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Analysis of Climate Change Impact on the Office of the Chief Actuary's Assumption-Setting Process

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1 Executive summary

1.1 Purpose

This is the twenty-fourth actuarial study to be published by the Office of the Chief Actuary (OCA). The OCA is responsible for conducting statutory actuarial valuations for federal public sector employee pension and insurance plans, and a range of Canadian social security programs, including the Canada Pension Plan (CPP), the Old Age Security (OAS) Program, the Canada Student Financial Assistance Program, and the Employment Insurance Program.

The purpose of this study is to assess how climate change can affect the OCA's overall assumption-setting process for its actuarial valuations. Climate change is increasingly recognized as one of the most pressing global risks impacting ecosystems, economies, and communities worldwide. Climate change can therefore affect the programs under OCA's responsibility through various channels as the demographic, economic and investment environments can all be affected by climate change in the future.

1.2 Scope

The OCA conducted literature research to better understand the potential impact from climate change on the assumptions underlying the actuarial valuations. The results of this research are presented in this study. Section 2 provides high-level background information on climate change and the programs under OCA's responsibility. Sections 3 to 5 discuss the potential impacts from climate change on demographic assumptions, economic assumptions, and investment assumptions, respectively. The last section presents the conclusions.

1.3 Main findings

There is presently a lot of uncertainty on the direction and magnitude of climate change potential impacts, and the risk is evolving. In addition, research and data to quantify the full impact of climate change remain incomplete and, in certain cases, somewhat conflicting. The OCA is thus not ready to incorporate the impacts from climate change explicitly in the best-estimate assumptions and continues to believe that scenario analysis is a sound approach to understanding and illustrating risk.

This study aims to refine the existing climate scenario analysis framework presented in the 31st Actuarial Report on the Canada Pension Plan (CPP31 AR). One area of consideration lies within the demographic assumptions. The OCA decided to exclude demographics from climate change scenario analysis, due to the high level of uncertainty and the lack of Canadian-specific research. The absence of reliable projections makes it challenging to assess the potential impacts of climate change on population dynamics and migration patterns, though it remains an important consideration.

For economic assumptions, the study recommends maintaining a similar framework to that used in the CPP31 AR. The existing framework builds on a foundation for relating economic assumptions to potential shocks in Gross Domestic Product (GDP) from climate change.

Finally, for investment assumptions, the focus is on enhancing the existing framework used in CPP31 AR by incorporating additional dynamics. This involves integrating factors such as climate change impact on fixed income returns, as well as varying GDP impacts by different markets under each climate scenario.

2 Background information

This section offers background information on climate-related risks as well as information on key organizations and climate scenarios that are commonly used as a reference when assessing climate change impacts. It also outlines the various programs under OCA's responsibility.

2.1 Climate-related risks

Climate change risks have been ranked among the top emerging risks globally, and they are generally classified into two categories: physical risks, which are linked to the increase in the frequency and severity of climate events, and transition risks, which are linked to efforts undertaken for a transition towards a lower carbon economy. It is also important to note that regardless of the transition path, full elimination of physical risks[1] is not realistic at this point given that a certain level of physical risk is already embedded from past global warming. However, physical risks may be reduced or mitigated if new technologies that reduce and/or capture carbon emissions are developed, or through adaptation to the increasing frequency and severity of hazard events.

2.1.1 Examples and types of physical risks

There are two types of physical risks: acute (short-term) physical risks arising from extreme weather events such as storms, flooding, wildfires, heatwaves; and chronic (long-term) physical risks represented by temperature rise, sea-level rise, changing precipitation patterns, etc. Physical risks can also be categorized into direct and indirect risks. Direct physical risks are the immediate, observable effects of climate change, generally resulting from extreme weather events and long-term environmental changes that directly impact assets, infrastructure, or systems. Indirect physical risks are linked to the secondary effects arising from the direct impacts of climate change, and through complex interactions within ecosystems, economies, and social systems. Examples include disruption of supply chains, increased insurance costs, loss of biodiversity, etc.

2.1.2 Examples of transition risks

Transition risks may include climate mitigation policies and legislation, adaptation measures, innovation technologies, shifting market preferences and investment sentiment, etc.

2.2 Climate change organizations and scenarios

This section provides a brief introduction on some climate change scenarios and climate organizations, which will be referred to in the rest of the study.

2.2.1 Key climate change organizations

Numerous climate modeling institutions around the world each produce their own climate model, and every five to seven years, come together to use the latest version of these models in a coordinated site of simulations. Such global collaboration, known as the Coupled Model Intercomparison Project (CMIP), strengthens climate projections by combining insights from various institutions.

