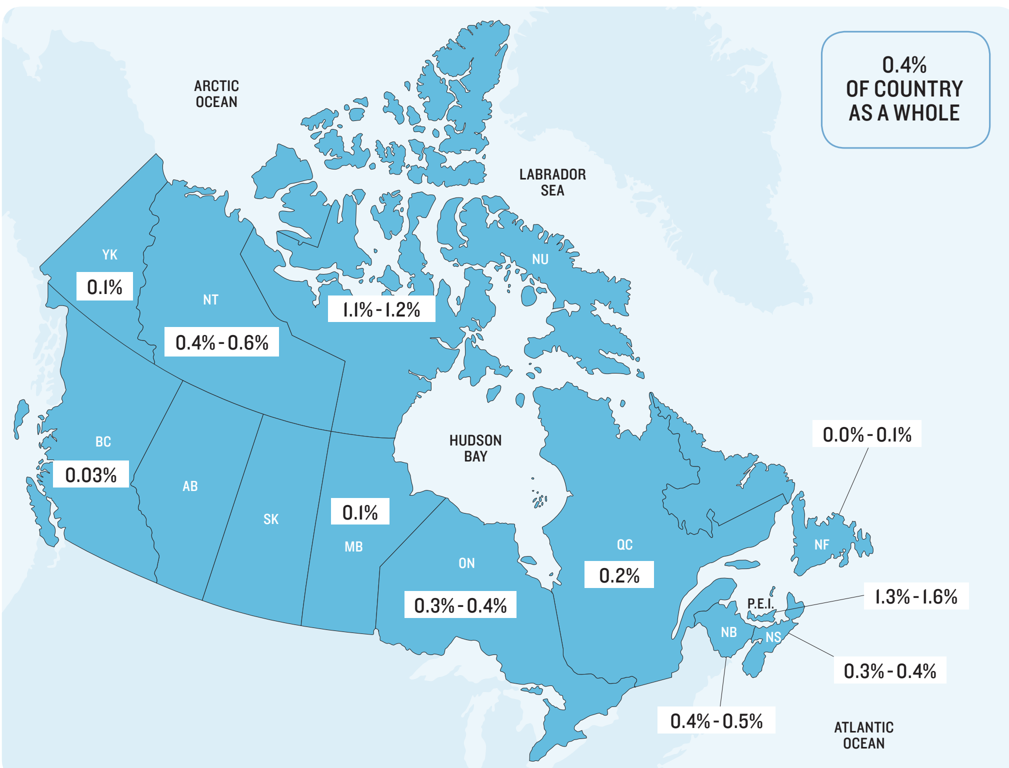


m The U.S. Federal Emergency Management Agency developed the HAZUS model to estimate economic losses from natural hazards. This model suggests that, for example, a split-level home with a basement would lose roughly 35% of its value at a flood height of 1 metre (Scawthorn et al. 2006).

Impacts are uneven across regions. Figure 12 shows the land area at risk as a share of each jurisdiction's total land area in the 2050s, ranging from the low to high climate change scenario. Prince Edward Island has the largest share of land at risk of flooding. The Northwest Territories, Nunavut, New Brunswick, Ontario and Nova Scotia also have a high portion of land at risk relative to the remaining jurisdictions. Our results show that British Columbia has the least land at risk relative to the province's total land area. This is due to the topography of that province's coasts.

FIGURE 12

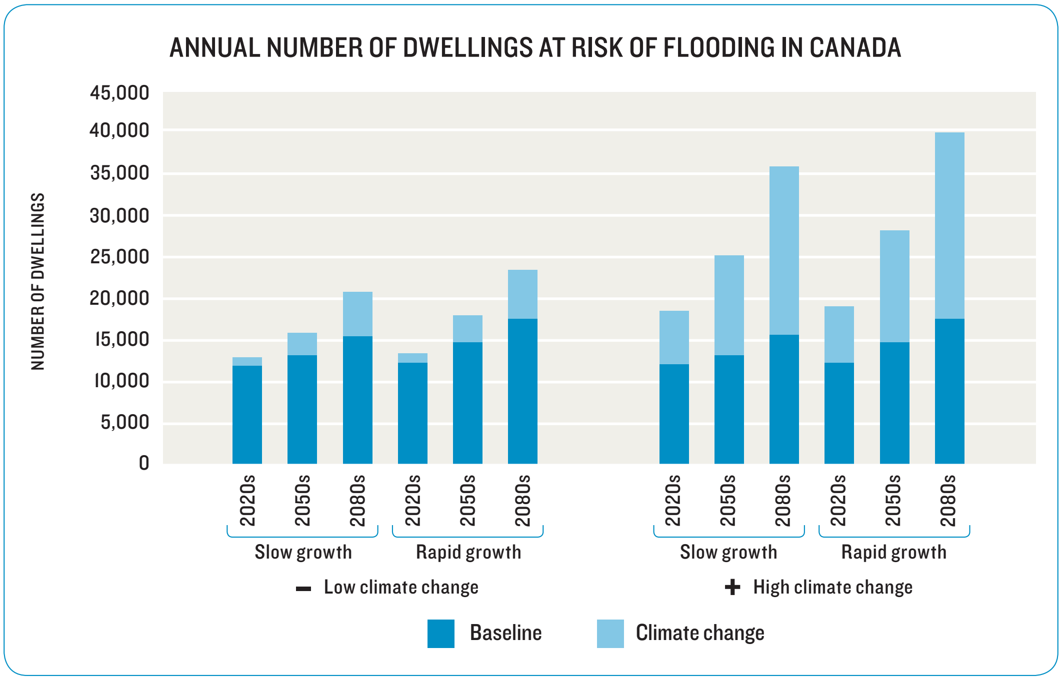
LAND AREA AT RISK OF FLOODING AS PERCENTAGE OF TOTAL LAND AREA BY REGION, 2050s



THE LOW END OF THE RANGE IS THE SHARE OF LAND AT RISK FROM BASELINE RISKS AND LOW CLIMATE CHANGE. THE HIGH END OF THE RANGE IS THE SHARE OF LAND AT RISK FROM BASELINE RISKS AND HIGH CLIMATE CHANGE.

By the 2050s, in any given year, 16,000 to 28,000 dwellings will be at risk of permanent flooding from sea-level rise and temporary flooding from storm surges. Unlike the estimates of land area exposed to flooding shown above, the number of dwellings at risk is a function of both climate change and population and economic growth. Figure 13 provides a breakdown of the estimated number of dwellings at risk in each of our four scenarios. It shows that climate change is responsible for an increasing share of flooding risk over time. Dwellings may be repeatedly destroyed by storm surges, with costs accumulating over time.

FIGURE 13



The majority of dwellings at risk are in British Columbia — about 8,900 to 18,700 by the 2050s. Above we saw that the area of land at risk of ocean flooding in British Columbia is small relative to the other provinces and territories. However, this small piece of land is much more densely populated than coastal areas in other jurisdictions. Table 7 shows the number of dwellings at risk of flooding in the 2050s for the low climate change–slow growth scenario and the high climate change–rapid growth scenario.

Our results for British Columbia require careful interpretation. First, we did not account for the role of dikes and other coastal defences in protecting land and dwellings from the risks of flooding. In the case of Metro Vancouver, an area that has many kilometres of protective dikes in place, much of the land (and dwellings on it) at risk of flooding in the baseline case is protected by dikes. However, dikes were not designed with climate change in mind, so additional risk from climate change remains a concern. Second, given that we did not include dikes, our modelling likely underestimates the number of dwellings at risk of flooding under baseline assumptions for the province — possibly by an order of magnitude — according to expert advice from British Columbia. Judging by maps of Metro Vancouver's floodplain, tens of thousands of homes would face a flooding risk were it not for the extensive diking system. Our analysis may be understating exposure for the following reasons: (1) our conservative approach to how we modelled flooding required land be adjacent to flooded areas in order to flood and (2) the resolution of data used to establish the elevation of coastal land was limited. Our methods were necessarily simplified to allow for a national assessment, but our findings emphasize the importance of a more detailed local assessment of Metro Vancouver.

TABLE 7

ANNUAL NUMBER OF DWELLINGS AT RISK OF FLOODING BY REGION, 2050s

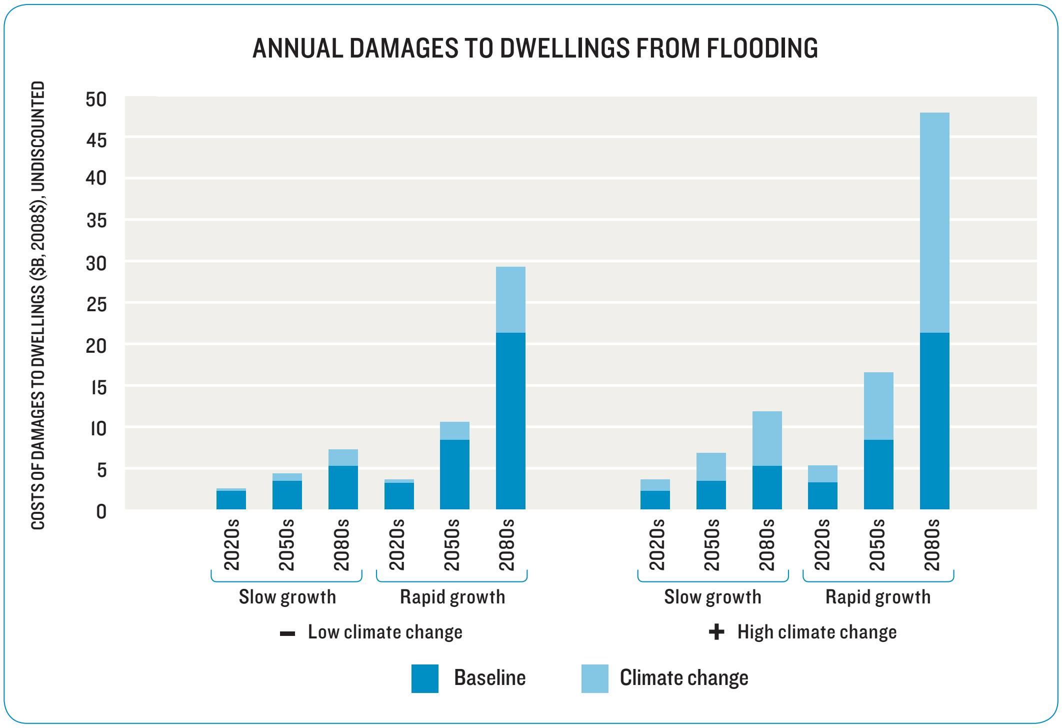
	SLOW GROWTH		RAPID GROWTH	
REGION	BASELINE EXPOSURE	ADDITIONAL EXPOSURE FROM LOW CLIMATE CHANGE	BASELINE EXPOSURE	ADDITIONAL EXPOSURE FROM HIGH CLIMATE CHANGE
YUKON	0	0	0	0
NORTHWEST TERRITORIES	2	0	2	0
NUNAVUT	300	81	336	306
BRITISH COLUMBIA	6,337	2,581	7,086	11,619
MANITOBA	2	0	2	5
ONTARIO	0	0	0	0
QUÉBEC	2,439	106	2,727	536
NEW BRUNSWICK	2,587	53	2,893	502
NOVA SCOTIA	849	48	949	289
PRINCE EDWARD ISLAND	325	18	363	109
NEWFOUNDLAND AND LABRADOR	373	18	417	108
CANADA	**13,214**	**2,817**	**14,776**	**13,132**

Aboriginal populations are disproportionately at risk of flooding. Aboriginal Canadians are expected to represent 10% of the population facing a flooding risk by the 2050s, much higher than their share of Canada's population would suggest. All or nearly all of the population exposed to inundation in Nunavut and the Northwest Territories is Aboriginal; the same is true for more than one-third of the exposed population in Manitoba and nearly 20% in Québec. The most suitable strategies to manage these flooding risks will vary across locations. In Northern and Eastern New Brunswick, the North Shore Micmac District Council is assessing the impacts of sea-level rise on their communities in an effort to safeguard essential services, and in Nunavut, the Nunavut Climate Change Partnership — a collaboration between the Government of Nunavut, Natural Resources Canada, and the Canadian Institute of Planners — is assessing the hazards that may be created by sea-level rise for coastal communities and using this information to inform adaptation planning guidelines.[55]

4.4 ECONOMIC IMPACTS

The annual cost of flooding of dwellings due to baseline risks and climate change could be $4 billion to $17 billion by the 2050s. Figure 14 shows these costs across time for each of our four scenarios. In Figure 11 we showed that climate change is responsible for between 6% and 18% of the land at risk of flooding in the 2050s. If we look at the costs we get a different message. Climate change is responsible for 20% to 49% of the dwelling damages. This suggests development to date may have taken into account baseline exposure to flooding to some extent but not additional exposure from climate change.

FIGURE 14



In absolute numbers, most of these costs are associated with dwelling damages in British Columbia. Table 8 shows the annual costs that each province and territory is expected to face due to baseline risk and additional risk posed by climate change for two scenarios in the 2050s. These results help underscore the potential scale of existing risk and the way in which climate change could exacerbate it. In recent years British Columbia has not experienced significant flood damage: a large portion of the baseline costs for British Columbia can be seen as the costs currently avoided through dike protection and development restrictions.[n] These restrictions will also serve to reduce exposure of dwellings to flooding from climate change. Adaptive strategies of this nature will be helpful in limiting the future costs of flooding.

n The Government of British Columbia's guidelines for development in flood-prone areas recommend that coastal buildings be at least 1.5 metres above the high-water mark along the Strait of Georgia (Ministry of Water Land and Air Protection 2004).

Our assumption that homes would be permanently abandoned from sea-level rise flooding but rebuilt after each flood from a storm surge caused some surprising economic results. For example, our results suggest that climate change may reduce the overall costs of flooding in Nova Scotia. In the baseline case, houses are repeatedly rebuilt after storm surges. In contrast, homes affected by sea-level rise in our climate change scenarios are permanently abandoned. Therefore, the costs of flooding are incurred once rather than repeatedly, highlighting the high costs of rebuilding in locations known to be vulnerable. This may be happening because Nova Scotia's coastline is highly sensitive to sea-level rise[56] and a given amount of sea-level rise may mean that many houses would need to be permanently abandoned. Moving away from at-risk locations may be less expensive than repeatedly rebuilding in expensive and/or densely populated areas after storm surges. Our results, however, are sensitive to some of our key assumptions: we do not factor in dikes, zoning restrictions or behaviour changes in response to flooding events (e.g., increasing protection measures) and we assume that the full value of a dwelling is lost from storm-surge flooding.

TABLE 8

ANNUAL DAMAGES TO DWELLINGS FROM FLOODING BY REGION, 2050s

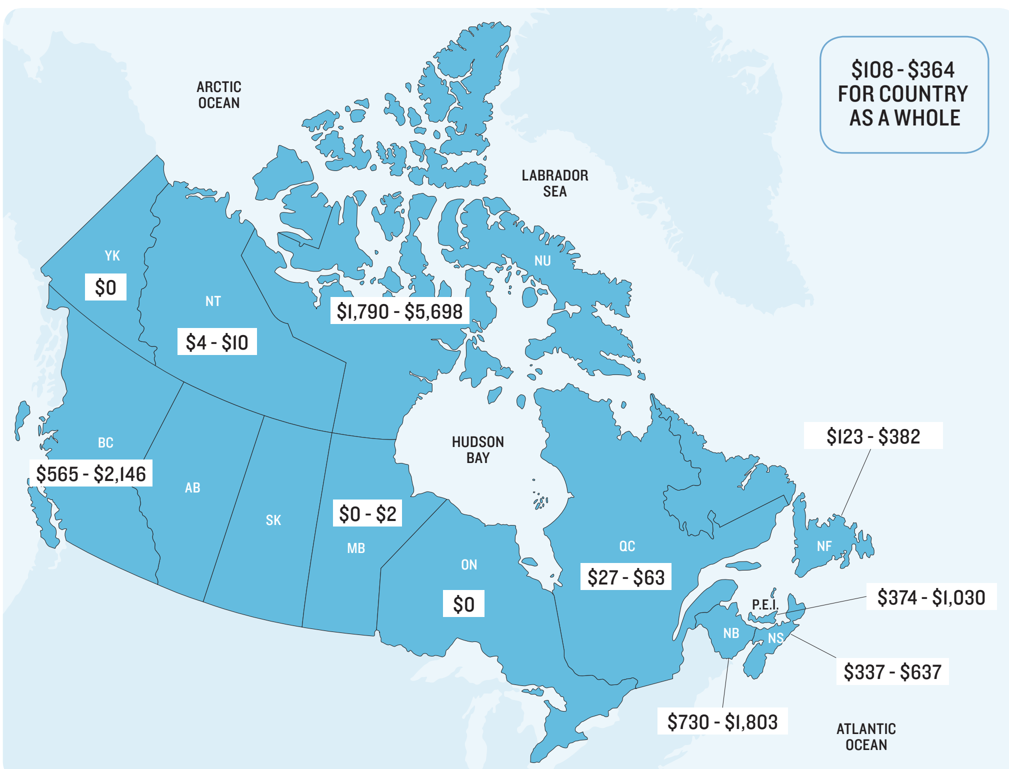
	SLOW GROWTH		RAPID GROWTH	
REGION	BASELINE COSTS	ADDITIONAL COSTS FROM LOW CLIMATE CHANGE	BASELINE COSTS	ADDITIONAL COSTS FROM HIGH CLIMATE CHANGE
YUKON	0	0	0	0
NORTHWEST TERRITORIES	0	0	1	0
NUNAVUT	$79M	$21M	$191M	$166M
BRITISH COLUMBIA	$2,215M	$838M	$5,332M	$7,647M
MANITOBA	0	0	$1M	$2M
ONTARIO	0	0	0	0
QUÉBEC	$271M	$5M	$649M	$54M
NEW BRUNSWICK	$538M	$11M	$1,292M	$227M
NOVA SCOTIA	$308M	-$12M	$738M	-$112M
PRINCE EDWARD ISLAND	$60M	$4M	$145M	$54M
NEWFOUNDLAND AND LABRADOR	$52M	$7M	$124M	$79M
CANADA	**$3,525M**	**$873M**	**$8,472M**	**$8,116M**

$(2008), UNDISCOUNTED

Per capita costs are highest in Nunavut, British Columbia, New Brunswick, and Prince Edward Island. Figure 15 shows costs per capita in the 2050s. Some jurisdictions face quite a large per capita burden and even within the provinces and territories where costs appear negligible, the costs could be very high at a local level. Disaster relief programs and insurance are both used to redistribute this burden within and across jurisdictions (see Box 5).

FIGURE 15

PER CAPITA COSTS OF DWELLING DAMAGES BY REGION, 2050s



THE LOW END OF THE RANGE IS PER CAPITA COSTS FROM BASELINE RISKS AND LOW CLIMATE CHANGE. THE HIGH END OF THE RANGE IS THE PER CAPITA COSTS FROM BASELINE RISKS AND HIGH CLIMATE CHANGE. $(2008), UNDISCOUNTED

BOX 5

THE ROLE OF INSURANCE IN PROMOTING FLOOD-AWARE DEVELOPMENT

Canadian home insurance policies provide very limited coverage for flooding, typically covering sewer backups but not flooding from storm surges or high river levels.[57] To compensate for this gap in insurance products, governments provide homeowners with financial support when uninsurable disaster-related property damages occur. Through the Disaster Financial Assistance Arrangements (DFAA), the federal government provides funds to provincial and territorial governments who in turn manage and distribute this money through their own programs.[58] These programs are primarily for flood damages as they are the main disaster-related damages that are not covered through insurance in Canada.[59] Between 1970 and 1998, the federal government paid out roughly $700 million to provinces and territories in flood-related assistance.[o 60]

One drawback to government relief programs, in contrast to private insurance, is that they tend to create distance between a household's actual exposure to risk and the household's perception of this risk. In the context of flood risk, this distance between actual and perceived risks likely encourages people to reside in flood-prone areas on the basis that the government will bear some of the costs in the case of a flood.[61] The expectation of guaranteed disaster relief also reduces the incentive to take precautions in the way of flood-proofing measures. A recent study conducted by the Institute for Catastrophic Loss Reduction and Swiss Re proposes including flood insurance in homeowner insurance plans, with premiums and deductibles that reflect the flooding risk that homeowners face.[62] This sort of insurance could encourage homeowners to reduce their flood risk by building more flood-resilient houses and/or building in less flood-prone areas. The report notes that insurance could be cost-prohibitive if it includes households that face a very high flooding risk and that government mechanisms may still be needed to address high-risk cases.

Overall, these costs could represent 0.2% to 0.3% of Canada's GDP each year by the 2050s while cumulative costs over the century could range from $109 billion to $379 billion using a 3% discount rate. Table 9 shows the damages over time as a share of the GDP. The relative impact of these damages rises over time and is consistently higher in the high climate change scenarios than in the low climate change scenarios.

TABLE 9

DWELLING DAMAGES FROM BASELINE RISKS AND CLIMATE CHANGE AS A SHARE OF EACH YEAR'S GDP

	− LOW CLIMATE CHANGE		+ HIGH CLIMATE CHANGE	
	SLOW GROWTH	RAPID GROWTH	SLOW GROWTH	RAPID GROWTH
2020s	0.1%	0.1%	0.2%	0.2%
2050s	0.2%	0.2%	0.3%	0.3%
2080s	0.2%	0.2%	0.3%	0.3%

o This total has not been adjusted to $2008 and instead reflects the currency at the year in which relief was provided.

Table 10 shows the estimated cumulative damages out to 2100 under each of the four scenarios. Again here the costs are much greater in the high climate change scenarios (roughly 50% higher).

TABLE 10

CUMULATIVE DWELLING DAMAGES FROM BASELINE RISKS AND CLIMATE CHANGE, 2011–2100

− LOW CLIMATE CHANGE		+ HIGH CLIMATE CHANGE	
SLOW GROWTH	RAPID GROWTH	SLOW GROWTH	RAPID GROWTH
$109B	$244B	$164B	$379B

$(2008), 3% DISCOUNT RATE

4.5 ADAPTATION STRATEGIES

Strategies to adapt to sea-level rise and the risk of storm surges are well known and fall into three broad categories: retreat, accommodate, and protect. "Retreat" involves moving away from vulnerable areas, "accommodate" involves, for example, redesigning homes and changing land use practices in a way that copes better with flooding and saltwater intrusion, and "protect" includes natural and engineered coastal defences to reduce flooding.

Our goal was to assess the cost effectiveness of two adaptation strategies of national application. We selected strategies that could yield benefits at low or no cost, could be flexible in their implementation, that limited the possibility of maladaptation, and that we could analyze in our modelling framework. In practice, adaptation decisions reflect local needs and contexts and likely require higher-resolution data than what we used here.

CLIMATE-WISE DEVELOPMENT PLANNING: The first strategy prohibits future construction in areas expected to be at risk of flooding by 2100 in a high climate change scenario. In this proactive strategy, the number of dwellings at risk of flooding stays at current levels, with existing dwellings being rebuilt following storm surges. No additional growth is allowed in these areas. Economic benefits are equal to the costs that would have been incurred by flooding of new homes — the avoided costs, in other words. Although our analysis assumes the strategy to be costless, we do recognize that including unearned property tax revenues and unrealized development value would provide a more complete picture.

STRATEGIC RETREAT: The second strategy entails a gradual abandonment of newly flooded areas. That is, we assume that the flooding takes place and the reactive adaptive response is to relocate to a safe area. The incremental costs of adaptation are zero since a home would otherwise be rebuilt in the current location. The only difference in the case of adaptation is the location of the rebuilt home. The economic benefits of this strategy are the savings from not rebuilding a home over and over in a flood-prone area. This strategy could also be proactive with retreat happening in advance of flooding once the risk passed a certain threshold. This would also allow for the possibility of relocating many of the assets before they are damaged. We recognize that infrastructure such as roads and utilities may also need to be relocated, increasing the costs of this strategy. We also recognize that procuring land on which to build may be difficult, but this was not included in our analysis. Indirect costs associated with community and employment disruptions could be significant but were beyond the scope of our modelling.

In practice, both strategies can be challenging and controversial, raising concerns about the loss of value for existing homes, lost tax revenues, and significant disruptions to existing communities. Adaptation is required to avoid possible last-minute relocation of communities with associated economic costs and social trauma. The right response to growing flood risks will be place-specific.

Both adaptation strategies reduce the costs of climate change but strategic retreat yields benefits one order of magnitude higher than climate-wise planning. This is because in the climate-wise planning strategy, existing homes that are flooded by storm surges continue to be rebuilt over and over during the century, accumulating costs each time. With a policy of strategic retreat, damaged homes are abandoned and the price of rebuilding them is invested instead into homes in less risky areas. Here we highlight the benefits of adaptation to climate change impacts, although we recognize the value of considering the potential of adaptation to reduce baseline risk. **Table 11** provides a summary of the results of our adaptation analysis.

TABLE 11

SUMMARY OF TWO COASTAL ADAPTATION STRATEGIES

	ADAPTATION STRATEGY #1				ADAPTATION STRATEGY #2			
STRATEGY	Climate - wise development planning: Prevent new development in areas that will be at risk of flooding				Strategic retreat: Rebuild homes in areas that are not prone to flooding			
OBJECTIVE	Reduce costs of flooding				Avoid rebuilding a home multiple times			
COSTS OF IMPLEMENTING STRATEGY	Assumed zero cost				Assumed zero cost			
BENEFITS OF IMPLEMENTING STRATEGY (PRESENT VALUE, 2010-2100)	–		+		–		+	
	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID
	$4.3B	$15.3B	$16.6B	$55.1B	$16.7B	$44.7B	$70.7B	$173.0B
BENEFIT-COST RATIO	Not applicable				Not applicable			
REMAINING COSTS OF CLIMATE CHANGE AFTER ADAPTATION (PRESENT VALUE, 2010-2100)	–		+		–		+	
	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID
	$13.2B	$32.2B	$56.8B	$127.0B	$0.9B	$2.7B	$2.7B	$9.1B
POTENTIAL CO-BENEFITS	• Avoided injury and loss of life • Avoided interruption to communities and households • Reduced flooding damage from baseline risks				• Avoided injury and loss of life • Reduced flooding damage from baseline risks			
IMPLEMENTATION CHALLENGES	• Difficult in densely populated areas where property is already expensive • Financial loss for current property owners				• Disruption to communities • Reduction in value of homes • Costs of servicing new developments • Limited options for relocation in densely populated areas			

Slow Canadian economic and population growth
Rapid Canadian economic and population growth
– Low climate change
+ High climate change
$(2008), 3% DISCOUNT RATE

When both adaptation strategies are pursued in combination, they could lower the cumulative costs of climate change impacts down to $1 billion to $6 billion over the century. Using climate-wise planning and strategic retreat in combination, cumulative damages are just 3% to 4% of the costs without adaptation to climate change. If the damage estimates were expanded to include commercial, industrial, and public property and infrastructure, the costs of climate change and the savings from adaptation would be much higher. These strategies also have co-benefits like reducing risks to human safety and reducing damages from flooding unrelated to climate change.

Some jurisdictions have begun to assess and implement these sorts of adaptive strategies. Prince Edward Island is currently considering increasing the setback for new coastal development in response to erosion exacerbated by increasing storm surges and declining sea ice in a changing climate.[63] New Brunswick has established a Coastal Areas Protection Policy that includes special zoning restrictions for coastal

lands. The policy limits development in coastal areas and adjacent buffer zones. The purpose is to maintain ecosystem functions and natural defences, reduce risk exposure and reduce public expenditures on rebuilding efforts and erosion control.[64] The Government of Québec and the council of regional municipalities for the Haute-Côte-Nord established regulations to manage construction and land use in areas exposed to erosion to protect people and assets from damage.[65]

We recognize that often the most "popular" adaptation strategy among owners of coastal property is the construction of seawalls and other engineered and natural defences. These defences were not a reasonable adaptation strategy for our national analysis since local conditions have an important impact on the cost, as do choices of what areas will and will not be protected. Defences can be problematic given their upfront and operational costs, maintenance requirements, and especially their interference with coastal ecosystems that serve as natural buffers. However, enhancing dikes and creating other defences, either engineered or natural, may be seen as a more attractive adaptation strategy in some densely populated areas to minimize disruption for dwelling owners and occupants (see **Box 6**).

BOX 6

FLOODING AND DIKES IN METRO VANCOUVER

Metro Vancouver faces two sets of flooding risks — risks from ocean flooding and risks from Fraser River flooding. Large parts of Delta, Richmond, Sea Island, and Surrey are on a floodplain (see image on next page), including the Vancouver International Airport, and some of these areas are heavily populated. In a changing climate, sea-level rise and storm surges will heighten the risk of ocean flooding.

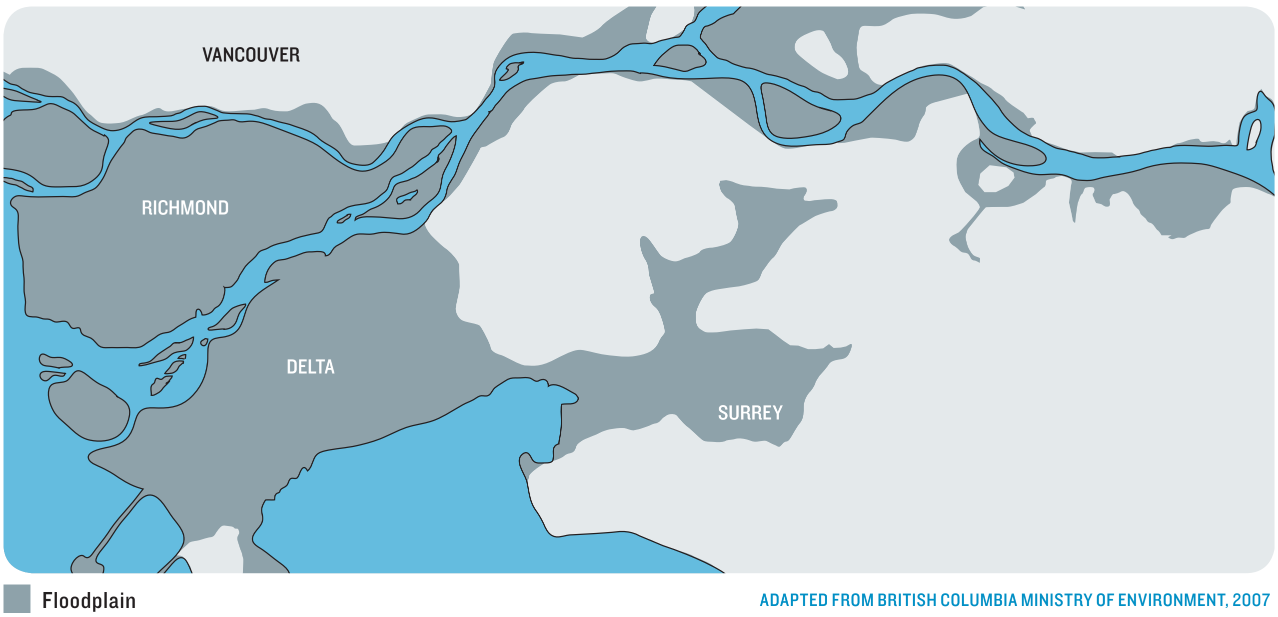
Events over the past 65 years illustrate Metro Vancouver's vulnerability to flooding under current climate conditions. In 1948 the Fraser River flooded and the dike system failed, resulting in 10 deaths, the destruction of 2,000 homes and roughly $184 million in damages.[66] In February 2006, a combination of a high tide and strong winds damaged dikes at Boundary Bay in Delta, resulting in damages to roughly 200 homes.[67]

In a changing climate, choices about adapting to sea-level rise and storm surge risks in Metro Vancouver will have to consider the value of the stock at risk, the level of investment needed to improve and maintain engineered defences, and the feasibility of continuing to rely on defences over the long term as a key adaptive strategy. No comprehensive assessment of the stock at risk or its value exists for Metro Vancouver. Some local governments have undertaken early costing, our study provides estimates of the dwellings at risk for the province as a whole, and an OECD study estimated the stock at risk in Vancouver as part of a study ranking the exposure of port cities around the world.[68]

At present, much of Metro Vancouver is protected by a 127 kilometre system of dikes, but the system was not built with sea-level rise in mind.[69] The provincial government is responsible for establishing dike guidelines and a process to upgrade these guidelines to account for climate change is underway. Costing future dike improvements is no easy task, given site-specific characteristics that factor into these calculations. A report prepared for the Richmond City Council estimates the costs to enhance Richmond's 49 kilometres of dikes to account for climate change in the order of $100 million.[70] This figure excludes costs of land acquisition that may be needed, and purchasing land on which to build defences can be one of the most expensive line items. An assessment of U.S. Army Corps of Engineers data found the costs of building hard coastal defences runs from $1,400 to $4,800 per linear metre.[71] In California,

raising existing dikes cost about $3,100 per linear metre, building a new dike $8,700 per linear metre, and building a seawall about $30,800 per linear metre.[p,72]

In areas with high concentrations of people and assets, enhancing coastal defences is typically the favoured approach to managing flood risk. Retreat could be a very expensive option in Metro Vancouver due to high property values and space constraints. The City of Delta has identified three strategies to manage flooding. These include assessing options for dike improvement and making some improvements to existing defences, with $300,000 already budgeted as a start; funding research to understand the risks and consequences of flooding, which is expected to cost $110,000; and limiting development on land below a certain flood level.[73] The city is also working with the Collaborative for Advanced Landscape Planning at the University of British Columbia to engage the community in discussions about the implications of climate change for Delta and potential adaptive responses.[74]



ADAPTED FROM BRITISH COLUMBIA MINISTRY OF ENVIRONMENT, 2007

4.6 CONCLUSION

Our analysis shows that Canadians living in some coastal communities face flood risks from sea-level rise and storm surges, and that climate change will exacerbate these risks in many cases. By the 2050s, across the country between 16,000 and 28,000 homes are estimated to face a flooding risk. Annual damages are estimated to be in the order of $4 billion to $17 billion per year, equivalent to 0.2% to 0.3% of GDP. The Metro Vancouver area is particularly exposed. We found that adaptation through ceasing development in flood-exposed areas and through rebuilding flood-damaged homes in areas that are not exposed to flooding can greatly reduce these costs. To inform planning decisions, such as those in Metro Vancouver, analysis will also need to factor in the role of dikes, current development rules, and trade-offs in implementing a range of adaptive strategies. Our analysis suggests that in the future more people and assets located by the coast may be put in harm’s way. Discussions about acceptable risk levels and the need to relocate should take place to proactively respond to these increasing risks based on local circumstances.

p For a new dike between 10 and 20 feet in height with a waterside slope of 3:1.

// CHAPTER 5.0

HUMAN HEALTH

5.0 // HUMAN HEALTH

5.1 // THE CLIMATE CONNECTION

5.2 // AN OVERVIEW OF OUR METHODS

5.3 // HEALTH IMPACTS DUE TO CLIMATE CHANGE

5.4 // ECONOMIC IMPACTS

5.5 // ADAPTATION STRATEGIES

5.6 // CONCLUSION

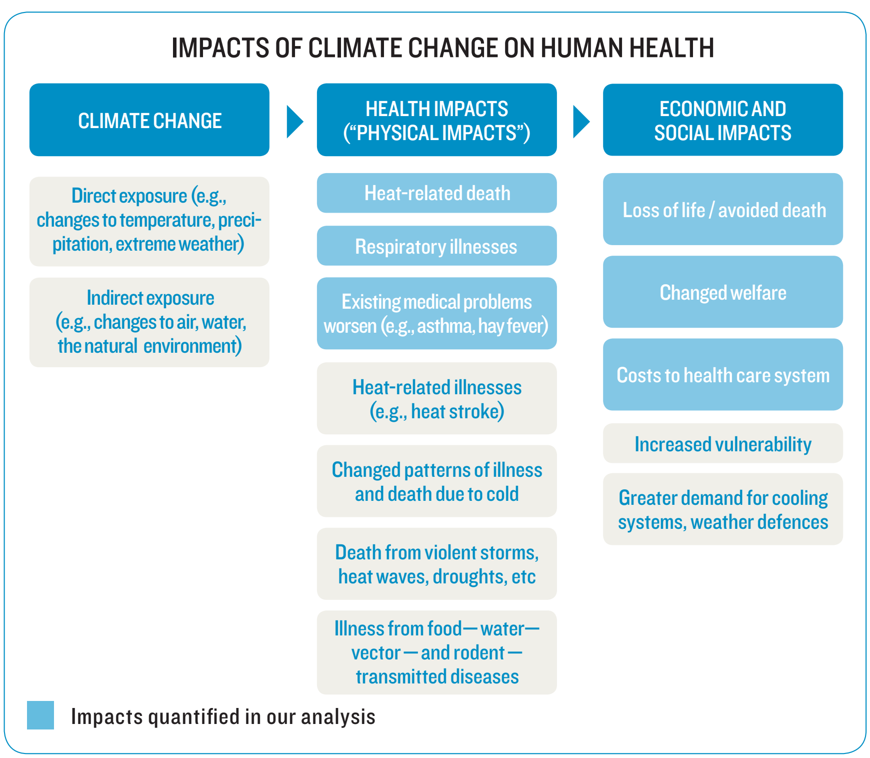
5.1 THE CLIMATE CONNECTION

Warmer summers and worsened air quality from climate change will have consequences for the health of Canadians. By mid-century, these impacts could be responsible for roughly 1% of deaths in Canada.

Weather and climate directly and indirectly affect our health. Illnesses, injuries, and deaths observed during and after events such as the 1998 ice storm in eastern Canada, the European heat wave in 2003, and recent flooding in Pakistan are all reminders of this reality.

A changing climate has the potential to affect our health status through several pathways (**Figure 16**).[75] For example, high temperatures exacerbate heat stroke risk and combined with changes in other weather indicators like air moisture, also alter air quality, affecting existing cardiovascular (e.g., heart conditions) and respiratory (e.g., asthma) illness. In some locations, heat spells, intense rains, and violent storms are likely to become more common compared with today, with the potential to increase the number of injuries, deaths, and evacuations (see **Box 7**). A drop in extreme cold days could reduce illnesses and deaths in winter. For some populations, greater risk of exposure to infectious diseases and diseases transmitted through water and food is also expected.

FIGURE 16



Growing concerns about the health impacts of climate change have encouraged investments to improve our understanding of the health risks we face and of actions needed to start managing them.[76] Although the knowledge base has grown, the NRTEE believes that a better grasp of the economic implications of health impacts of climate change and of investments needed to reduce negative health outcomes is important. We value our health greatly — promotion and enhancement of Canadians' health is consistently a national political issue, with significant public investment attached to it.[q] Climate change has the potential to reduce the quality of life and ability of some Canadians to be productive members of society. It also has cost implications for the health care system.

This chapter contributes to what we expect to be a growing evidence base linking health impacts of climate change to broader implications for our economy and society. We focus on two of the ways climate change could affect health by assessing (1) the health impacts of warmer summers and poorer air quality in four Canadian cities and (2) the economic consequences of those effects for the welfare of Canadians and the health care system, as highlighted in **Figure 16**[r]. Using Toronto as an example, we then analyze the costs and benefits of two strategies aimed at reducing the health impacts of climate change related to heat and air quality.

BOX 7

THE HEALTH TOLL OF THE 1998 ICE STORM IN EASTERN CANADA

Experience with extreme weather and climate-related events in our recent past shows that the number of Canadians affected and economic costs involved can be high, as we illustrate here with the example of the 1998 ice storm in eastern Canada. For about a week, large amounts of freezing rain fell in parts of Ontario, Québec, and New Brunswick, which led more than 250 communities in Ontario and Québec to declare a disaster and over 4.5 million people to lose access to electrical power,[77] some for up to a month.[78]

The massive power outage caused by the ice storm disrupted access to essential services, threatening human health in several ways. The ice storm resulted in 28 deaths, primarily from exposure to carbon monoxide with far fewer cases from hypothermia.[79] Power losses led to the indoor use of open flames, gas barbeques, and heaters, resulting in carbon monoxide poisoning. In addition, about 945 people suffered injuries[80] and over 100 people required emergency medical attention to treat carbon monoxide poisoning from generator use.[81] In Montréal, some water pumping stations lost power, compromising water quality and supply.[82] Icy road conditions — worsened by fallen tree branches and electrical wires — resulted in several car accidents.[83] Medical services were compromised in cases where poor road conditions interfered with ambulance operations, and hospitals had to rely on generators.[84]

Extreme events such as these can also have lasting health impacts. Research shows that among the population studied, children whose mothers were pregnant during the ice storm have lower cognitive and language skills relative to other children at 2 years-old, 5½ years old and even at 8½ years old.[85] This research attributes differences in cognitive and language skills to the high stress levels of expectant mothers during the ice storm.