In addition to these modeling efforts, several international organizations focus on

[1] IPCC Summary for policymakers

collaborative climate change initiatives. Among them the most prominent ones are the Intergovernmental Panel on Climate Change (IPCC) and the Network for Greening the Financial System (NGFS).

The IPCC is the United Nations body for assessing the state of science related to climate change. While IPCC does not conduct its own research, it performs comprehensive assessments of scientific literature related to climate change and releases these findings in Assessment Reports (ARs) periodically.

The NGFS is a group of more than 100 central banks and supervisors and a score of observers committed to sharing best practices, contributing to the development of climate and environment-related risk management in the financial sector and mobilizing mainstream finance to support the transition toward a sustainable economy. NGFS also publishes its climate scenarios and updates regularly.

2.2.2 Key climate change scenarios

In the IPCC sixth assessment report (IPCC AR6), various scenarios based on the Shared Socio-economic Pathways (SSPs) from the sixth phase of the Coupled Model Intercomparison Project (CMIP6) are discussed. These scenarios are based on information on social-economic development and climate projections. They are labelled as "SSPx-y", where "SSPx" refers to a specific Shared Socio-economic Pathway and "y" indicates the radiative forcing level (measured in W/m^2, the higher the value, the stronger the climate warming effects) at the end of the 21st century. There are five SSPs, SPP1 to SPP5, each with different assumptions of human developments (population, education, urbanization, etc.), economic growth, technology developments, gas emissions, energy supply and demand, and so on. Each SSP can lead to multiple scenarios depending on the associated radiative forcing levels. AR6 mentions 5 top priority scenarios of SSPs, as follows.

- SSP1-1.9 and SSP1-2.6: the low end of future CO_2 and other greenhouse gas (GHG) emissions pathways, warming by 2100 possibly limited to be below 2°C.
- SPP2-4.5: intermediate future CO_2 and GHG emissions, warming by 2100 possibly limited to be below 3°C.
- SPP3-7.0: high future CO_2 and GHG emissions, warming by 2100 around 3.6°C.
- SPP5-8.5: very high future CO_2 and GHG emissions, warming by 2100 around 4.4°C.

The SSPs were designed to complement and function in combination with the Representative Concentration pathways (RCPs), which are introduced in the Coupled Model Intercomparison Project Phase 5 (CMIP5) and the IPCC fifth assessment report (IPCC AR5). The RCP scenarios are named by the radiative forcing level projected for 2100. There are four RCPs in AR5, as follows.

- RCP2.6: the radiative forcing level decreased to 2.6 W/m^2 by 2100.
- RCP4.5: the radiative forcing level stabilized at 4.5 W/m^2 by 2100.
- RCP6.0: the radiative forcing level stabilized at 6.0 W/m^2 by 2100.
- RCP8.5: the radiative forcing level increased to 8.5 W/m^2 by 2100.

Note that both SSPs and RCPs specify the radiative forcing level projected for 2100, thus providing a way of comparison between their scenarios. However, for a given radiative forcing level, the composition of greenhouse gases and emission trajectories between the SSPs and RCPs may differ.

2.3 Programs under OCA's responsibility

The OCA, as an independent unit within the Office of the Superintendent of Financial Institutions (OSFI), provides advisory services to the Government of Canada. As part of its mandate, the OCA conducts statutory actuarial valuations for federal public sector employee pension and insurance plans, and a range of Canadian social security programs (Canada Pension Plan (CPP), Old Age Security (OAS) Program, Canada Student Financial Assistance Program and Employment Insurance Program).

2.3.1 Old Age Security Program

The OAS program comprises a universal basic pension and targeted supplements aimed at poverty reduction. The OAS program is financed through the general tax revenues on a pay-as-you-go basis. One of the measures of the program's cost is the ratio of expenditures to Gross Domestic Product (GDP). The OCA conducts triennial valuations of the OAS program, which present the projected and historical expenditures and cost ratios. Such projections involve assumptions of both demographic and economic variables. Key demographic assumptions include fertility rates, mortality rates, and net migration; key economic assumptions include inflation, real wage increase, and assumptions related to labour force.

2.3.2 Canada Pension Plan

The CPP is a mandatory earnings-related defined benefit social insurance program, with the primary purpose of providing basic retirement income. The CPP consists of two parts: the base CPP (benefits in existence prior to the enhancement) and the additional CPP (the enhancement), which commenced in 2019. The base CPP is partially funded while the additional CPP is fully funded, both through employee and employer contributions. Contributions that are not immediately needed to pay expenditures are invested in financial markets.

2.3.2.1 Base CPP

Triennial valuations determine the minimum contribution rate (MCR) on an open-group-projection basis. Such MCR represents the lowest contribution rate that results in the ratio of projected assets over the projected expenditures being generally constant. Important demographic assumptions to determine the MCR include fertility, mortality, migration, retirement patterns and disability rates; key economic assumptions are real wage increase, labour force, inflation, and investment returns.