Many lessons were learned from the ice storm. Hydro-Québec made some improvements to its power grid to reduce the impact of a similar weather event in the future.[86] The Québec government also adopted new public-safety legislation in 2001 to improve emergency preparedness and to establish a surge capacity in order to maintain essential services, ensure the availability of sufficient human resources, and clearly identify the responsibilities of various actors.[87]

q Health care spending accounted for about 10% of Canada's gross domestic product in 2008 (OECD 2010).

r A technical report underpinning this chapter is available upon request: *Costing Climate Impacts and Adaptation: A Canadian Study on Human Health* (Marbek, Kinney, and Anthoff 2011).

5.2 AN OVERVIEW OF OUR METHODS

SEE CHAPTER I FOR A REMINDER OF OUR SCENARIOS

This section provides highlights of the methods used to guide our analysis. Additional information on the methods and limitations is available in **Appendix 8.5**.

PHYSICAL IMPACTS: We estimated the future[s] costs of climate change separately for two types of health impacts under each of our four **SCENARIOS**: changes in risk of death from increased summertime heat and changes in risk of illnesses and deaths from poorer air quality. We chose these two types of health impacts because of (1) the degree of scientific confidence in the connections (a) between heat and deaths and (b) between heat and air pollution and deaths and illnesses; (2) the vulnerability of the Canadian population to these impacts; and (3) the data and research available to guide our analysis. We investigated costs for four of Canada's largest cities — Vancouver, Calgary, Toronto, and Montréal — representing almost 40% of country's population.[t,88] A local lens was necessary for this analysis due to the variability of environmental factors that impact health (such as baseline temperatures and air quality) from location to location, current health status, and public health and other options available to prevent or minimize harm. The two health impacts selected for study are a concern across the country but are of heightened concern in large cities due to the urban heat-island effect and existing air quality problems.[u] These health impacts also present risks in rural areas where the availability of and access to support services are more limited.[89]

// HEAT: Drawing on existing evidence, we quantified the effect of rising temperatures on deaths related to heat, and since high temperatures primarily occur in the summer in Canada, our analysis focused on this season. We used forecasted changes in temperatures over the century and health research linking temperatures to death rates to estimate the additional deaths from heat expected to arise from climate change.

We take into account levels of acclimatization and adaptation to the extent that they were captured in the published research we used, but we do not make assumptions about how Canadians could further acclimatize or about how their behaviour could shift to adapt to warmer temperatures in the future. Recent European research suggests that acclimatization and behavioural shifts could decrease the health impact of heat by a factor of five.[90] We don't know if the same effect would be true for cities in Canada. We did not assess potential benefits stemming from reduced winter cold — recent North American research has shown that winter death rates are not sensitive to differences in temperatures across locations.[91]

s In other words, our analysis does not explicitly draw out cases of deaths and illnesses attributable to changes in climate conditions experienced to date.

t According to Statistics Canada, the 2009 population (millions) and population as a share of national total (%) for each city were Vancouver (2.3; 7%), Calgary (1.2; 4%), Toronto (5.6; 17%), and Montreal (3.8; 11%).

u According to Environment Canada, between 2003 and 2005, 40% of Canadians lived in communities with ozone levels exceeding the Canada-wide standard (Environment Canada 2007).

// **AIR QUALITY:** Again drawing on the existing evidence base, we used year-round changes in average temperatures to forecast the corresponding increase in ozone concentrations for each city over the century. We then used Health Canada's Air Quality Benefits Assessment Tool (AQBAT) to generate statistical estimates of the increased incidence of death and illness based on expected increases to individual risk levels from changes in ozone concentrations.[v] This analysis does not incorporate any future improvements in air quality that may result from government policies, technological change, or other forces. There may be synergies between the heat and air quality impacts on health, but we could not find sufficient evidence to guide a quantitative approach to incorporating them.

Particulate matter in the air also influences health, and recent research has shown that the impacts of climate change on fine particulate matter may have greater health consequences than the impacts of climate change on ozone.[92] However, more research on the impacts of climate change on ozone has been conducted to date[93] and we did not find sufficient scientific evidence to establish a relationship between changes in climate conditions and changes in concentrations of fine particulate matter.[w]

ECONOMIC IMPACTS: The health impacts of climate change are most readily understood in terms of changes in the rate and overall incidence of additional deaths and illnesses that are expected. However, economics can also provide a useful tool to understand and value the health impacts of climate change. Climate change carries social costs that do not register in our national economic accounts but are nonetheless important in allocating public resources. A failure to capture these costs in economic terms can lead to the exclusion of these costs in decision making — when we don't value something, often the default value can be zero. To start a conversation about the economic consequences of climate change for our health, we need to acknowledge that each individual life is priceless. We do not try to assign a value to an individual life, but instead we rely on a widely accepted metric — a welfare indicator — called the "value of a statistical life" (VSL). Broadly speaking, summing how much a population is willing to pay for a small reduction in the risk of dying provides the VSL — the willingness to pay to avoid one death within that population. The VSL is used widely by government to quantify the benefits of new regulations expected to reduce the risk of death within a population. These benefits can be compared with the costs of the regulation in a cost-benefit analysis. The Treasury Board Secretariat recommends a VSL of $6.8 million,[94] and we apply this value throughout our analysis.[x]

Our estimates of added costs of climate change to the health care system focus on increased cases of illness related to air quality. Estimates of the costs to the health care system arising from these illnesses factored in public spending on hospital admissions, emergency room visits, drugs, and doctor's office visits. We relied on data from the Canadian Institute for Health Information and other sources to develop cost estimates.

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v The impact estimates are based on the increased risk of illness and death across the population. We use these to develop statistical estimates of the likely increase in the overall incidence of illness and death.

w Early results have suggested that higher temperatures may reduce concentrations of fine particulate matter, but more research is needed to account for other factors such as precipitation and emissions in warmer climate conditions (Lamy et al. 2008).

x Adjusted from $(2004) 6.1 million based on inflation and real income growth. We do not further scale up the VSL over time based on income growth and the corresponding increase in willingness to pay that could be expected. A large share of future increases in willingness to pay for mortality risk reductions would be nominal, and keeping the VSL constant is appropriate since we use the current period as our evaluation point for the adaptation strategies.

5.3 HEALTH IMPACTS DUE TO CLIMATE CHANGE

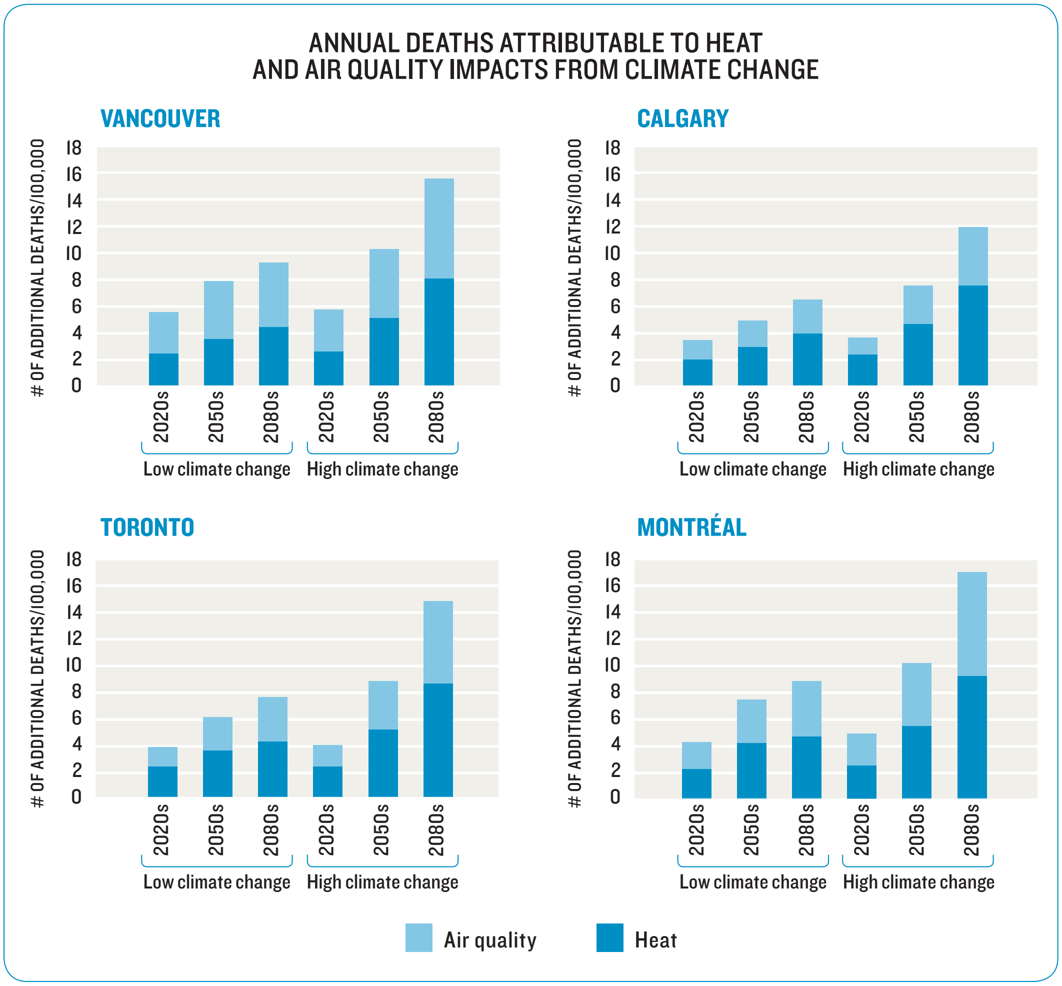
Climate change results in additional deaths from heat and air pollution across the four cities on the order of three to six deaths per 100,000 people per year in the 2020s, with impacts worsening in future decades. Figure 17 shows the combined effect of climate change on heat and air quality expressed as the yearly average number of cases per 100,000 people. Our analysis indicates that climate change could be responsible for roughly five to 10 additional deaths per 100,000 people by the 2050s and seven to 17 by the 2080s.[y]

Taking Toronto as an example, our analysis shows that additional deaths per 100,000 people could double in the low climate change scenario but more than triple between the 2020s and 2080s in the high climate change scenario. By the 2080s, Toronto could see from 570 to 1,238 additional deaths per year reflecting the growing impact of climate change and also the growing size of the city.

In proportional terms, results are similar across the four cities, with some variation due to differences in the magnitude of temperature change expected from climate change.

y Presenting results as rates (per 100,000 people) removes the influence of alternative population growth assumptions used in the analysis. This is why we show results for the two climate change scenarios rather than all four future scenarios. Absolute numbers of death and illness vary based of future population growth.

FIGURE 17



According to our analysis, by the 2080s, deaths related to higher temperatures and poorer air quality attributable to climate change could account for 1% to 2% of the total deaths within the cities examined. Table 12 shows the percentage of overall deaths attributable to the impact that climate change will have on temperature and air quality relative to current death rates assumed to occur without climate change.[z] For the cities we considered, deaths are estimated to increase between 0.5% to 0.7% by the 2020s and between 0.9% and 1.3% by the 2050s over and above deaths that could be expected in the absence of future climate change. As a comparison, in 2007 kidney disease was the cause of 1.6% of deaths in Canada, and influenza and pneumonia were the cause of 2.3% of deaths.[95] These impacts will not be evenly distributed across the year — they will be much more pronounced in the summer months when the deaths from heat occur.

z We assume current death rates continue over time. However, Informetrica Ltd. forecasts for Canada as a whole indicate an increase in deaths as a percentage of the population peaking at about 2050, stabilizing thereafter (Informetrica Limited 2010).

TABLE 12

DEATHS ATTRIBUTABLE TO HEAT AND AIR QUALITY IMPACTS FROM CLIMATE CHANGE AS A PROPORTION OF OVERALL DEATHS

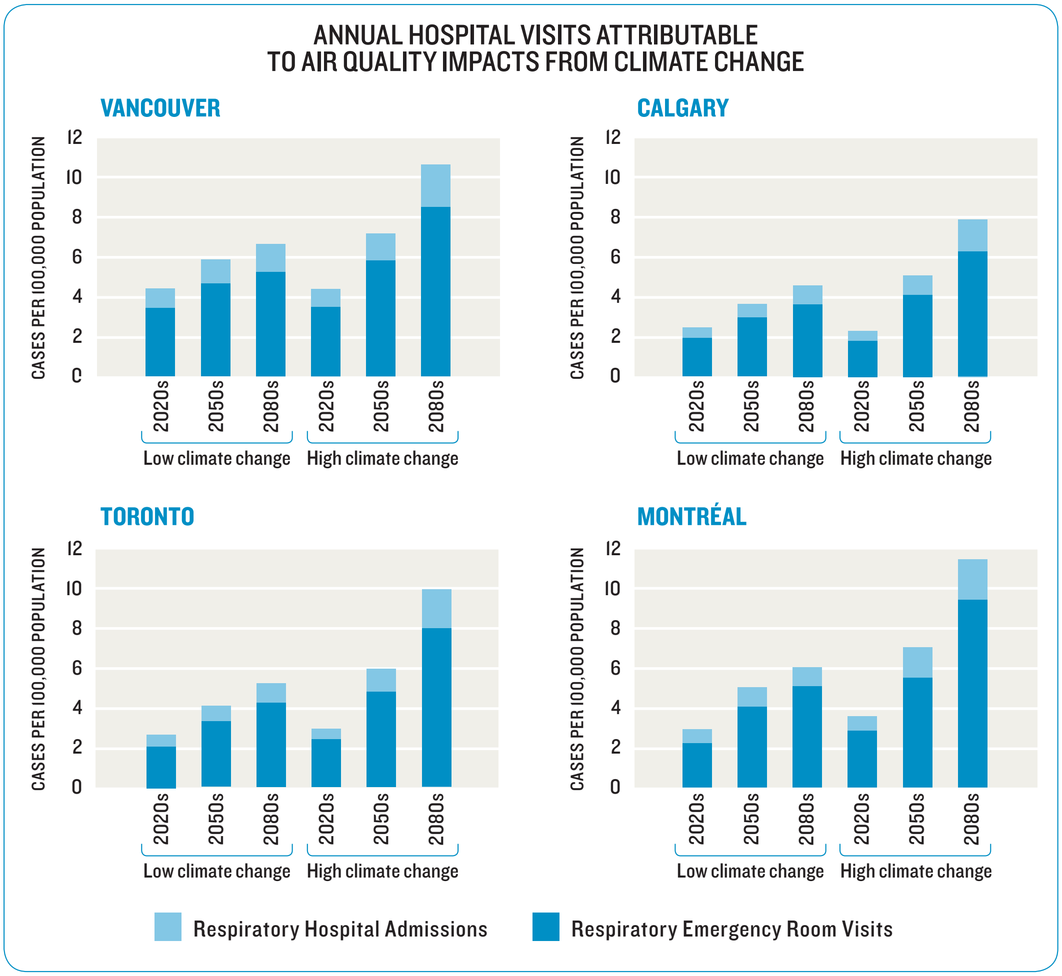
	VANCOUVER		CALGARY		TORONTO		MONTRÉAL	
	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE
2020s	0.7%	0.7%	0.6%	0.6%	0.5%	0.6%	0.5%	0.6%
2050s	0.9%	1.2%	0.9%	1.3%	0.9%	1.2%	0.9%	1.2%
2080s	1.1%	1.9%	1.1%	2.0%	1.1%	2.1%	1.1%	2.1%

In a changing climate, deteriorating air quality will lead to an additional four to seven hospital visits per 100,000 people per year by the 2050s. Figure 18 shows hospital visits — both trips to the emergency room and hospital admissions — increasing over time. For example, Vancouver will experience an average of six additional visits per 100,000 people in the 2050s, and most of those will be emergency room visits. Applying population growth assumptions to the rates in **Figure 18**, our analysis suggests that by the 2050s Vancouver could see an additional 124 to 169 respiratory emergency room visits and 31 to 42 respiratory hospital admissions each year.

Cities where temperatures are expected to increase the most will be more adversely affected. For example, in Vancouver, a rise in annual average temperatures of 2.7°C by the 2050s in the low climate change scenario results in six additional hospital visits per 100,000 people, whereas in Calgary, a rise in annual average temperatures of 1.9°C would result in roughly four additional hospital visits.

Air quality is a particular health concern for those with respiratory problems such as asthma, for people working outdoors, and for the elderly and infants. We can expect future impacts of climate change to disproportionately affect these groups but our analysis does not account for these demographic differences.

FIGURE 18



Poorer air quality will also increase the number of days people present with respiratory problems resulting in a roughly three-fold increase with high climate change and a roughly two-fold increase with low climate change, between the 2020s and 2080s. The consequences of these health impacts include reduced quality of life, employee absenteeism, and costs to the health care system. **Table 13** shows what could happen to three illness indicators in the 2050s. For example, in Calgary under a low climate change scenario, we can expect an additional 1,134 days that people with asthma have symptoms per 100,000 people.

Consistent with the impacts expected for hospital visits, for the four cities we studied, cities where temperature changes are most pronounced (e.g., Vancouver) will be the most adversely affected and certain groups within the population, for example asthma sufferers, will disproportionately bear the burden of these impacts.

TABLE 13

ANNUAL CASES OF ILLNESS PER 100,000 PEOPLE ATTRIBUTABLE TO AIR QUALITY IMPACTS FROM CLIMATE CHANGE, 2050s

	VANCOUVER		CALGARY		TORONTO		MONTRÉAL	
	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE
DAYS THAT PEOPLE HAVE RESPIRATORY SYMPTOMS LIKE COUGHING OR CHEST DISCOMFORT	11,161	13,538	7,677	10,671	7,876	11,451	8,784	12,485
DAYS THAT PEOPLE WITH ASTHMA HAVE SYMPTOMS, SUCH AS WHEEZING AND SHORTNESS OF BREATH	1,652	2,006	1,134	1,579	1,164	1,695	1,298	1,849
DAYS WHERE PEOPLE'S ACTIVITIES ARE RESTRICTED DUE TO POOR AIR QUALITY	1,029	1,249	707	984	726	1,056	810	1,152

5.4 ECONOMIC IMPACTS

The costs of premature death risks from climate change calculated based on the VSL are in the order of billions of dollars per year for each city, and they grow over time. Table 14 shows the evolution of annual costs over time for each city in the highest and lowest cost scenarios. For example, the results for Montréal indicate that by the 2050s, annual costs will be greater than $2 billion per year with low climate change and slow population growth, and greater than $3 billion per year with high climate change and rapid population growth.

These costs are a function of the health impacts, themselves a function of population size and the severity of climate change. The growing difference in costs between the two "book-end" scenarios reflects diverging population and health impact forecasts over time: costs by the 2080s are about half as large in the low climate change–slow growth scenario relative to the high climate change–rapid growth scenario. Costs vary among cities — the largest cities incur the greatest costs primarily because of the exposure of a greater number of people to climate change impacts in those cities.

TABLE 14

ANNUAL COSTS OF PREMATURE MORTALITY RISK ATTRIBUTABLE TO HEAT AND AIR QUALITY IMPACTS FROM CLIMATE CHANGE

		VANCOUVER		CALGARY		TORONTO		MONTRÉAL	
		-	+	-	+	-	+	-	+
		SLOW	RAPID	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID
2020s	PER PERSON	$381	$391	$231	$251	$257	$274	$285	$327
	CITY TOTAL	$0.9B	$1.0B	$0.3B	$0.3B	$1.5B	$1.6B	$1.1B	$1.3B
2050s	PER PERSON	$530	$692	$342	$517	$412	$594	$503	$685
	CITY TOTAL	$1.3B	$2.0B	$0.4B	$0.7B	$2.6B	$4.2B	$2.2B	$3.4B
2080s	PER PERSON	$625	$1,049	$446	$820	$510	$995	$594	$1,152
	CITY TOTAL	$1.9B	$3.5B	$0.7B	$1.3B	$3.9B	$8.4B	$3.1B	$6.8B

Slow Canadian economic and population growth

Rapid Canadian economic and population growth

− Low climate change

+ High climate change

$(2008), UNDISCOUNTED

In present value terms, the costs for each city between now and the end of the century will be in the tens of billions of dollars. Table 15 shows the range of cumulative costs for each city, which were summed using a 3% discount rate. Costs are lowest in Calgary — ranging from $11 billion to $17 billion depending on the scenario — primarily because Calgary has the smallest population of the four cities considered.

TABLE 15

CUMULATIVE COST OF PREMATURE MORTALITY RISK ATTRIBUTABLE TO HEAT AND AIR QUALITY IMPACTS FROM CLIMATE CHANGE, 2010–2100

CITY	COST
TORONTO	$65 BILLION TO $96 BILLION
MONTRÉAL	$52 BILLION TO $77 BILLION
VANCOUVER	$36 BILLION TO $48 BILLION
CALGARY	$11 BILLION TO $17 BILLION

$(2008), 3% DISCOUNT RATE

A further way to understand the health costs associated with climate change is to explore potential implications for Canada's health care system. Health care spending accounted for about 10% of Canada's gross domestic product in 2008, with 70% of spending coming from public sources.[96] Rising hospital admissions and rates of respiratory illness linked to degraded air quality in a changing climate will add to future health care costs. Since health care is already a chief line item in public budgets, estimating the potential size of this added economic burden is an important step in considering investments today to save on costs to treat illness tomorrow. Similar to preventative care that seeks to reduce the incidence of disease before it occurs, understanding the economic implications of climate change adaptation can highlight whether and where a form of proactive adaptation could yield similar benefits.