2.3.2.2 Additional CPP

Since the additional CPP is fully funded, the investment income is an important source of revenue. The projected revenues (contributions and investment income) should be sufficient to fully pay the projected expenditures of the additional CPP over the long term. With this as one of the objectives, triennial valuations determine the additional minimum contribution rates (AMCRs) on an open group basis. Unlike MCR for base CPP, AMCRs for additional CPP are not very sensitive to fertility, labour force, or migration assumptions, because of the stronger link between individuals' contributions and their future benefits. Meanwhile, AMCRs are sensitive to mortality, real wage, and investment assumptions (real rate of return assumptions), which is similar to public sector pension plans.

2.3.3 Public sector pension plans

Public sector pension plans provide defined pension benefits to various groups of federal employees. Generally, such benefits are proportional to the accrued service and salary. For major public sector pension plans (Public Service, Canadian Forces, Royal Canadian Mounted Police), benefit accruals for service since 1 April 2000 are fully funded. Contributions by employees and the government are put into specific funds, which are expected to grow with investment returns. Triennial valuations determine the financial position (in terms of actuarial surplus/deficit and funding ratio)[2], and the contributions (which include employee contributions, government contributions and if applicable, government special payments) for these plans. The financial position and the required contributions are sensitive to demographic assumptions and economic assumptions used in the valuations. One of the key demographic assumptions is mortality, and key economic assumptions include investment return, pension indexation, salary increase and inflation.

For each of the above plans, the contributions made, and benefits earned up to 31 March 2000 are tracked through a special account, which is credited with interest earnings as if the net cash flows were invested quarterly in certain government bonds. The triennial valuations determine the financial position of these accounts and the special credit to be made to the accounts in case of a deficit. The financial position of the accounts is sensitive to demographic assumptions such as mortality rates and to economic assumptions such as bond yield, pension indexation, salary increase and inflation.

Additionally, there are a couple of relatively small public sector plans which are unfunded. Either there is a special account established for the plan to hold the contributions and the account is credited with a prescribed interest rate; or the plan is financed through the Consolidated Revenue Fund (CRF) on a pay-as-you-go basis.

2.3.4 Other programs

This study focuses on the impact of climate change on the above programs/plans, and CPP in particular. The following sections will discuss key considerations and potential impact of climate change on the main demographic, economic and investment assumptions made by the OCA to evaluate these programs/plans.

There are some other programs for which OCA prepares the actuarial reports, for example, the Canada Student Financial Assistance programs, the Employment Insurance Program, and several public sector benefit programs. These programs are not addressed in this study.

[2] Financial position is measured by the actuarial value of assets as at the valuation date relative to the actuarial liability as at the valuation date, which is based on the snapshot of membership data as at that date.

3 Demographic assumptions

This section of the study discusses key considerations when evaluating the potential impacts of climate-related risks on the demographic assumptions that are developed by the OCA when preparing actuarial reports for the CPP, the OAS program and public sector pension plans.

Population size and age structure could undergo changes in the future due to climate variability or natural disasters. For example, rising sea levels, extreme weather events, changes in temperature and precipitation patterns may exacerbate health issues, affecting birth rates and mortality rates, and could disrupt agriculture leading to global food scarcity and forced migration. On the other hand, warmer winters could reduce cold-related and flu-related mortality. These impacts are interconnected and can have complex and varying effects on a country's demographics.

The following part explores, with a focus on the Canadian perspective when feasible, the potential implications of climate-related risks on three main demographic assumptions: fertility, mortality, and migration.

3.1 Fertility

The impact of climate-related risks on fertility can vary widely depending on geographical location and socio-economic factors, as well as access to healthcare and family planning services.

The first two subsections investigate potential directional impacts on fertility from direct physical risks and from indirect transition and physical risks. These subsections are meant to identify potential drivers in general, and they do not necessarily translate into material impacts on fertility in Canada. The third subsection provides a summary from a Canadian-centric perspective. Finally, the last subsection presents a case study exploring a framework to quantify the potential impacts of climate-related risks on fertility rates by linking historical fertility data to environmental stressors.

3.1.1 Direct impacts

Climate-related risks can affect fertility through direct physical impact channels, such as temperature rise, air pollution, sea-level rise, as well as food and water scarcity. Studies generally show that direct physical impacts from climate-related risks have a negative effect on fertility (i.e., downward pressure). This section discusses some examples of such downward pressure.