The economic burden on the public health care system from illness in a changing climate amounts to millions of dollars per year for each city and grows over time. In a high climate change scenario, this economic burden, on average, grows from 40 cents per person per year in the 2020s to over $5 per person per year in the 2080s. Table 16 shows added health care costs from rising hospital admissions, trips to the emergency room, and days with acute respiratory symptoms, asthma symptoms, and restrictions in physical activity due to degraded air quality in a changing climate. For example, our results suggest that additional cases of illness in Toronto in the 2050s could add $3 million per year to public health care costs in the lowest case scenario and over $11 million in the highest case scenario. Expressed differently, our results show that respiratory illness due to climate change in the 2050s could add between 50 cents and $1.60 per person per year to public health care costs. To put these costs into context, the annual costs for Toronto in the 2050s would be comparable to paying the annual salaries of between six and nine doctors or 32 and 52 nurses.[aa]

For all cities and time periods, about 70% of added costs to the health care system are due to the high incidence of acute respiratory symptom days, with manifestation such as coughing, nasal drip, and chest discomfort. Days with asthma symptoms and respiratory hospital admissions each represent over 10% of the costs. These added costs derive from more spending on drugs and more doctors' visits than would be the case in the absence of climate change. Within the categories of public spending, medication costs represent roughly 60% of the overall costs, followed by doctor's office visits and hospital admissions. Similar to welfare impacts of premature death, differences in total costs across cities are a function of the number of people exposed to climate change impacts.

aa Estimated total clinical costs per full-time equivalent family medicine physician from the Canadian Institute for Health Information (Canadian Institute for Health Information 2010c). These costs are scaled up over time with GDP.

TABLE 16

ANNUAL HEALTH CARE COSTS ATTRIBUTABLE TO AIR QUALITY IMPACTS FROM CLIMATE CHANGE

		VANCOUVER		CALGARY		TORONTO		MONTRÉAL	
		-	+	-	+	-	+	-	+
		SLOW	RAPID	SLOW	RAPID	SLOW	RAPID	SLOW	RAPID
2020s	PER PERSON	$0.4	$0.6	$0.3	$0.4	$0.2	$0.6	$0.2	$0.4
	CITY TOTAL	$1M	$1M	$0M	$0M	$1M	$2M	$1M	$2M
2050s	PER PERSON	$0.7	$1.9	$0.5	$1.6	$0.5	$1.6	$0.5	$1.7
	CITY TOTAL	$2M	$6M	$1M	$2M	$3M	$11M	$2M	$8M
2080s	PER PERSON	$1.0	$5.9	$0.8	$5.1	$0.8	$5.3	$0.8	$5.8
	CITY TOTAL	$3M	$20M	$1M	$8M	$6M	$45M	$4M	$34M

Slow Canadian economic and population growth
Rapid Canadian economic and population growth
– Low climate change
+ High climate change

$(2008), UNDISCOUNTED

In present value terms, the added costs to the health care system from cases of rising illness in the four cities between now and the end of the century totals hundreds of millions of dollars. Table 17 presents the range of cumulative costs that climate change adds to the public health care system, using a 3% discount rate. For all cities, the low end of the range pertains to the low climate change–slow growth scenario and the high end to the high climate change–rapid growth scenario.

TABLE 17

CUMULATIVE HEALTH CARE COSTS ATTRIBUTABLE TO AIR QUALITY IMPACTS FROM CLIMATE CHANGE, 2010-2100

CITY	COST
TORONTO	$72M to $285M
MONTRÉAL	$54M to $213M
VANCOUVER	$46M to $140M
CALGARY	$16M to $54M

$(2008), 3% DISCOUNT RATE

Additional public health care costs are only one aspect of the social costs arising from climate change. Lost productivity and pain and suffering also present social costs but we do not put a dollar value on those in this report.

5.5 ADAPTATION STRATEGIES

Several strategies exist to reduce the adverse impacts of climate change on our health.[97] Examples of adaptive measures pertaining to heat and air quality impacts of climate change include public education (e.g., reducing physical activity at times when temperatures or air pollution are particularly high), reducing the urban heat-island effect, putting in place early warning systems, opening cooling centres during heat waves, and treating illnesses as they arise. Air conditioning is among the most effective ways to deal with health issues arising from heat, and public health agencies promote this coping strategy among vulnerable populations. However, increasing electricity production to meet the demand created by air conditioners can worsen local air quality and add to greenhouse gas emissions (depending on the electricity source), creating further health risks. Strategies often include a range of measures. **Box 8** provides a description of one such strategy.

BOX 8

REDUCING VULNERABILITY TO HEAT IN URBAN CENTRES

An innovative approach to managing urban heat issues is afoot in Canada. Building on experiences with heat waves in Europe and the United States in the past 15 years, Canadian cities are starting to put systems in place to monitor and respond to hot weather conditions posing health threats. Toronto and Montréal have both implemented heat alert and response systems, and Health Canada has recently launched a pilot project in four more communities to establish and evaluate these systems and develop guidance for other communities.[98]

Heat alert and response systems trigger public alerts and a number of follow-up actions when weather conditions reach certain thresholds. A range of triggers exist, but most often they are based either on the humidex and minimum and maximum temperatures as in Montréal[99] or on an analysis of local weather and mortality patterns as in Toronto.[100] When a heat alert or an extreme heat alert is triggered in Toronto, a hot weather response plan prompts several actions, such as issuing media alerts advising the public of the health risks,[101] delivering bottled water to vulnerable groups, extending operational hours of recreational facilities, and opening community cooling centres.[102] Toronto Public Health coordinates Toronto's system, which involves a wide range of partner agencies such as the Canadian Red Cross, community health centres, and public libraries.[103]

Early evidence suggests that heat alert and response systems are a wise investment. Between 1995 and 1998, Philadelphia's heat wave warning system cost US$210,000 to operate, but saved an estimated 117 lives during that three-year period.[104] Using the value of statistical life that we used in our main analysis, we determined that this is equivalent to roughly $800 million in savings, with benefits of the program outweighing costs nearly 4,000 to 1. Costs in Canada may be on the same order of magnitude: in 2010, Toronto Public Health had a budget of $458,000 for the heat health alert system and response plan but other city departments also incurred costs.[105]

A range of criteria shape decisions to select and apply one or another strategy — from an economic perspective, we focus on cost-effectiveness. Using Toronto as an example, we estimate the potential costs and benefits of two strategies to reduce exposure to heat and poor air quality in a changing climate: replacing conventional roofs with green roofs to cool temperatures and installing pollution control technologies to limit ozone formation. Beyond reducing exposure of individuals to health risks, both strategies have the potential to yield other community benefits such as improved stormwater management in the case of green roofs and reduced impact on the natural environment in the case of pollution control.

REDUCING THE URBAN HEAT-ISLAND EFFECT THROUGH GREEN ROOFS: The heat-island effect can make cities several degrees warmer than the rural areas that surround them. This is by virtue of heat-absorbing building and pavement materials and widespread processes that release waste heat that are concentrated in cities (e.g., automobiles). Strategies to enhance evapotranspiration, reduce the heat flow through walls and roofs, and make cities reflect more sunlight, for example through lightening the colour of surfaces and increasing vegetation, can reduce air temperatures.[106]

Our analysis looks at the costs of widespread installation of green roofs and benefits (i.e., welfare savings) from reduced deaths as an example of this broader approach to countering the health impacts of the warmer temperatures. We assessed the costs and benefits of installing enough green roofs to reduce the summertime temperatures by 1°C in Toronto. We estimate the incremental costs[bb] of installing green roofs between 2035 and 2050 (once conventional roofs reach the end of their lifetime) and of maintaining these roofs until 2059 and compare these costs to the welfare savings from reduced deaths from 1°C cooler temperatures between 2050 and 2059. To compare streams of costs and benefits over time and cast them in present value terms, we use a 3% discount rate (see **Appendix 8.5** for details).

Table 18 summarizes the results of our economic analysis. The present value cost of installing and maintaining the green roofs between 2035 and 2059 amounts to $7.3 billion. Reductions in risks of deaths from heat can compensate for almost one-third of these costs, with the present value of the health benefits ranging from $2.1 billion to $2.4 billion. Looking only at the reductions in deaths from heat, the benefits of this strategy do not outweigh the costs, and our benefit-cost ratio is roughly 0.3. Capturing the value of co-benefits from widespread green roof installation, such as fewer heat-related illnesses, decreased impacts on worker productivity, fewer air pollution–related deaths, energy savings, improved storm water management, and increased habitat for pollinating insects would improve the business case for this strategy. A recent study compared the overall flows of costs and benefits of a green roof to a conventional roof, factoring in storm water, energy, and air quality benefits. It found that over a long time horizon, green roofs are less expensive than conventional roofs.[107] Other strategies to enhance urban vegetation such as planting trees and expanding green space could achieve the same cooling effect and are also being explored by the City of Toronto, among others. Enhancing vegetation could be particularly effective in low-income areas with limited green space. A lack of green space has been shown to contribute to higher mortality rates among low-income populations.[108]

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bb Over and above the costs of installing conventional roofs.

IMPROVING AIR QUALITY BY INSTALLING CONTROLS TO REDUCE OZONE-FORMING EMISSIONS: The concentration of cars, industry, and households in urban areas contributes to local air pollution and ozone formation. Some air pollutant emissions like nitrogen oxides (NO_x) and volatile organic compounds (VOCs) are considered to be ozone "pre-cursors" in the sense that these pollutants can cause ozone to form in the lower atmosphere. Strategies that reduce ozone-forming air pollutant emissions could help to offset the air quality impacts of climate change.

Our analysis looks at the costs and benefits of investing in pollution control to a level that would fully offset the ozone concentration increase expected from warmer temperatures in a changing climate. We compare the present-value costs of pollution control to the present-value welfare savings from reduced death risk from 2050 to 2059 (see **Appendix 8.5** for details). Our pollution control strategy is generic and the costs of control are based on cost estimates developed by the U.S. Environmental Protection Agency drawing from known control technologies and possible future innovations covering a range of emissions sources, both stationary and mobile.[109]

Table 18 summarizes the main findings from this analysis. The total costs of pollution control for 2050 to 2059 are $0.7 billion to $3.1 billion once discounted to the present value using a 3% discount rate. We then compare the costs with the present value welfare benefits of deaths avoided in that decade — $3.0 billion to $4.8 billion. We find that in every scenario, the present value of the benefits exceeds that of the costs, with the benefit-cost ratio varying between 1.4 and 4.5. This adaptation strategy could also provide important co-benefits to the natural environment and health by reducing other forms of air pollution. The specific costs of emissions control would vary from city to city, and further investigation of these costs is warranted. Based on the cost figures used in this analysis, there could be a solid business case for investing in local pollution control as a climate change adaptation strategy.

TABLE 18

SUMMARY OF TWO HEALTH ADAPTATION STRATEGIES

	ADAPTATION STRATEGY #1				ADAPTATION STRATEGY #2			
STRATEGY	Reduce the urban heat-island effect by 1°C through widespread installation of green roofs (evaluation between 2035 and 2059)				Improve air quality Install air pollution control technologies to offset increases in ozone concentrations induced by climate change (evaluation between 2050 and 2059)			
OBJECTIVE	Reducing exposure to heat avoids between 116 and 129 deaths in Toronto per year between 2050 and 2059				Reducing ozone concentrations avoids 163 to 265 deaths per year in Toronto between 2050 and 2059			
COSTS OF IMPLEMENTING STRATEGY (PRESENT VALUE)	–		+		–		+	
	SLOW	RAPID	SLOW	RAPID				
	$7.3B				$0.7B		$3.1B	
BENEFITS OF IMPLEMENTING STRATEGY (PRESENT VALUE)					–		+	
	SLOW		RAPID		SLOW	RAPID	SLOW	RAPID
	$2.1B		$2.4B		$3.0B	$3.3B	$4.3B	$4.8B
BENEFIT-COST RATIO					–		+	
	SLOW		RAPID		SLOW	RAPID	SLOW	RAPID
	0.29:1		0.32:1		4.0:1	4.5:1	1.4:1	1.6:1
REMAINING COSTS OF CLIMATE CHANGE AFTER ADAPTATION (PRESENT VALUE)	–		+		There are no residual impacts since we assume that the strategy fully offsets the health impacts of climate change			
	SLOW	RAPID	SLOW	RAPID				
	$2.0B	$2.2B	$3.8B	$4.2B				
POTENTIAL CO-BENEFITS	• Storm water management • Habitat restoration • Energy savings				• Reduced impact on natural environment • Reduced fuel consumption • Reductions in other air pollutant emissions			
IMPLEMENTATION CHALLENGES	• Requires coordination between urban planning and public health • Not suitable for all building types				• Requires coordination between air quality regulators and public health • Opposition from organizations that would be required to reduce their emissions			

SLOW: Slow Canadian economic and population growth
RAPID: Rapid Canadian economic and population growth
– Low climate change
+ High climate change

$(2008), 3% DISCOUNT RATE

5.6 CONCLUSION

Our analysis shows that warmer summertime temperatures and higher ozone concentrations in a changing climate could lead to a greater risk of illness and death in Montréal, Toronto, Calgary, and Vancouver. In these four cities, there could be an additional five to ten deaths and four to seven hospital visits per 100,000 people by the 2050s. These changes will impact our welfare. Using the value of statistical life concept, we determined that people living in these four cities would be willing to pay $300 to $700 per person by the 2050s to avoid this increase in risk of dying. Increases in incidence of respiratory illnesses will impact the health care system, imposing costs in the order of millions of dollars each year by the 2050s. Adapting to climate change could reduce some of the negative impacts. Installing green roofs could help reduce urban temperatures but does not appear cost-effective strictly from a climate change perspective. Reducing air pollution could cost-effectively offset the negative impacts of climate change on ozone concentrations.

// CHAPTER 6.0

ECOSYSTEMS

6.0 // ECOSYSTEMS

6.1 THE CLIMATE CONNECTION

Our entire well-being — economic and otherwise — relies on healthy, functioning ecosystems. Ecosystem stress from climate change will play out across Canada's economy in some unexpected ways.

Canada is rich in ecosystem diversity, with 15 distinct ecozones on land and five marine-based ones.[110] Increasingly, there is understanding of the economic value and linkage of ecosystems based on the services they provide to both our environment and our economy. A changing climate is altering the quality and health of Canada's ecosystems, some of which are already under pressure from pollution, overuse, habitat fragmentation, and introduction of invasive species.[111] Alongside assessing potential ecological changes in future climates, communities and governments the world over are considering ecosystem conservation and restoration as an option that delivers climate adaptation and mitigation co-benefits.[112]

In *Degrees of Change: Climate Warming and the Stakes for Canada*, the NRTEE highlighted how a changing climate is altering the quality and health of Canada's ecosystems. Our report noted the implications of changes in ocean temperatures and chemistry on marine life and the sustainability of marine food webs, the northward migration of boreal forest species, shifts in the timing of seasonal activities such as the flowering of plants, and threats to killer whales from the decline in availability of traditional food sources.

Ecosystems perform a range of services that matter to our health, our economy, and our overall prosperity (see **Box 9**). Yet, much of their value remains economically invisible.[113] An analysis of the economics of climate change that excludes welfare implications of shifts in ecosystem services understates the costs of inaction. We miss an important part of the climate change impact story. And it runs the risk of either under- or overstating the costs and benefits of options to adapt to and limit the impacts of climate change.

BOX 9

ECOSYSTEM SERVICES

Ecosystem services are the link between nature, people, and the economy. Scientists recognize four categories of services: cultural, habitat, regulating, and provisioning.[114]

// Ecosystems are important for recreation, tourism, and spiritual purposes, and as sources of inspiration for culture, art, and design ("cultural services"). Our national parks system, for example, receives over 10 million visits per year, on average.[115]

// Ecosystems supply living spaces for plants and animals and maintain genetic diversity ("habitat services").

// Ecosystems regulate natural processes and furnish natural controls ("regulating services"). Our expansive forests — representing about 10% of the world's forest cover — and soils absorb and store carbon dioxide, playing a key role in regulating the global climate. Our forests also influence rainfall patterns and clean the air. The 1.2 million square kilometres of wetlands covering about 14% of Canada's land help absorb high-energy waves and control coastal erosion.[116]

// Ecosystems provide freshwater, food, fibre, and medicinal resources for our direct consumption or as inputs for industry ("provisioning services").

Our continued ability to benefit from these services depends on underlying physical, chemical, and biological processes or attributes. These processes or attributes, such as nutrient cycling and photosynthesis, sustain life as we know it.[117]

Integrating ecosystem impacts into the economics of climate change, while critical, is challenging on a number of levels. Gaps in our global understanding of complex ecosystem dynamics and difficulties applying economic valuation methods to the task[118] are made apparent by the lack of national studies that include detailed analysis of shifts in ecosystem services in costing climate change. The most comprehensive economic assessments of climate change for Australia and Sweden released to date, for example, discuss ecosystem impacts qualitatively.[119] A study commissioned by the U.K. government to estimate the costs of impacts and adaptation quantified shifts in species distribution and habitats in a changing climate but did not monetize impacts due to gaps in valuation data.[120]

This chapter discusses some of the economic ripple effects of climate change on Canadian ecosystems. It highlights the growing importance of addressing gaps in our ecological and economic knowledge. Guided by information availability, we chose to look at examples of the economic consequences of climate change on Canada's national parks and fisheries habitat in forested lands as illustrations of the more tangible connections between ecosystems and the economy — two very small examples in a universe of possible impacts. Through these examples, we explore possible implications of climate change on two types of ecosystem services: cultural and habitat services. We focus primarily on values we derive from recreation but also provide some examples of "non-use values." We rely on published literature and mainly use a qualitative lens to do so.

When it comes to assessing potential gains and losses of ecosystem services and determining solutions, economics is not always the best lens to use. The chapter concludes by noting the limits of economic valuation.

6.2 ECONOMIC IMPACTS

CANADA'S NATIONAL PARKS

Canada's National Parks generate value in many ways: as iconic symbols of Canadian identity; as cultural and spiritual places; by protecting the genetic diversity of plants and animals; and by performing important services such as water purification, pollination, and soil stabilization, and many more. In addition, parks provide valued opportunities for nature-based recreation like hiking, bird watching, and skiing, to name a few. In 2008, our seven mountain parks — Banff, Jasper, Yoho, Kootenay, Waterton Lakes, Mount Revelstoke, and Glacier — received 6.9 million visitors or 58% of all visits to national parks.[121] Visits to less accessible parks, such as the seven located in the Northwest Territories and Nunavut, were far fewer by comparison. These visits were nonetheless important to the local economy and highly valued, judging by visitors' willingness to pay to reach those destinations.

Several studies document the relationship between climate and recreation opportunities, with fewer assessing the implications of a changing climate on nature-based recreation in Canada's parks system.[122] We know that day-to-day weather and seasonal outdoor conditions affect decisions to visit parks in the first place, the quality of and satisfaction with the outdoor experience, and the duration of seasonal recreation such as skiing. We also know that climate conditions heavily influence key physical and ecological features that sustain nature-based recreation, such as biodiversity and patterns of river flow.[123]

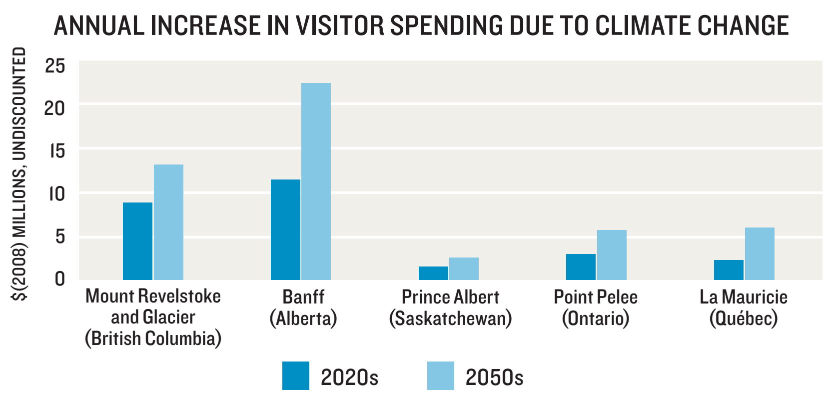
So what could visitor patterns to National Parks look like in a changing climate? What about spending by parks' organizations and visitors, and the jobs, income for local businesses, and tax revenues that flow from this spending? Here, we rely on published research and our own analysis to shed light on these issues.

VISITOR PATTERNS IN A CHANGING CLIMATE: We might expect warming temperatures to increase the popularity of Canada's national parks as climate change unfolds. Today, nearly 70% of visits to our national parks occur between May 1 and September 30.[124] Among other factors, this "seasonality" in nature recreation has to do with higher levels of participation in warm-weather activities relative to cold-weather activities,[125] and with summer vacation patterns of most Canadians. Yet, we know little about the numerical link between future changes in climate indicators, such as daily temperature, and visits to Canada's national parks.

Relying on relationships observed between monthly park visits and daily temperature highs, one study forecasts the impact of climate change on visitation rates in 15 of Canada's national parks[cc] using three climate futures and a 1961–1990 baseline.[126] It suggests that climate change could increase visits to these 15 national parks on average by 6% to 8% by the 2020s, 9% to 29% by the 2050s, and 10% to 41% by the 2080s. Under the highest climate change scenario, half the parks assessed would see a doubling of visits by the 2080s. Most of the forecasted increase takes place during spring and fall months. The study also highlights the importance of demographic changes in forecasting future visits, showing that changes in demographics contribute to visitation growth two or three times more than does climate change in the 2020s.

VISITOR SPENDING: Spending related to Canada's network of national parks adds to the wealth of our national economy. On an annual basis, visitor spending in and around our national parks and spending related to park management contribute about $1.5 billion to the gross domestic product — including just over $1 billion related to jobs — and channel more than $85 million to the federal government.[127] By implication, the rise in visits to national parks forecast to occur as a result of warmer temperatures in a changing climate could translate into economic benefits. We estimated just how much climate change could boost visitor spending in the 2020s and 2050s, using five parks as examples (**Figure 19**). On a yearly basis, visitor spending for these five parks alone could be $26 million more in the 2020s and $48 million more in the 2050s than would have been the case without climate change.

FIGURE 19



SOURCES: ADDITIONAL VISITS TAKEN FROM EARLIER RESEARCH ON THE EFFECTS OF CLIMATE CHANGE ON NATURE-BASED TOURISM (SCOTT 2006), WHICH USES A 1961–1990 BASELINE FOR VISITS AND CLIMATE. WE USE THE RESULTS REPORTED FOR THE HIGH CLIMATE CHANGE SCENARIO, ASSUMING NO DEMOGRAPHIC CHANGE AND CONSTANT DEMAND. VISITOR SPENDING PER NEW PERSON VISIT IS FROM THE CANADIAN PARKS COUNCIL AND PARKS CANADA, UNADJUSTED FOR FUTURE ECONOMIC GROWTH (PARKS CANADA VISITOR EXPERIENCE BRANCH 2010; THE OUTSPAN GROUP 2005).

cc The 15 parks are Pacific Rim, Waterton Lakes, Prince Albert, Mount Revelstoke/Glacier, Kootenay, Yoho, Banff, Jasper, Point Pelee, Pukaskwa, La Mauricie, Prince Edward Island, Kouchibouguac, Cape Breton Highlands, and Terra Nova.

Potential gains from a longer warm-weather season are but one factor in assessing the impact of climate change on revenues related to park use. Several others warrant attention. Winter sport operators may lose business and while downhill ski facilities will be able to compensate to some degree through snowmaking, cross-country ski activities will be more vulnerable.[128] Recreation providers catering to year-round activities could see a shift in the mix of goods and services demanded but no overall reduction in demand. In some parks, water sports and providers of boating and related services may suffer due to drier conditions and reduced water levels.[129] The opening of Arctic waterways to cruise ships is already altering visitor patterns in northern parks, with benefits and challenges to surrounding communities (e.g., Pond Inlet next to Sirmilik National Park). Finally, higher influxes of visitors to parks also mean higher operating costs for parks managers, including the cost of putting in place measures to safeguard the ecological integrity of parks and the safety of park visitors.[dd]

BEYOND DOLLARS SPENT TO PARTICIPATE IN NATURE-BASED RECREATION: Ecosystem services, including those derived from our national parks, are worth more to us as individuals than what we can currently express through market transactions. A range of attributes shape our valuation of nature including personal satisfaction, quality of experience, attachment to place, and status. Ecological and physical impacts of climate change, such as the disappearance of glaciers, altered biodiversity, and fire or insect-affected forests, may influence these elusive attributes and our welfare by implication.

Insufficient information exists to usefully quantify changes to the net worth of nature to us due to climate change. Canadian studies are few, dated, and not specific to shifts in welfare resulting from impacts of climate change. But, we can say something about how much we value nature beyond what we spend on recreation and how these values can change:

// With over 1,000 kilometres of backcountry trails tucked in the Canadian Rockies, Jasper National Park was the site of a study looking into the value of trails dominated by ancient forests relative to that of younger forests of the same type.[130] It found that the gains in welfare from adding trail segments along ancient forests as opposed to mature, but younger forest ecosystems were higher by an order of magnitude.

// Wood Buffalo National Park, straddling Alberta and the Northwest Territories, provides the only known breeding ground for the endangered whooping crane in its globally significant wetlands.[131] A U.S.-based study estimated the average value that each household would be willing to pay to avoid the loss of the whooping crane at $66 per year.[132]

// A survey of 1,300 Canadians found that 61% of respondents would pay more to maintain and complete the national parks system. On average, a respondent would pay an additional $56 per household and 47% of respondents said they would pay this on an annual basis.[133]

dd Unseasonably warm and wet weather on Baffin Island prompted an evacuation of 21 visitors from Auyuittuq National Park in the summer of 2008 (The Vancouver Province 2008).

The impact of climate change on these more intangible economic values is on balance unclear. First, our preferences and reference points vary. Climate change may contribute to irreparable losses of species and environments that matter greatly to people. As this risk heightens, our overall welfare could suffer, with no actions able to compensate for the extinction of species of cultural significance, like polar bears, salmon, and killer whales, and disappearance of unique environments like tundra and coral ecosystems.

In less dire cases, people may be able to maintain levels of welfare by switching to locations and activities better suited to changing climate conditions; our preferences could adapt to what's available. Climate change could actually reinforce people's perception of parks as iconic destinations. For example, parks could be the places people visit to see the last vestiges to melting glaciers. Gradual ecological changes, like shifts in the unique tundra-like environments in Gros Morne National Park (Newfoundland and Labrador) and migration of ecosystem types to higher altitudes in mountain parks, may largely go unnoticed by most visitors. The impact on long-term visitation of major ecological changes, like a major fire that burns a large part of a park, is hard to predict and would partly depend on the range of attractions available in a park. Some research suggests a short-term boost in welfare for hikers following major forest fires, but welfare losses thereafter.[134]

THE LAKE TROUT SPORTS FISHERY

Landscapes across Canada dotted with lakes and streams provide habitat for diverse communities of plants and animals, and many valued recreation benefits. In 2005, spending on recreational fishing in Canada totalled about $7.9 billion, with one-third of that spending occurring in Ontario.[135] Biodiversity levels, including in freshwater habitats, are declining here and around the world.[136] Canada's 2010 assessment of ecosystem trends concluded that 18% of fish inhabiting or passing through freshwater are endangered or threatened, noting an upward trend in fish at risk since the 1980s.[137]

A changing climate is one among several pressures to freshwater fish, affecting habitats and biodiversity in various ways.[138] It could cause temperature and moisture stress along with changes in oxygen levels, triggering migration of fish species to more suitable habitat (contingent on access to north–south river systems), and leading to local losses in a given species. Shifts in the range of one species have cascading effects for others, such as the case for predators and their prey. Warmer temperatures can also expand the range and viability of pests and pathogens, increasing fish exposure to disease.

How could risks to biodiversity from climate change create losses or gains in our welfare? Using the lake trout fishery in Ontario as an illustration, we examine potential shifts in the distribution of fish species due to climate change and the implications for recreational fishing and angler spending. We focus on the dynamics of lake trout and smallmouth bass, both highly valued sportsfish,[139] but expected to respond very differently to climate change. But first, a few key characteristics of lake trout and smallmouth bass:[140]

// Lake trout are ubiquitous in Canadian lakes, mainly inhabiting deep lakes but also shallow lakes and rivers in northern parts of the country. They have a strong affinity for cold water and tend to prefer temperatures of about 8–12°C although individual fish can stray outside the "normal range." Their food consists of a range of creatures, including crustaceans, insects, many species of fish, and even small mammals.

// Smallmouth bass mainly occur east of Manitoba, although small pockets occur in westerly provinces too. They occupy much warmer waters than do lake trout, with preferred summer temperatures of 20–22°C but sometimes as high as 28°C. Adult bass feed on insects, crayfish, and smaller species of fish.

FISH IMPACTS IN A CHANGING CLIMATE: Warmer climates are likely to lead to range contractions and reduced abundance of lake trout, which are likely to require more energy to function in warmer waters. Based on statistical relationships between forecast air temperatures and lake characteristics, one study suggests an overall drop in suitable habitat for lake trout in Ontario by 30% to 40% by the end of the century in a high climate change scenario.[141] These conclusions are qualitatively consistent with other research.[142] In contrast, studies on climate change impacts on smallmouth bass indicate northward gains in suitable habitat. One study relating forecasts of summer lake temperatures and temperature preferences of smallmouth bass showed the potential for most lakes in Canada to contain suitable temperature conditions for this fish by 2100.[143]

In summary, research shows that the range and quality of lake trout habitat could decrease and the opposite will happen for smallmouth bass, but what about interactions between these fish species and others? The two species have overlapping food habits, but smallmouth bass have the ability to outcompete trout for food. Results from a recent Ontario study suggest that the northward gain in suitable habitat for smallmouth bass could increase the number of lakes with vulnerable trout populations from 118 today to 1,612 by 2050.[144] This simple example hints at the web of cascading ecological effects resulting from habitat changes. Scientists can predict some of them, but others will come as surprises.

ANGLING PATTERNS AND COSTS: Recreational fishing adds to the wealth of Ontario's economy, contributing in 2005 approximately $2.6 billion via spending on transportation, food and lodging, fishing, boating, and camping equipment, to name a few items.[145] Lake trout comprises only about 1% of the fish caught and 2% of the fish kept in Ontario.[146] Although the economic contribution of the lake trout fishery is unclear, trout fishers are notoriously dedicated anglers.[147]

As to the future outlook, one study assessing angler preferences and the economic implications of decreased lake trout availability in Thunder Bay due to climate change estimated a 2% drop in daily fishing effort overall should the lake trout fishery cease to exist in the area.[148] Related economic losses amounted to just under $100,000 per year from expenditures associated with day fishing trips and about $80,000 from multi-day trips. Extrapolating these results province-wide could mean $9 million less per year in income generated due to the loss of lake trout fishing opportunities.

These estimates are only indicative. Factors such as changes in the actual distribution of fishing opportunities, relative preferences between local and out-of-province fishers, and willingness of anglers to switch to other species if their preferred species are not available are important to bring into the analysis. Fisheries management will also adjust in reaction to or in expectation of changes in fish distributions, including measures to conserve cold-water species, to take advantage of increases in warm-water species, and to limit economic activity with the potential to increase stream temperatures.[149]

6.3 ADAPTATION STRATEGIES

Strategies that promote healthy and productive ecosystems can help secure the flow of services we derive from them in the face of climate change. Three broad strategies are apparent.[150] One includes using market mechanisms to set up incentives for households, businesses, and communities to restore, conserve, and enhance ecosystem services. Internationally and here in Canada, governments and others are assessing options for the development of carbon markets with schemes that value the carbon absorbed by forests and soils. A second strategy emphasizes the expansion of conservation areas including parks and protected areas. Ecosystems in park systems, like our own, are managed for ecological integrity as opposed to economic development outcomes. As such they are important vehicles to enhance ecosystem resilience. Our national parks could well form conservation nodes, in connection with other provincial and territorial parks and areas that are lightly managed — including tracts of private land. Maintaining corridors between the nodes becomes a key part of the strategy in order to help facilitate the movement of plants and animals as well as gene flows. A third and related strategy is to invest in conserving and restoring natural ecosystems and green spaces in developed areas as a way to complement other policy objectives including climate change adaptation and mitigation. For example, investments in wetland protection have been shown to yield cost savings in disaster prevention.[151]

Recognizing the fundamental link between healthy ecosystems, benefits to society, and overall prosperity, governments are starting to promote ecosystem-based solutions to address climate change. Recent international discussions under the United Nations Convention on Biological Diversity, to which Canada is a party, reflect this direction.[152] In light of a changing climate, the U.K.'s coastal zone policy is expanding its traditional focus on maintaining sea defences and erosion controls toward approaches that promote their deliberate breaching, ultimately restoring carbon-rich salt marshes as a means to absorb wave energy.[153] Canada stands to benefit from a better understanding of the services provided by Canada's ecosystems, how climate change could affect these services, and what their corresponding economic values could be, in order to assess the cost-effectiveness of ecosystem investments.

6.4 THE LIMITS OF ECONOMIC VALUATION

The world risks making poor choices if we fail to take into account the value of ecosystems, biodiversity, and natural resources in responding to climate change.[154] That is a key message of the United Nations initiative on *The Economics of Ecosystems and Biodiversity* — the Stern Review equivalent for biodiversity. This same initiative acknowledges the limits of ascribing price tags to ecosystems and the many benefits they provide us. We highlight two cases below.

WHEN INDICATORS OTHER THAN DOLLAR VALUES MATTER MORE TO PEOPLE, AND THEIR UNDERSTANDING OF PROBLEMS, CHOICES, AND SOLUTIONS: Our assessment of the implications of climate change for Canada in this report is through an economic prism, because we recognize the power of the bottom line in attracting decision makers' attention and inspiring action. However, we also recognize that economic valuation is not always necessary or constructive, not only when it comes to ecosystem impacts of climate change but also in terms of impacts on people's health, sense of place, culture, and other aspects of well-being (see **Box 10**). In such cases, measuring the number of people potentially affected by heat waves, the extent of land and ecologically sensitive habitat at risk from permanent flooding, or the number of people dependent on healthy ecosystems for their livelihoods could well be more revealing than measuring these changes in terms of money.

BOX 10

FORESTS AND THE WOLF LAKE FIRST NATION — MORE THAN ECONOMIC VALUE

Wolf Lake First Nation (WLFN) is one of ten communities of the Algonquin Nation. The traditional territory of the Algonquin Nation includes the entire Ottawa River watershed straddling Québec and Ontario.

Algonquin people have traditionally regarded forests as more valuable left standing and healthy, forested watersheds as both essential to their way of life and a responsibility to past and future generations. For over 7,000 years the forest has provided the Algonquin people their livelihood, including food, energy and materials, landscapes, spiritual grounds, goods for trading, and peace. Algonquin peoples organized themselves around watersheds, which served as their transportation corridors and family land-management units. Algonquin peoples regard themselves as "keepers of the land," with seven generations worth of responsibilities for livelihood, security, cultural identity, territoriality, and biodiversity.

These values form the basis for community watershed conservation projects led by WLFN on their territory. For several years, WLFN has prioritized long-term strategies to restore ecosystem health and economic alternatives to intensive resource extraction industries with the potential to

// restore levels of ecosystem functioning and biodiversity of the territory to promote resilience in changing conditions;

// provide alternative employment to the community's growing population faced with fewer jobs options in the conventional commercial forest industry; and

// build on environmental stewardship opportunities that reflect and strengthen cultural values, with climate change mitigation and adaptation co-benefits and possible economic opportunities.

As a concrete example, WLFN partnered with a climate change biotechnology firm, Mikro-tek, in 2007 to apply a management technology that increases the growth and carbon sequestration potential of reforestation sites in the boreal forest. It is the only registered technology of its kind in Canada.

As a result of its priorities, WLFN has worked to prevent deforestation of key watersheds and frontier forests on its territory, leading to several benefits beyond dollars and cents. Recognizing the importance of policy in shaping forest land use in the future, WLFN is also working with governments to expand dialogue and collaboration toward the implementation of the United Nations Declaration on the Rights of Indigenous Peoples now endorsed by the Government of Canada.

SOURCE: R. VAN SCHIE, ECONOMIC DEVELOPMENT OFFICER, WOLF LAKE FIRST NATION

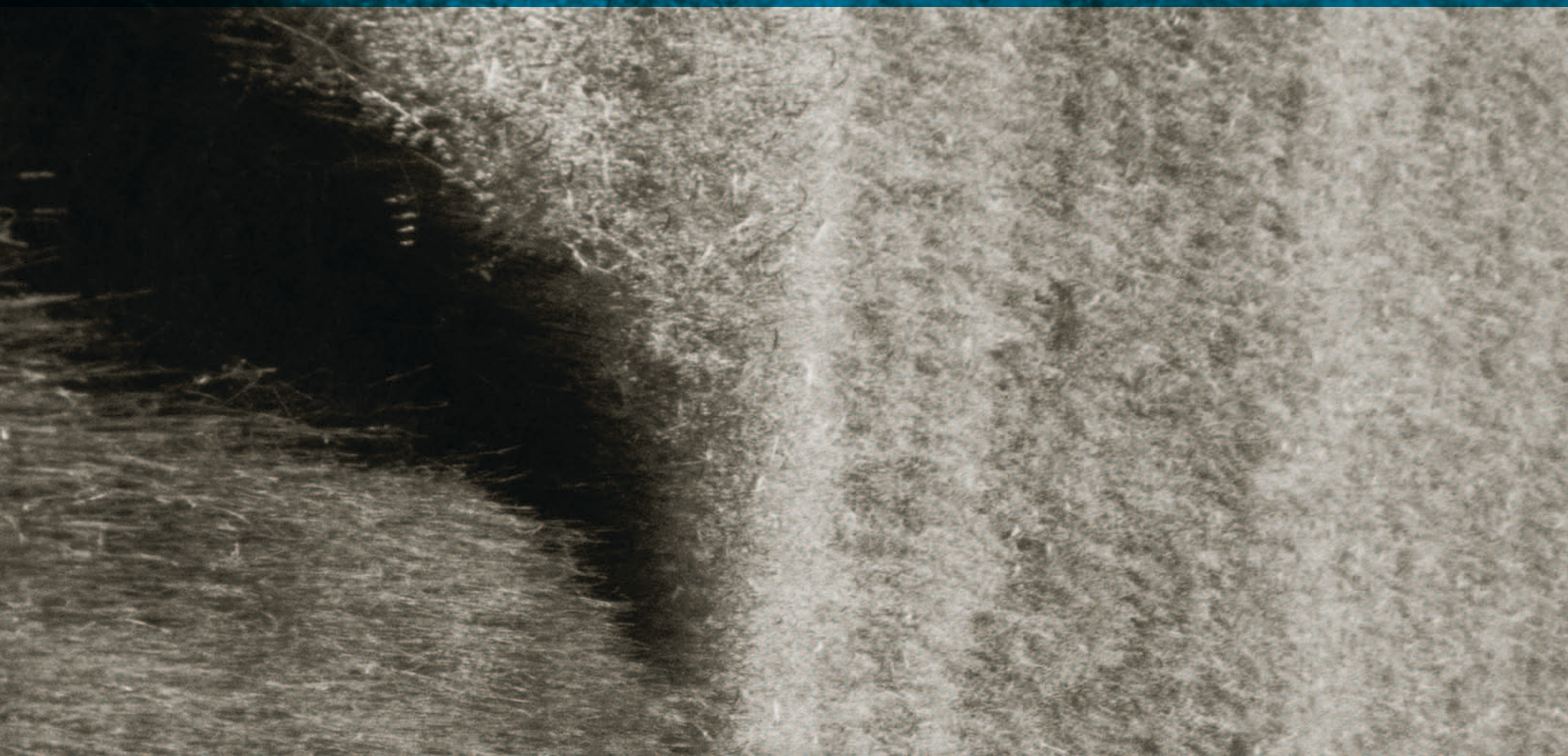
WHEN WHAT WE FACE IS NOT A "MARGINAL" PROBLEM: In economic analyses, and cost-benefit analysis specifically, we are trying to capture the additional cost or benefit attributed to small increments of change. In a changing climate, the potential exists for ecosystems to experience major shifts abruptly and without warning. By implication, economic valuation of ecosystem impacts that simply assumes continued incremental losses may be misleading. In this context, spotting early warning signs of abrupt ecosystem change is critical to take preventative action,[155] but current gaps in ecological knowledge inhibit our ability to do so with any precision.[156] The looming, potentially irreversible loss of tropical coral reefs is an example of a problem that is not "marginal," where economics falls short in capturing the sum total of the potential damage to global fisheries, global food supply, and livelihoods of hundreds of millions of people.[157]

6.5 CONCLUSION

The impacts of climate change on Canada's ecosystems will impose a wide variety of economic costs: conventional costs like those associated with changes in recreational expenditures, costs through changes to ecosystem services that are not readily expressed in monetary terms, and costs through species loss or deterioration of natural spaces whose existence is highly valued. A better understanding of both the ecological impacts of climate change and the economic values of ecosystem services are needed to advance our understanding of this critical economic and non-economic dimension of climate change.

CONCLUSIONS AND RECOMMENDATIONS

// CHAPTER 7.0



7.0 // CONCLUSIONS AND RECOMMENDATIONS

7.1 WHAT DID WE FIND?

Degrees of Change showed what the physical impacts of climate warming could be for Canada; *Paying the Price* shows what the economic impacts could be for Canada.

Many of these impacts will be negative and many will carry a cost. Together, these two NRTEE reports help Canadians know more about what climate change impacts could be and how much they could cost.

Understanding the costs of climate change in economic terms is essential to help us remain prosperous through climate change. This understanding helps all of us — governments, business, communities — make climate-wise investment choices. Economic information helps us understand what is at stake if we fail to respond and global greenhouse gas emissions continue to rise. Here we underline the economic damages associated with global emissions. Canada contributes approximately 1.5 per cent of global emissions[158]; although high on a per capita basis, it is dwarfed by emissions from everywhere else. Emissions from abroad — not just our own — represent the greatest economic risk to Canada. But equally, our emissions contribute to imposing costs on the rest of the world. This NRTEE analysis shows compelling evidence for Canada to advocate for a strong international arrangement that brings those emissions down, on both environmental and economic grounds.

Throughout this report, we explored the potential economic costs — of impacts as well as adaptation investment — associated with climate change in Canada. We did so to learn more about the economic scale of the problem to our country. And we did so to begin to figure out how to cope with what can only be a growing challenge by considering how adaptation can reduce impacts of climate change and lessen costs to Canadians.

To do so — the first time ever in Canada — we conducted original economic modelling of the costs of *inaction* to Canada, of letting growing climate change run its course. Next, to fill out our analysis and understanding, we undertook detailed representative studies of what climate change could mean to Canada's prosperity (timber supply), places (coastal areas), and people (human health). Finally, we explored the economic value of ecosystems to understand how a changing climate could affect how Canadians use and view this aspect of Canada.

HERE'S WHAT WE FOUND:

// **CLIMATE CHANGE IS EXPENSIVE:** Our assessment demonstrated that the costs of climate change are high and will only grow. They are expected to escalate over time from an average of $5 billion per year in 2020 across all scenarios, to $21 billion per year in the low climate change–slow growth scenario, to $43 billion per year in the high climate change–high growth scenario by 2050.

// **THERE IS A RISK THAT THE COSTS COULD BE FAR HIGHER THAN WE EXPECT:** By the 2050s we expect annual costs of $21 billion in the low climate change–slow growth scenario but there is a 5% chance that the costs could exceed $44 billion. Similarly, we expect annual costs of $43 billion in the high climate change–rapid growth scenario but there is a 5% chance that costs could exceed $91 billion. This wide range of possible costs within each scenario reflects existing uncertainties in climate change science and economics. But it also highlights the risks and costs of what could occur.

// **ADAPTATION CAN SAVE US MONEY:** Our assessment shows that climate change adaptation can save money by reducing the physical and economic impacts of climate change. Despite the investments required, our analysis demonstrated that in four of the five adaptation strategies considered for timber supply, coastal regions, and human health, adaptation saves money and these actions appear to be cost-effective.

// **GLOBAL MITIGATION REDUCES CANADIAN ECONOMIC IMPACTS AND MAKES ADAPTATION CHEAPER:** Our modelling shows that in a low climate change future, the costs of the impacts of climate change and the costs of adaptation are less than they would be in a high climate change future. Taking Toronto as an example, our health chapter showed, that, in present value terms, a low climate change scenario and the resulting air quality related illnesses could add $72 million in costs to the health care system between now and the end of the century. A high climate change scenario could add $285 million in costs to the health care system. Similarly, adapting by reducing ozone-forming emissions in Toronto is less expensive in the low climate change scenario since fewer air pollution reductions would be needed to return air quality to its original levels. In present value terms, the costs of air pollution control from 2050 to 2059 are estimated at $0.7 billion in the low climate change scenario and $3.1 billion in the high climate change scenario. Reducing economic impacts in Canada requires reducing global emissions around the world while implementing sensible adaptation strategies here at home.

// **THE COSTS OF CLIMATE CHANGE IMPACTS AND ADAPTATION ARE UNEVEN ACROSS THE COUNTRY:** The costs will be unequally distributed across regions and groups. Some coastal areas will face far greater costs than others: the per capita costs of dwellings damage in New Brunswick from climate and non-climate related factors are estimated at $730 to $1,803 by the 2050s, higher than the national average. Regional economies with larger forest industries or larger reliance on the forest industry will be more adversely affected: GDP in British Columbia could fall by 0.2% to 0.4% by the 2050s due to changes induced by climate change to the timber supply compared to average national GDP reductions of 0.1% to 0.3%. The

four cities we considered in our health analysis will be affected by climate change differently: cities that experience greater amounts of warming could see more adverse impacts. The unequal distribution of costs and impacts reinforces the need to consider local, sectoral, provincial, and regional adaptation plans and efforts to cope with climate change.

7.2 WHAT DOES IT MEAN?

// IGNORING CLIMATE CHANGE COSTS NOW WILL COST US MORE LATER: The highest costs result from a refusal to acknowledge these costs and adjust through adaptation. In particular, long-lived decisions such as those that are made about coastal development, infrastructure, and forest management should consider the expected impacts of climate change and take steps to account for these costs through adaptation strategies.

// ADAPTATION ISN'T COST-FREE BUT OFTEN YIELDS BENEFITS: The costs of adaptation are often readily identified, leading to adaptation strategies being dismissed as too costly. A more complete accounting needs to also factor in the benefits of adaptation — both from reducing the impacts of climate change and from reducing baseline risks of current climate conditions. As shown in this report, once the benefits of adaptation are incorporated, adaptation can often lead to greater savings than costs.

// ADAPTATION POLICY AND DECISION MAKING CAN BENEFIT FROM ECONOMIC ASSESSMENTS: Our research shows the need to integrate economics into analytical and decision-making frameworks that governments, communities, and businesses are currently using to identify problems and choose among solutions. Decision makers should further explore the economics of climate change impacts and adaptation at the appropriate scale to identify cost effective adaptation strategies. Adaptation decision making can be encouraged through further economic research along the lines presented in this paper. Economics can be used as a tool to justify investments in adaptation, especially when resources are limited.

7.3 WHAT DO WE RECOMMEND?

Canadians can use economic information to decide how to best prepare for and respond to the impacts of climate change. Our recommendations are as follows:

1 // The Government of Canada invest in growing our country's expertise in the economics of climate change impacts and adaptation so we have our own Canadian-focused, relevant data and analysis for public- and private-sector decision makers.

2 // The Government of Canada cost out and model climate impacts to inform internal decisions about adapting policies and operations to climate change and allocating scarce resources to programs that help Canadians adapt.

3 // Governments at all levels continue investing in generating and disseminating research to inform adaptation decision making at the sectoral, regional, and community level. This research should, as a matter of routine, incorporate economic analysis of the costs and benefits of options to adapt to climate impacts because the current data is insufficient for decision makers and is not readily or consistently available.

4 // The Government of Canada forge a new data- and analysis-sharing partnership with universities, the private sector, governments, and other expert bodies to leverage unique and available non-governmental resources for climate change adaptation.

7.4 WHERE DO WE GO FROM HERE?

Paying the Price highlights areas where additional research and analysis on climate change impacts and adaptation are needed for Canada. Having clearly identified economic risks associated with a changing climate, we need to turn our attention to exploring the economic opportunities of adaptation — to both cope and prosper through inevitable degrees of climate change. A key player is Canada's private sector. Economic analysis of the kind conducted here, matched with business understanding of what's at stake and how to manage risks and opportunities, can move Canada forward. Knowing what is needed and indeed justifiable from government to support and incent private-sector actions must also be part of this assessment. Public action — by governments funded through taxpayers — to increase resilience to climate change can actually generate private benefits in response. For example, investments in public infrastructure built to withstand future climates help business productivity. But effective adaptation requires concerted local and private-sector actions focused on the situations close at hand.

Our fifth report in the *Climate Prosperity* series will examine the ways Canadian businesses can and should address the impacts of climate change and the roles of governments in supporting this.

// CHAPTER 8.0

APPENDICES


Collection nationale
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8.0 // APPENDICES

8.1 ANALYTICAL FRAMEWORK

We developed an analytical framework that we applied to each of the sectors we evaluated in Chapters 3 to 5. This ensured a consistent approach and presentation of results to the extent feasible.[ee]

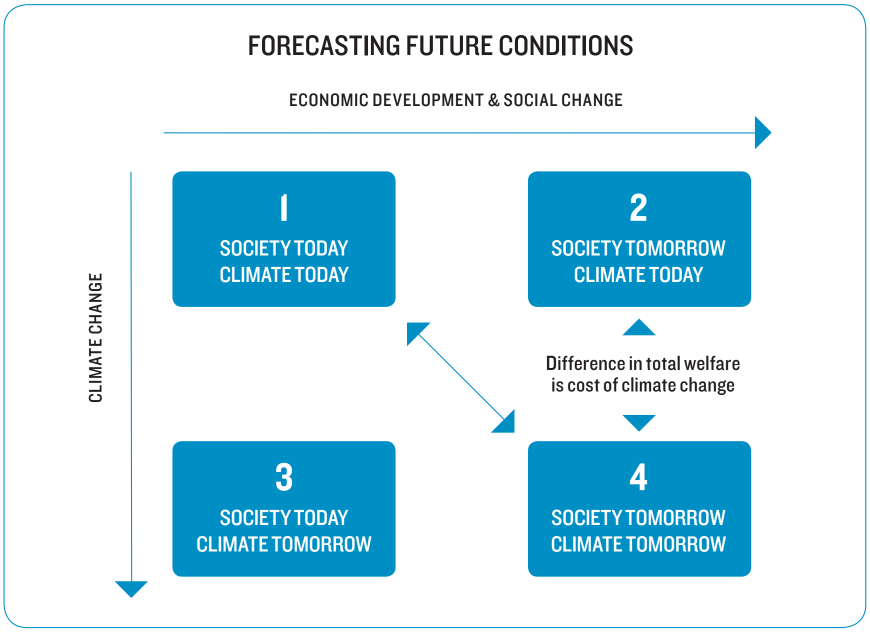
STEP 1 // DEFINE THE SCOPE: Each of the studies looked at three 30-year time slices centered on the 2020s (2010–2040), 2050s (2041–2070) and 2080s (2071–2100). The coastal areas and timber supply study provide results for Canada as a whole while the human health study looked at four Canadian cities. It would not be feasible to conduct an analysis of each and every way climate change could impact a given sector. Each study focuses on priority impacts of climate change for the sector, factoring in the availability of data and research to inform the choice of impacts evaluated.

STEP 2 // ESTABLISH BASELINES AGAINST WHICH TO MEASURE CHANGE: We used the four scenarios described in the introduction to the report so we would have a means of comparing climate impacts to a baseline impact level. Using these scenarios we were able to answer the following questions: What could society in Canada look like in the future? How could current climate affect Canada's future society? How could climate change affect Canada's future society?

Figure 20 shows that climate and socioeconomic development can both influence forecasts of future states. We want to highlight the role of climate change in influencing future outcomes, and to do so we first forecast future baseline conditions in the absence of climate change (box 2 in **Figure 20**). We then forecast future conditions with climate change (box 4 in **Figure 20**). The difference between theses two futures shows the impact of climate change.

ee This framework is described in more detail in a technical document that is available upon request: *NRTEE: Economic Risks and Opportunities of Climate Change For Canada: Technical Guidance for "Bottom-up" Sectoral Studies* (Hunt 2010).

FIGURE 20



STEP 3 // ASSESS PHYSICAL AND ECONOMIC IMPACTS OF CLIMATE CHANGE: In order to determine the impact of changes in climate, we used global climate models (GCMs) to pull out estimates of climate variables like temperature changes and sea-level rise. Different models provide different types of information and we used several GCMs to appropriately capture uncertainty. We selected models separately for each study based on data needs. We assessed physical and economic impacts for each combination of socioeconomic and climate scenarios.

STEP 4 // EVALUATE ADAPTATION OPTIONS: In the final step we identified adaptation options that could be used to reduce the costs of climate change for the sector. We quantified the effect of adaptation on the physical and economic impacts of climate change and then assessed the cost-effectiveness of adaptation.

8.2 COST DISTRIBUTIONS UNDER FOUR CLIMATE AND GROWTH SCENARIOS

The distributions of possible costs of climate change for Canada in 2050 for the four scenarios are provided in **Figure 21**, **Figure 22**, **Figure 23**, and **Figure 24**:

FIGURE 21

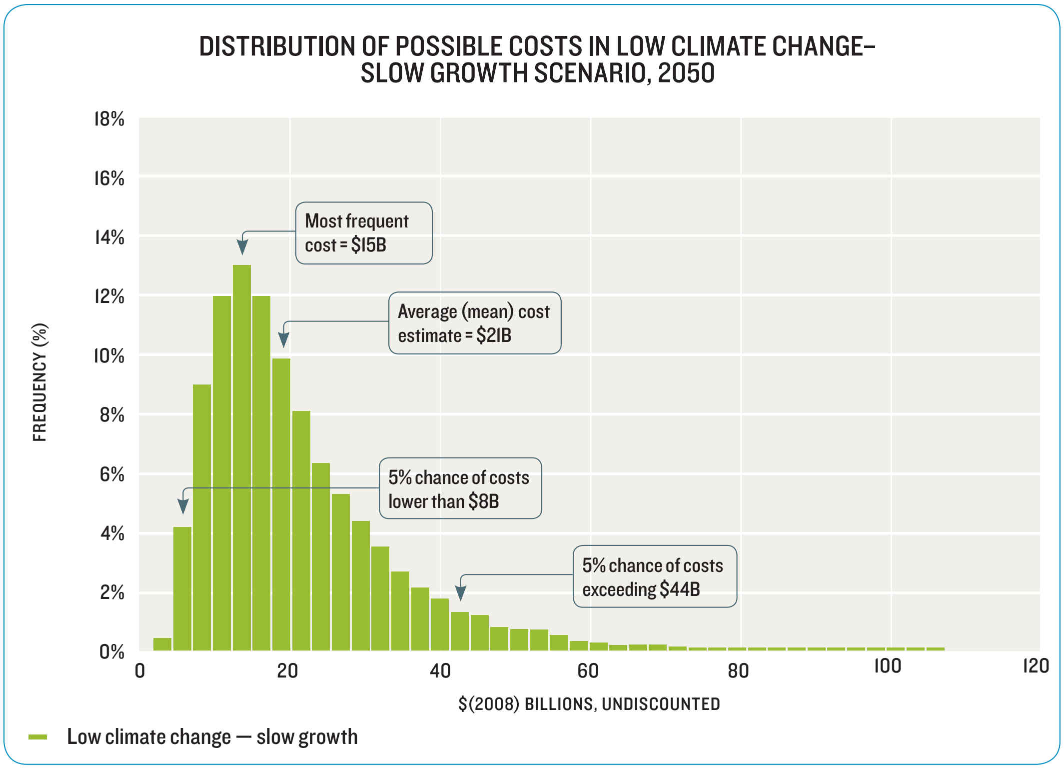


FIGURE 22

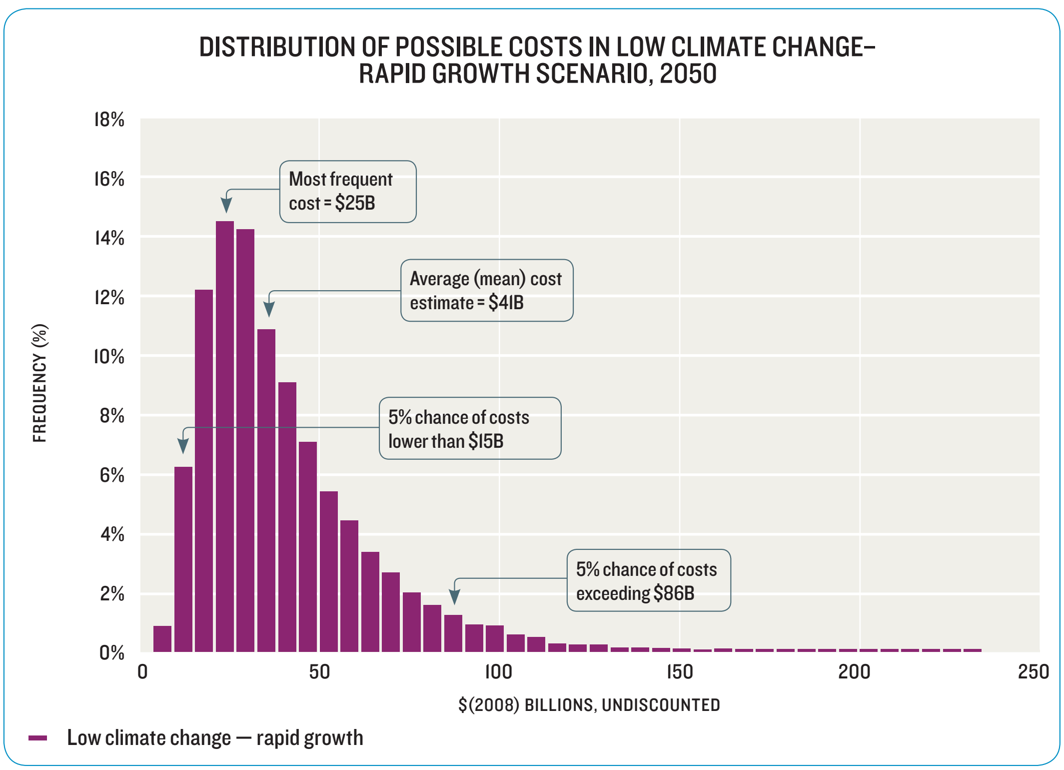


FIGURE 23

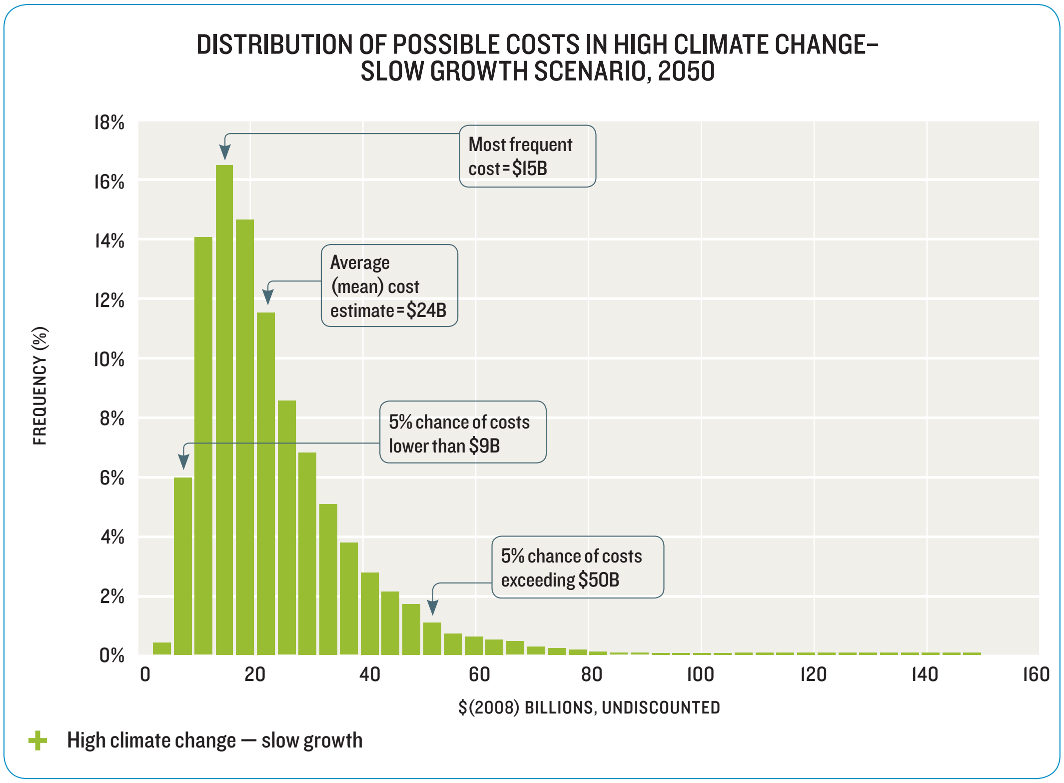
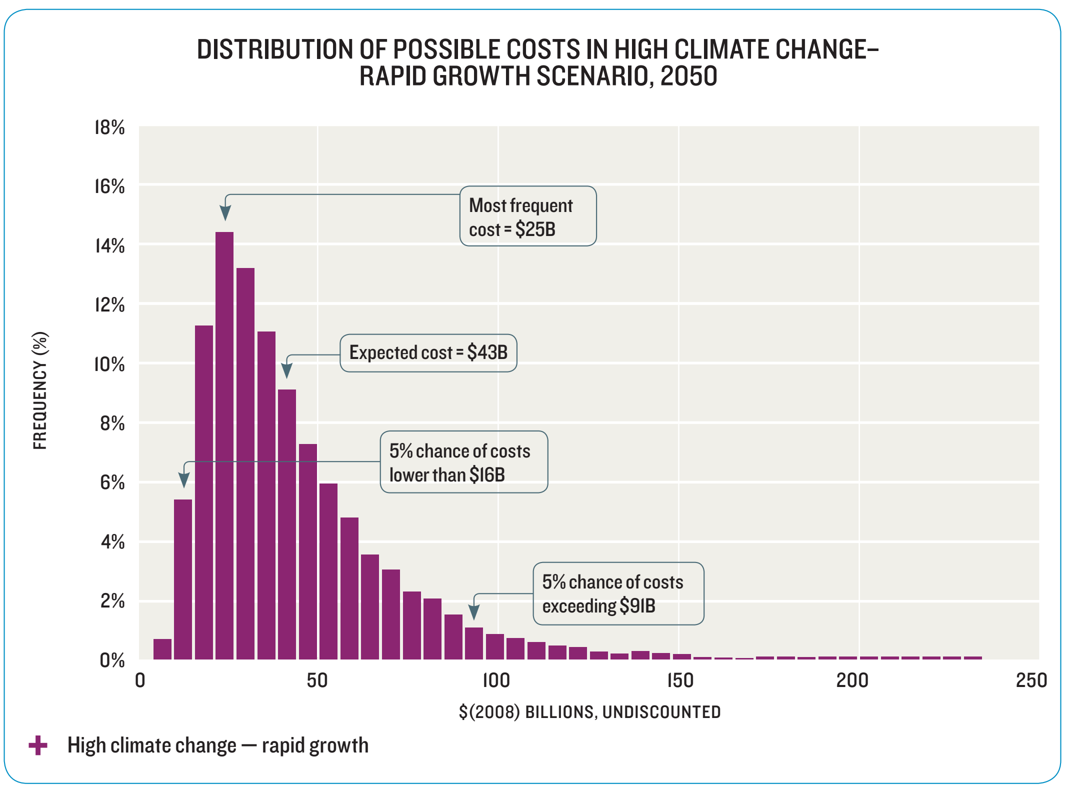


FIGURE 24



8.3 ADDITIONAL DETAILS ON THE METHODS USED FOR THE TIMBER SUPPLY STUDY

STEPS TO ESTIMATE THE IMPACTS ON TIMBER SUPPLY

We developed estimates of the expected changes to timber supply for each region and climate change scenario, using the following approaches, sources, and assumptions:

// **FOREST FIRES:** Our estimated percentages of timber supply lost to fires under changing climate conditions drew on forecasts of forest area burned in different forest regions due to climate change.[159] These forecasts lined up with our high climate change scenario for the 2080s, but we had to make inferences for earlier time periods and for our low climate change scenario. To then convert changes in forest area burned to percentage changes in timber supply, we conservatively assumed that 10 square kilometres of forest area burned corresponded to 1 square kilometre of timber loss.[ff]

// **FOREST PRODUCTIVITY:** Qualitative assessments of the impacts of climate change on forest productivity for Canada's forest regions are available from the Canadian Forest Service.[160] The assessments take into account changes in temperature and precipitation but not the potential of higher levels of carbon in the atmosphere to accelerate productivity. We used judgment based on the literature and consultation with the Canadian Forest Service to map these qualitative assessments of changes in forest productivity to percentage changes in timber supply.

// **PESTS:** Our approach to estimating the impacts of pests was similar to that for forest productivity, using judgment to map qualitative assessments of the impacts of climate change on pests published in science literature[gg,161] to percentage changes in timber. For distant time periods, the magnitude and direction of impact of pest outbreaks are uncertain. We carried forward the qualitative assessment given for the preceding period. Uncertainty stems from our inability to use the present as a good guide to the future, particularly when it comes to the state of Canada's forests and the types and prevalence of pests late in the century.[162]

We developed "optimistic" and "pessimistic" estimates for changes to forest fires, productivity, and pests for each climate scenario and carried these through to our economic analysis. However, for simplicity and consistency with the other sectoral studies, we presented averages of the optimistic and pessimistic results throughout this report. Under the more optimistic scenarios Ontario, Québec, and Atlantic Canada could see modest increases in the timber supply in some scenarios that could correspond to economic gains.

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ff Earlier research suggests that a 50% increase in the area burned would result in a 20% decrease in the annual allowable cut (Van Wagner 1983) but we saw this estimate as an upper bound since the annual allowable cut is currently higher than the actual harvest and since there is salvageable timber from areas that have been burned. Our estimates could also be viewed as conservative since fires could be expected to burn all age classes equally, but only the youngest stands are readily replaceable (Williams 2011).

gg The qualitative assessment applied to biotic disturbances including insects, pathogens and parasites but the foundation for the assessment was mostly from research on insects.

For all three impact types, the research we drew from presents the impacts for forest regions defined according to the specific studies. We present results differently, so in each case we mapped the forest regions to our six Canadian geographic regions.

STEPS TO ASSESS THE ECONOMIC CONSEQUENCES

We developed single-region CGE models for each of the six regions of the country included in our analysis. The CGE models were built with 2004 regional input-output tables from Statistics Canada, which we scaled up and down to our rapid and slow growth scenarios for 2020 and 2050 using Informetrica forecasts. We extrapolated from 2050 out to 2080 to develop the 2080 input-output table. Several iterations of CGE modelling were necessary for each region. We first constructed baseline forecasts of economic indicators such as gross domestic product and sectoral output values corresponding to high and low economic development scenarios without climate change. We then took our estimates of percentage changes in timber supply due to climate change and introduced them into the modelling framework by assuming that a 1% change in the timber supply is equivalent to a 1% change in the economic output from forestry. We then reran each of the six regional models to generate economic indicators with climate change. Each regional CGE model was run once from 2004 to 2020, once from 2004 to 2050, and once from 2004 to 2080. Since the model was only calibrated to 2080, we used the annual average for 2071 to 2080 as our results for 2085, leading us to understate the impacts for the latest period, as economic growth between 2080 and 2100 is not reflected. We compared the results between the model runs with climate change and without climate change to develop quantitative estimates of the economic impacts of different climate futures.

STEPS TO ESTIMATE THE COSTS AND BENEFITS OF ADAPTATION

For each of the adaptation strategies considered in our analysis, we first estimated the extent to which each strategy would increase the timber supply and then estimated the costs of the strategy.

// ENHANCING FOREST FIRE PREVENTION, CONTROL, AND SUPPRESSION

// We estimated the area expected to burn by applying projected changes in timber supply to the 2008 provincial harvest levels.[hh] Second, we had to make an assumption about how effective this strategy would be in reducing the impacts of climate change on the timber supply: we assumed it would be 75% effective (i.e., 75% of the area treated would not be lost to fire). For example, if British Columbia harvested 100,000 hectares of forest in 2008 and in 2050 forest fires are expected to reduce British Columbia's timber supply by 5%, then 5,000 hectares would be lost without adaptation.

// The costs depend on two key factors — the unit cost of deployment and the extent of deployment. We assumed that implementation costs are $250 per hectare and that the strategy would need to be applied to an area ten times as large as that expected to burn. Continuing the example from above,

hh In cases where these levels were lower than normal (as was the case in British Columbia), the costs of adaptation are understated.

applying the adaptation strategy to an area ten times as large as that expected to be subject to fire, we treat 50,000 hectares of forest with this strategy. Applying an effectiveness rate of 75% within the 5,000 hectares at risk, only 1,250 hectares would be lost after adaptation. The cost of this strategy would be $250/hectare times 50,000 hectares, which equals $12.5 million.

// INCREASING PEST PREVENTION AND CONTROL

// We also used 2008 provincial harvest levels to estimate the area expected to be effected by insect outbreaks. We assumed that this strategy would be 50% effective in reducing the impacts of climate change on timber, though some experiences with pest management in the context of the mountain pine beetle suggest that our estimated effectiveness could be optimistic.

// Similarly to the approach used for forest fires, here we assume that implementation costs are $40 per hectare and the strategy would need to be applied to an area one hundred times as large as that expected to be affected by pests.

// PLANTING TREE SPECIES SUITABLE TO FUTURE CONDITIONS

// In our analysis, we assume this strategy has no effect in the 2020s and reduces adverse impacts of climate change by 20% in the 2050s and 50% in the 2080s.

// Here we assume that implementation costs include an upfront investment in research of $100 million to $150 million to identify the most suitable tree species, and $10 million per year in planting costs over and above replanting costs incurred regardless of adaptation. We divide the costs of planting alternative species among regions based on the share of seedlings planted in 2008.

To estimate the benefits of adaptation, we adjusted the economic output from forestry based on the estimated change in timber supply with adaptation and re-ran each CGE model. Benefits were estimated by comparing economic indicators from CGE model results with and without adaptation.

LIMITATIONS

This type of assessment has important limitations which make our estimates uncertain. To reflect this uncertainty we explored several scenarios and have provided ranges in our results. The following list highlights the key assumptions and uncertainties that should be kept in mind when interpreting our results.

// Given the fundamental complexity of ecosystems, the physical impacts of climate change on the timber supply are highly uncertain. Ecosystems are subject to both internal and external forces.[163] In the case of forests these forces could include internal factors like changing species composition or external factors like important weather events. The impacts that climate change will have on forests could be magnified or dampened by these other forces, making it especially difficult to forecast the impact of climate change on forests.

// We have greater confidence in the estimated impact of climate change on forest fires than on productivity and pest outbreaks because the forest fire estimates are drawn from a quantitative analysis.

// The extent, value, and role of salvageable timber in reducing the negative impacts of timber supply reductions is uncertain.

// We assume the impacts of climate change on pests, fires, and forest productivity are additive. In reality these impacts could interact.

// Our assumption that a percentage change in timber supply leads to a corresponding change in forestry output is an oversimplification of the likely impacts.

// The modelling approach also leads to oversimplification since (1) impacts may be non-linear over time and (2) additional inter-regional trade impacts may exist that are not captured in the single-region models. A more advanced modelling approach would be to use a dynamic, multi-regional CGE model.

// We do not consider the impacts of climate change on foreign timber markets and any resulting price changes.

// Grouping Manitoba, Saskatchewan, and the Territories together in one region masks important differences among these provinces and territories.

// Our assumptions about future growth trajectories of the various industry sectors in regional economies are based on Informetrica forecasts, which are widely used in government and private-sector macroeconomic analysis. Any limitations in these forecasts carry through to our results.

8.4 ADDITIONAL DETAILS ON THE METHODS USED FOR THE COASTAL AREAS STUDY

STEPS TO ESTIMATE THE IMPACTS ON COASTAL AREAS

In our analysis we considered the baseline impacts from sea-level rise and storm surge in the absence of climate change and then looked at how climate change could exacerbate these impacts. Using data and approaches that we could apply to the country as a whole, we mapped out Canada's coastal areas and determined the amount of land that would be flooded (either permanently from sea-level rise or temporarily through storm surges) under each future climate scenario — without climate change, with low climate change, and with high climate change. We then estimated the area of land and number of dwellings that could be lost due to sea-level rise and storm surge and the value of those dwellings losses, both in the baseline and due to climate change in all four scenarios. To assess the regional implications we present results separately for each province and territory with an ocean coast, which includes all three territories and eight of the ten provinces.

FIRST, using digital elevation data from the National Aeronautics and Space Administration[164] and the Commission for Environmental Cooperation,[165] we started by identifying the elevation of coastal land relative to the ocean and the area of land flooded at mean high tide for three meta-scenarios: a 1-metre, 2- metre, and 3-metre increase to sea level above today's mean high tide. We used a "flood-fill" technique so that land can only be flooded if it is adjacent to either the ocean or another flooded area and creates adjoining areas of flooding. This step provides us with a classification of each piece of coastal land according to the meta-scenario in which it would be flooded.[ii]

SECOND, we found information about the land use and number of dwellings in the areas that could be flooded. Using a program called PCensus we extract Canadian 2006 Census data for each of the flooded areas, which provides information such as the population, demographics, number of households, and average value of dwellings.

THIRD, we assessed the expected sea-level rise and storm surge for different parts of the country in the future — both with and without climate change. Natural processes affect sea levels, including subsidence or uplift of the landmass, and changes in the global ocean basin or volume of the global ocean. We gathered information on the relative sea-level rise being experienced by different coastal regions[jj] and the current frequency and severity of low-intensity, high frequency storm surges for each region. We also developed assumptions about the effects of climate change on sea-level rise and storm surge risk. For our high climate change scenario we assumed that sea levels would rise linearly by 85 cm by 2100[166] and the severity of storm surges would increase by 10%.[167] For our low climate change scenario we assumed that sea levels would rise linearly by 28 cm by 2100[168] and storm surge severity would stay at current levels.

FOURTH, an Excel-based model interpolated between the one-metre sea-level rise increments assessed in step 1 to identify the amount of land that would be lost in the baseline and due to climate change in each scenario and time period. Then pulling in the information from step 2 the model assessed the number of dwellings that would be permanently abandoned due to sea-level rise in the baseline and due to climate change. These results were then scaled to each growth scenario based on our expectations of how development could affect the number of homes in the future. The approach was similar for storm surges, looking at the incremental increase of land/dwellings flooded above and beyond those flooded by sea-level rise. The estimates of costs of dwellings exposed to storm surges were weighted by the risk of a storm surge occurring, but the land area exposed was not risk-weighted. The model then aggregated results for each province or territory.

ii It is important to note that all results are also net of the current land area, population, and dwellings that fall below the stylized high-tide line. Excluding populations and infrastructure below the high-tide mark was an artifact of data availability, not a modelling choice.

jj This could include eustatic sea-level rise from oceans' slow expansion unrelated to climate change and vertical crustal movements (subsidence and uplift). Negative overall sea-level rise is modelled as zero sea-level rise.

LIMITATIONS

The study could be strengthened by better data availability and a more comprehensive assessment of impacts. The following assumptions and exclusions should be kept in mind when reviewing our results.

// The elevation data that we use are the best available consistently across the entire Canadian coastline. A more accurate study of the economic damages of climate change for Canada's coastal areas would require better underlying elevation data.

// The mean sea level varies across the country but this is not captured in our model.

// We correct for vertical land movements and eustatic sea level changes at a provincial or territorial and sub-provincial scale rather than locally.

// Our estimates of the frequency and intensity of low intensity, high frequency storm surges are developed at a provincial or territorial and sub-provincial scale rather than locally, and their accuracy is limited. This is a particular concern for British Columbia where storm surge damages represent the vast majority of damages rather than sea-level rise and where the economic damages may be concentrated in a small number of densely populated areas. If our storm surge frequency and intensity are not accurate for these areas then the overall results will be affected.

// Our choice to use low intensity, high frequency storm surges may lead us to overstate damages. In many cases development may have been designed to avoid damage from these surges: it could be that the high intensity surges are the ones that create damage. British Columbia's flood guidelines recommend that coastal buildings be built 1.5 metres above the high-water mark[169], so these buildings should not be affected by the low intensity surges.

// Our analysis excludes areas below the mean high-tide line. The impact of this exclusion on the overall analysis should not be significant.

// Our flood-fill method is conservative since the water level is required to exceed the elevation of land in a given area in order to cause inundation.

// There is a possibility that population density along Canada's coasts could change relative to national population density but this was not explored.

// Our analysis excludes dikes and other coastal defences. Dikes can be effective in reducing the risks of flooding in the baseline but they were not designed taking climate change into account.

// A more complete assessment would have looked at impacts from erosion and declining sea levels, and would also assess the impacts on ecosystems, commercial properties, and public infrastructure. We were not able to explore these areas due to resource limitations and data availability.

8.5 ADDITIONAL DETAILS ON THE METHODS USED FOR THE HUMAN HEALTH STUDY

Our analysis focuses on the impacts of heat on deaths and the impacts of higher ozone concentrations on illness and deaths. **Table 19** sets out some of the considerations that led us to focus on these health impacts of climate change.

TABLE 19

NRTEE CRITERIA FOR THE SELECTION OF HEALTH IMPACTS TO INCLUDE IN ANALYSIS

HEALTH ISSUE	EXPOSURE OF CANADIAN POPULATION	AVAILABILITY OF DATA AND RESEARCH
DEATHS FROM HEAT	Illness and deaths attributable to temperature change (heat and cold) already occur in many Canadian cities. People living in densely populated urban areas are especially susceptible.	Relatively well understood and researched area Many peer-reviewed studies exist Numerical data available
RESPIRATORY AND CARDIOVASCULAR ILLNESS AND DEATHS LINKED TO POORER AIR QUALITY	Canadians are already affected by poor air quality. Ozone is a non-threshold pollutant, so any level of that compound increases health risk. Montréal and Toronto exceed the Canada-wide standard for ozone while parts of Vancouver and Calgary are within 10% of that standard.[170] The human health costs of air pollution are recognized by the government and included in regulatory cost-benefit analysis.	Growing research and interest in this area Assessments of air quality and climate impacts carried out for Canada and the U.S. Numerical data available

STEPS TO ESTIMATE HEALTH IMPACTS OF HEAT

FIRST, we selected the types of health impacts related to heat we could credibly include in our analysis. Changing temperatures, both averages and extremes, have the potential to directly affect our health. Drawing on the existing evidence base, we quantified the effect of rising temperatures on deaths related to heat, and since high temperatures occur in the summer in Canada, our analysis focused on this season.

// A COUPLE OF CONSIDERATIONS UNDERLYING OUR CHOICES ARE WORTH NOTING HERE:

// Research shows that higher temperatures can lead to illnesses including heat stroke, heat exhaustion, skin rashes, cramps, and unconsciousness.[171] However, the evidence base at the time of our analysis was insufficient to allow us to develop numerical estimates of additional cases of illness from heat due to climate change. Gaps in the evidence base partly relate to the limited tracking of illnesses caused by heat in ambulance and hospital admission records.[172]

// The widespread perception that health improvements due to warmer winter temperatures could offset damages due to warmer summer temperatures may be unfounded. Recent U.S. and Canadian research comparing death rates across cities against a range of average temperatures indicates that the widely observed increase in winter death rates may be as prominent in warm as in cold locations.[173] This suggests that winter death rates are insensitive to differences in yearly or seasonal temperatures across locations. The increase in wintertime deaths is primarily linked to flu deaths rather than rare deaths from extreme cold (i.e., hypothermia). By implication, rising temperatures linked to future changes in climate conditions are unlikely to be a major driver of winter death rates.

SECOND, we acquired information on summertime temperatures forecast over the century for our four cities. Average summertime temperatures are forecast to rise by between 1.6°C and 2.8°C by the 2050s depending on the climate scenario and city. **Table 20** provides the historical average daily summer temperatures and the forecast change that was used in our heat analysis. We relied on average daily temperatures since the scientific evidence we built from (described below) provided relationships between death rates and daily average temperatures.

TABLE 20

HISTORICAL TEMPERATURE AND FORECAST CHANGE IN AVERAGE DAILY SUMMER TEMPERATURES (°C)

	BASELINE (1971–2000)	LOW CLIMATE CHANGE (2020s)	HIGH CLIMATE CHANGE (2020s)	LOW CLIMATE CHANGE (2050s)	HIGH CLIMATE CHANGE (2050s)	LOW CLIMATE CHANGE (2080s)	HIGH CLIMATE CHANGE (2080s)
VANCOUVER	16.8	1.3	1.4	1.9	2.7	2.3	4.3
CALGARY	15.2	1.1	1.3	1.6	2.6	2.2	4.2
TORONTO	20.9	1.2	1.2	1.9	2.8	2.3	4.7
MONTRÉAL	19.6	1.1	1.2	2.0	2.7	2.3	4.5

SOURCE: FORECASTS ARE AVERAGES OF OUTPUTS FROM TWO GLOBAL CLIMATE MODELS DEVELOPED BY THE CANADIAN CENTRE FOR CLIMATE MODELLING AND ANALYSIS: MODEL CGCM3T47 AND MODEL CGCM3T63. WE DID NOT USE DOWNSCALING TECHNIQUES AS THE RESOLUTION PROVIDED BY THE OUTPUTS OF GLOBAL CLIMATE MODELS WAS CONSIDERED APPROPRIATE FOR OUR HIGH-LEVEL ANALYSIS. BASELINE TEMPERATURES ARE FROM ENVIRONMENT CANADA'S CANADIAN CLIMATE NORMALS (ENVIRONMENT CANADA 2010A).

THIRD, we derived a numerical relationship between future summer temperatures and death rates. Drawing from three studies conducted in the northern U.S. and Canada,[174] we related each 1°C increase in average daily summer temperature to a 1.4% increase in deaths and applied this relationship to our four cities. We forecast summertime deaths that would occur in the absence of climate change using Statistics Canada data and then applied the relationship between temperature increase and percentage death increase to derive the additional deaths from heat that would occur due to climate change.[kk]

kk To generate baseline assumptions of monthly death rates for each city, we started with Statistics Canada's annual figures for "total mortality age-standardized rates per 100,000 people" and removed non-external causes of death like accidents and suicide. We converted annual to monthly rates for each city using five-year provincial averages. For simplicity, we assume that these baseline death rates for each city continue over the rest of the century.

STEPS TO ESTIMATE HEALTH IMPACTS OF DETERIORATED AIR QUALITY

FIRST, we identified impacts that we could include in our analysis based on the current evidence base. Our analysis builds from research relating higher temperatures to greater concentrations of ground-level ozone.[175] Temperature also interacts with particulate matter but these interactions are not as well understood.[176]

SECOND, we acquired temperature forecasts for each city over the century. For the purposes of AQBAT simulation, annual changes in temperature were used to approximate ozone concentration increases. AQBAT estimates changes in death rates based on annual ozone changes and changes in illness based on seasonal ozone changes for May through September. For simplicity, we applied annual temperature change estimates in both cases. Temperatures are forecast to rise by between 1.9°C and 3.3°C by the 2050s depending on the climate scenario and city. **Table 21** provides the historical average daily temperatures and the forecast change that was used in our ozone analysis.

TABLE 21

HISTORICAL TEMPERATURE AND FORECAST CHANGE IN AVERAGE DAILY TEMPERATURES (°C)

	BASELINE (1971–2000)	LOW CLIMATE CHANGE (2020s)	HIGH CLIMATE CHANGE (2020s)	LOW CLIMATE CHANGE (2050s)	HIGH CLIMATE CHANGE (2050s)	LOW CLIMATE CHANGE (2080s)	HIGH CLIMATE CHANGE (2080s)
VANCOUVER	10.1	2.0	2.0	2.7	3.3	3.1	4.8
CALGARY	4.1	1.3	1.2	1.9	2.6	2.3	4.1
TORONTO	9.2	1.2	1.4	1.9	2.8	2.5	4.6
MONTRÉAL	6.2	1.3	1.5	2.2	3.1	2.7	5.0

SOURCE: THESE FORECASTS WERE DEVELOPED FROM AVERAGING RESULTS FROM TWO MODELS DEVELOPED BY THE CANADIAN CENTRE FOR CLIMATE MODELLING AND ANALYSIS: MODEL CGCM3T47 AND MODEL CGCM3T63. THE RESOLUTION PROVIDED BY THE GCM OUTPUTS WAS CONSIDERED APPROPRIATE FOR OUR HIGH-LEVEL ANALYSIS SO WE DID NOT DO ANY DOWNSCALING. BASELINE TEMPERATURES ARE FROM ENVIRONMENT CANADA'S CANADIAN CLIMATE NORMALS (ENVIRONMENT CANADA 2010A).

THIRD, we developed forecasts of ozone concentrations linked to climate change for each city over the century. Based on research conducted in the U.S. Great Lakes region, and the northeastern U.S., we related a 1°C increase in year-round daily average temperature in each of our four cities to a 2.25 part per billion volume (ppb(v)) increase in one-hour ozone concentrations.[177] This is a simplistic approach. The impact of climate on ozone concentrations is complex, influenced by local factors such as temperature, humidity, rainfall, and sunlight.[178] In some cases climate change may reduce ozone levels where humidity is higher and more precipitation occurs. The local changes to humidity and precipitation from climate change are uncertain.[179] **Table 22** provides the forecast change in ozone concentrations relative to 1971–2000.

TABLE 22

FORECAST CHANGE IN OZONE RELATIVE TO 1971–2000

	LOW CLIMATE CHANGE (2020s)	HIGH CLIMATE CHANGE (2020s)	LOW CLIMATE CHANGE (2050s)	HIGH CLIMATE CHANGE (2050s)	LOW CLIMATE CHANGE (2080s)	HIGH CLIMATE CHANGE (2080s)
VANCOUVER	4.6	4.6	6.2	7.5	7.0	10.8
CALGARY	2.9	2.8	4.2	5.9	5.3	9.2
TORONTO	2.7	3.1	4.3	6.3	5.6	10.4
MONTRÉAL	2.9	3.4	4.8	6.9	6.0	11.3

PARTS PER BILLION BY VOLUME

FOURTH, we relied on Health Canada's Air Quality Benefits Assessment Tool (AQBAT) to estimate additional deaths and cases of illness resulting from changes in ozone concentrations. The AQBAT model estimates the health and welfare[ll] implications of changes in air quality.[mm] We fed the forecast changes in ozone concentrations into AQBAT to compare the health outcomes under baseline ozone concentrations and those forecast in a changing climate. These health outcomes were then scaled up over time based on our population projections.

STEPS TO ESTIMATE THE COSTS TO THE PUBLIC HEALTH CARE SYSTEM

Our estimates of public health care costs are a function of (1) the five indicators of illness arising from increased ozone concentrations from climate change quantified ("health endpoints") for Montréal, Toronto, Calgary, and Vancouver, (2) the way we mapped these cases of illness to specific cost categories of the health care system, and (3) the cost assumptions we developed for each health care system category per health endpoint per city. What follows is an explanation of key steps and assumptions.

FIRST, to convert the five types of cases of illness quantified previously to health care costs, we identified the interaction between these health endpoints and common categories of expenditure for the health care system. **Table 23** summarizes this mapping exercise, highlighting an interaction that we were unable to monetize due to data gaps.

ll In this context welfare refers to an economic indicator of people's well-being.
mm For more information on AQBAT specifications and assumptions see Judek and Stieb 2006.

TABLE 23

INTERACTIONS BETWEEN TYPES OF ILLNESS AND CATEGORIES OF EXPENDITURE FOR THE HEALTH CARE SYSTEM

HEALTH CARE SYSTEM CATEGORY	HEALTH ENDPOINT				
	RESPIRATORY HOSPITAL ADMISSIONS	RESPIRATORY EMERGENCY ROOM VISITS	DAYS WITH ACUTE RESPIRATORY SYMPTOMS	DAYS WITH ASTHMA SYMPTOMS	DAYS WITH RESTRICTIONS IN ACTIVITY DUE TO POOR AIR QUALITY
HOSPITAL ADMISSION	X				
EMERGENCY ROOM VISIT		X			
PUBLICLY FUNDED MEDICATION	X	X	X	X	X
DOCTOR'S OFFICE VISIT			X	X	
RESPIRATORY THERAPISTS	X (NOT MONETIZED)	X (NOT MONETIZED)	X (NOT MONETIZED)	X (NOT MONETIZED)	X (NOT MONETIZED)

SECOND, we developed estimates of the health care costs associated with each health care system category. Three main sources informed our approach to convert cases of illness to health care costs: *The Case of Illness Handbook* of the U.S. Environmental Protection Agency, the Illness Cost of Air Pollution model, and information in reports by the Canadian Institute for Health Information (CIHI) and CIHI's Patient Cost Estimator.[180]

// **HOSPITAL ADMISSION:** For Toronto, Calgary, and Vancouver, the Patient Cost Estimator was used to extract cost estimates per respiratory hospital admission. Provincial estimates were then adjusted upward or downward to region-specific estimates based on the ratio of average regional costs to average provincial costs. In the case of Montréal, 2005–06 data was taken from the Illness Cost of Air Pollution model and then scaled up to 2008–09 based on the growth in costs experienced in Ontario.

// **EMERGENCY ROOM VISITS:** Using CIHI information for Ontario in 2008 we developed an estimated cost of a respiratory emergency room visit and then scaled to the other three provinces.

// **PUBLICLY FUNDED MEDICATION:** We estimated the costs of medication for each health endpoint and identified the costs that would be publicly funded based on the share of overall medication costs that are publicly funded.

// **DOCTOR'S OFFICE VISIT:** We used the Illness Cost of Air Pollution model to identify the frequency of doctor's office visits in Ontario associated with minor respiratory illness and used data from the Ontario Medical Association to estimate the costs of these visits. Costs for other provinces are scaled based on the relative costs of service.

THIRD, we totalled up the costs by health endpoint to develop our cost estimates for each type of illness. The resulting distribution of costs between health endpoints was largely invariant across cities and timeframes.

ASSUMPTIONS UNDERLYING ADAPTATION ANALYSIS

GREEN ROOFS: We assume that the replacement of 50 million square metres of conventional roofs with extensive green roofs could lead to a 1°C reduction in summertime temperatures within Toronto. This relationship comes from a City of Toronto study that analyzed the environmental benefits of widespread implementation of a green roofs program.[181] We assume that the current stock of conventional roofs reaches the end of its lifetime before being replaced by green roofs, so that green roof installation takes place between 2035 and 2050. The costs of installing and maintaining green roofs are from the Toronto and Region Conservation Authority.[182] The benefits of widespread green roof installation are those associated with reduced deaths from heat in a changing climate.

OZONE CONTROLS: We developed generic pollution control cost estimates from estimates developed by the U.S. Environmental Protection Agency[183] and applied these to Toronto as a proxy. These estimates are based on the costs of existing and possible future emissions control technologies, and our analysis yields order of magnitude estimates only as a result. Examples of emissions controls could be low-NO_x burners or low-VOC paints. Our benefits are then estimated by applying the VSL to the number of deaths avoided by pollution control.

LIMITATIONS

By necessity, we made key assumptions and simplifications in conducting our analysis, which we list here. These assumptions and simplifications introduce a degree of uncertainty into the analysis, with effects on the magnitude and direction of physical impacts estimated and corresponding costs, with and without adaptation.

// Relationships between temperature and death rates and between temperature and ozone formation from the literature are transferred to the cities in our analysis. We were careful in selecting source studies applicable to our context, but relationships may in reality vary due to differing environmental, geographic, and social circumstances.

// Relationships between temperature and death rates and between temperature and ozone formation are linear for all time periods.

// We do not separate the impacts by age group due to data limitations. Impacts will vary by age group, with children, the elderly, and those whose health is already compromised being the most vulnerable.

// We treat the effect of heat and ozone concentrations on death rates as independent and additive. Air quality and heat could have synergistic effects on health, worsening overall outcomes. However,

evidence to substantiate an assumption other than additive is limited. Our approach is justified in that the source studies for deriving heat and ozone effects controlled for the other environmental factor in their analysis.

// We do not make assumptions about acclimatization to higher temperatures over time. People are likely to acclimatize to higher temperatures, but uncertainty exists as to the extent and rate of this phenomenon. A degree of acclimatization is inherently embedded in our analysis since it builds on observed relationships between temperature and death rates. However, if further acclimatization occurs the impacts of climate change will be lower than estimated in our analysis.

// People may autonomously adapt to warmer weather, and the heat alert response systems that are currently emerging may also enhance adaptation. A richer future society may be able to afford greater levels of air conditioning. This could reduce the death rates resulting from higher temperatures.

// We assess the effect of changes in average temperatures on death rates rather than changes in the intensity and duration of heat waves. The frequency, intensity, and duration of heat waves are expected to increase with climate change, so our results are conservative.

// We assume that temperature rise from climate change is the only factor affecting ozone concentrations in the future. We would need to make a number of assumptions to develop forecasts of future air quality, including ozone concentrations, which was beyond the scope of this analysis. In practice, in our low climate change scenario the levels of air pollution would be likely lower than in the high climate change scenario (and possibly the same would occur in both slow growth scenarios).

// We assume that a rise in ozone concentrations is the only impact of climate change on air quality. Others include enhanced emission of noxious chemical compounds from plants (volatile organic compounds) and soils (nitric oxide), production of pollens and other aeroallergens.

// We used the VSL to estimate the economic impact of the increased risk of death. Other similar economic valuation metrics vary the cost estimates based on the estimated number of years by which death is brought forward and on the quality of an individual's health during those years. Relative to the VSL, less of a consensus about the appropriate value of these alternative costing techniques exists, but broadly speaking the costs estimated with such approaches would be lower than with the VSL.

// Data gaps likely lead us to understate actual costs to the public health care system. Some cost categories proved impossible to credibly derive, such as the cost of respiratory therapists. Within specific cost categories, not all costs are captured, the most important gap being physician costs associated with hospital admissions and emergency room visits.

// Unit costs related to medical consumption, although inflated to today's dollars, come from an Ontario-based study from the 1990s. Since medical consumption is a main contributor to our health care cost estimates, updated and city-specific unit costs would improve our estimates as would an illness-specific breakdown of public versus private medication expenditures.

8.6 EXPERT STAKEHOLDER ENGAGEMENT

This appendix lists the individuals that contributed to this project through formal engagement mechanisms, reflecting the individual's affiliation at the time at which they were involved.

CLIMATE IMPACTS SCOPING SESSION

This meeting took place on July 30, 2009, to solicit input on the most useful focus of the sectoral studies.

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Advisory committee members met four times during 2010 to provide feedback on the sectoral studies.

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REGIONAL OUTREACH SESSIONS

The NRTEE held five regional sessions in October 2010 to elicit feedback on the sectoral study results.

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8.7 GLOSSARY

KEY TERMS	DEFINITION
ADAPTATION	Adjustment in natural or human systems in response to actual or expected climate stimuli and their effects, which moderates harm or exploits beneficial opportunities. There are various types of adaptation, including anticipatory, autonomous, and planned adaptation.[184*]
ADAPTIVE CAPACITY	The whole of capabilities, resources, and institutions of a country, region, community, or group to implement effective adaptation measures.[185*]
BENEFIT-COST RATIO	The ratio of the economic benefits of an action relative to the costs. A ratio larger than one indicates that the benefits exceed the costs.
BIODIVERSITY	The total diversity of all organisms and ecosystems at various spatial scales (from genes to entire biomes).[186]
CLIMATE	Climate in a narrow sense is usually defined as the average weather or, more rigorously, as the statistical description of mean values and variability of variables such as surface temperature, precipitation, and wind over a period of time ranging from months to thousands or millions of years. Climate in a wider sense describes the state of the climate system.[187*]
CLIMATE CHANGE	Climate change is a significant and persistent change in an area's average climate conditions or their extremes.[188]
COMPUTABLE GENERAL EQUILIBRIUM (CGE) MODEL	CGE models are economic models used to estimate the impacts of policies and other factors such as technological changes on the economy as a whole.
COST	Economic damage resulting from climate change.
DAMAGE	Negative physical impact of climate change.
DISASTER	Social phenomenon resulting from the intersection of a hazard with a vulnerability that exceeds or overwhelms the ability to cope and may cause harm to the safety, health, welfare, property, or environment of people.[189]
ECOSYSTEM	The interactive system formed from all living organisms and their physical and chemical environment within a given area. Ecosystems cover a hierarchy of spatial scales.[190*]
EVAPOTRANSPIRATION	The combined process of evaporation from the Earth's surface and transpiration from vegetation.[191]

* Modified from source

EXPOSURE	The nature and degree to which a system is exposed to significant climatic variations.[192]
EXTREME WEATHER EVENT	An event that is rare within its statistical reference distribution at a particular place. Definitions of “rare” vary, but an extreme weather event would normally be as rare as, or rarer than, the tenth or ninetieth percentile. By definition, the characteristics of what is called “extreme weather” may vary from place to place.[193]
FOREST INDUSTRY	The forest industry includes forestry and logging, pulp and paper manufacturing, and wood product manufacturing.[194]
FORESTRY	The forestry and logging sector, including timber production, harvesting, reforestation and gathering of forest products.[195]
GLOBAL WARMING	The observed increase in average temperature near the Earth’s surface and in the lowest layer of the atmosphere. In common usage, “global warming” often refers to the warming that has occurred as a result of increased emissions of greenhouse gases from human activities. Global warming is a type of climate change: it can also lead to other changes in climate conditions, such as changes in precipitation patterns.[196]
GREEN ROOF	A roof of a building that is covered with vegetation.
GROSS DOMESTIC PRODUCT	The total unduplicated value of the goods and services produced in the economic territory of a country or region during a given period.[197]
HABITAT	The locality or natural home in which a particular plant, animal, or group of closely associated organisms lives.[198]
IMPACT	The effects of climate change on natural and human systems.[199]
INCENTIVES	Incentives broadly refer to mechanisms that encourage or discourage certain types of behaviour. Incentives can include relevant information, price signals, regulations, and financial rewards or penalties. Provision of or access to these incentives can be by design or unintentional.
INFRASTRUCTURE	The physical foundation of a society, community or enterprise. Infrastructure comprises assets, installations or systems used to provide goods or services.[200]
MALADAPTATION	Maladaptation refers to a strategy that reduces one sort of vulnerability but heightens another sort of vulnerability in turn. For example, subsidizing flood insurance can encourage maladaptation by encouraging people to live in areas prone to flooding.

MITIGATION	In the context of climate change, mitigation is an intervention intended to reduce adverse human influence on the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.[201*]
PERMAFROST	Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.[202]
PRESENT VALUE	The current value of a future cost calculated using a given discount rate.
RESILIENCE	The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the same capacity for self-organization and the same capacity to adapt to stress and change.[203]
RISK	A combination of the likelihood (probability of occurrence) and the consequences of an adverse event (e.g., climate-related hazard).[204] In line with the multi-dimensional character of climate change, the framing of risk considers three questions: What can happen? How likely is it to happen? If it does happen, what are the consequences? Thus, risk from the impacts of climate change is an expectation that involves a threat or hazard (climate change as a source of or contributor to adverse outcomes), adverse outcomes (losses or harm to conditions that Canadians value such as healthy communities and ecosystems), and uncertainty of occurrence and outcomes (the likelihood of adverse outcome actually materializing).
RISK MANAGEMENT	A systematic approach to setting the best course of action under uncertainty, by applying management policies, procedures and practices to the tasks of analyzing, evaluating, controlling and communicating about risk issues.[205]
SCENARIO	A simplified representation of a possible future based on a credible set of assumptions. Here, our scenarios reflect the extent of future climate change along with the growth of the Canadian economy and population.
SENSITIVITY	The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).[206]
UNCERTAINTY	An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour.[207]
URBAN HEAT-ISLAND EFFECT	A phenomenon where temperatures in urban areas are several degrees higher than in the surrounding rural areas due to the relative concentration of paved and dark coloured surfaces in cities that absorb heat.

* Modified from source

VALUE OF A STATISTICAL LIFE	The economic value reflecting people's willingness to pay for reducing risk. This value is derived from the aggregation of many small risks over an exposed population.[208]
VULNERABILITY	Vulnerability to climate change is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability to climate change is a function of the character, magnitude, and rate of climate change variation to which a system is exposed, its sensitivity and its adaptive capacity.[209]*
WEATHER	State of the atmosphere at a given time and place with regard to temperature, air pressure, humidity, wind, cloudiness and precipitation. The term is mainly used to describe conditions over short periods of time.[210]

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* Modified from source

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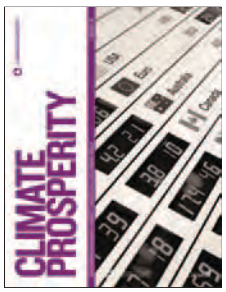

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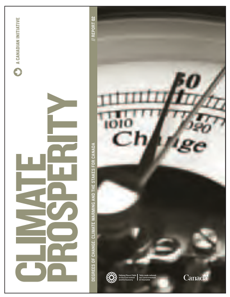

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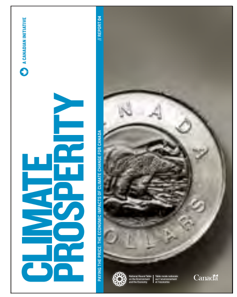

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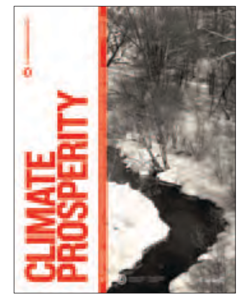

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