First, fertility can be impacted by the environment, which in turn can be aggravated by the changing climate. For example:

- Air pollution[3] could reduce fertility (Gaskin, et al., 2019), and greater air pollution exposure could increase time to pregnancy. Multiple studies found that an increase in fine particle matter decreases fecundability (Mahalingaiah, et al., 2016) (Slama, et al., 2013) (Wesselink, et al., 2022). High levels of pollutants are also shown to be linked to increased risk of miscarriages and adverse pregnancy outcomes (Ha, et al., 2018).

[3] Air pollution is mainly composed of nitrogen dioxide, carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), particulate matter <2.5 µm in diameter ($PM_{2.5}$) and <10 µm in diameter (PM_{10}), as well as some endocrine-disrupting chemicals (EDCs), as in diesel exhaust. (Segal & Giudice, 2022)

- Extreme heatwaves can lead to heat stress, which can affect fertility. Studies show that exposure to extreme heat in the preconception period can decrease the probability of conception. It also increases pregnancy losses, reduces gestational length, and lowers birth weight (Hajdu & Hajdu, 2021).
- Research suggests that changes in precipitation levels can have differential effects on fertility. Extreme precipitation events may lead to decreased fertility in the short term, due to reduced plant productivity and potential food insecurity (Segal & Giudice, 2022) (Zeppel, Wilks, & Lewis, 2014). In the long term, climate change may exacerbate inequalities by increasing fertility in poorer tropical regions while decreasing it in the richer northern areas (Casey, et al., 2019). These effects are largely influenced by socio-economic factors (discussed below). Additionally, rising sea levels, are predicted to increase the salinity levels in drinking water, which is associated with the development of preeclampsia (Khan, et al., 2014).

Second, climate change can disrupt food production through droughts, floods, and other extreme weather events. Similarly, water scarcity, exacerbated by climate change, can affect hygiene and sanitation. Lack of food and access to clear water and sanitation facilities may create downward pressure on fertility through malnutrition impacting reproductive health and increased risk of waterborne diseases, respectively (O'Kelly & Lambert, 2020). The geographic distribution of vector-borne diseases like malaria and Zika virus could also be altered by the changing climate (Cella, et al., 2019) (Mills, Gage, & Khan, 2010), which can have serious implications on pregnancy, including birth defects and miscarriages (Oberlin & Wylie, 2023).

3.1.2 Indirect impacts

Climate-related risks can also affect fertility through indirect impact channels caused by the transition to a low carbon emission economy or through the aftereffects of physical impacts. Based on the research, the indirect impacts could create both downward and upward pressure on fertility.

In the shorter term, transitioning to a low carbon economy could cause disruption in employment and income stability, which may lead some part of the population to delay having children or having fewer children. The cost of living might also increase due to the transition, causing short-term financial challenges for families, potentially influencing family planning and fertility. Finally, the psychological stress associated with climate-related events, loss of livelihoods and uncertainty about the future can impact mental health, potentially affecting decisions related to family planning and fertility (Smith, Sales, Williams, & Munro, 2023).

In the longer term, a successful climate transition can improve the environmental conditions which could increase fertility. An unsuccessful climate transition could lead to decreased fertility in the longer term as a result of increased economic uncertainty and psychological stress, as well as higher impacts stemming from the direct impacts mentioned in the previous subsection.

Depending on the socio-political stability of a country, climate change can also cause societal disruption and increase both intragenerational and intergenerational conflicts (Hsiang, Meng, & Cane, 2011) (Islam & Winkel, 2017). In turn, this can reduce fertility due to increased stress and uncertainty in the lives of the affected population.

Extreme weather events associated with climate change can displace communities and force people to migrate. Research has shown that migration can impact fertility, and that differences in fertility can arise based on the mothers' birth places (Beine, Docquier, & Schiff, 2009). The demographic composition of displaced populations can therefore influence fertility patterns. For example, if a significant portion of the displaced population consists of workers of childbearing age, it could lead to a temporary increase in fertility for the receiving country provided there are no challenges in accessing healthcare, family planning services and other infrastructure.

Finally for certain developing countries, another argument for increased fertility due to climate change is for the agriculture sector. Studies show that family size might increase to compensate for the reduced crop production due to climate change (Casey, et al., The Impact of Climate Change on Fertility, 2019).

3.1.3 Summary and Canadian perspective

Based on the research performed, this subsection provides a summary of conclusions thus far, and how they could affect the OCA's assumption-setting process for fertility in Canada. This subsection is meant to represent the OCA's current observations which will evolve as more research and data become available. For context, lower fertility leads to higher cost ratios for pay-as-you-go and partially funded programs, and vice versa.

Overall, on a global scale, direct physical risks stemming from climate change are expected to exert downward pressure on fertility. In terms of timeframe, the impact would be expected to occur more in the medium to long term. For Canada more specifically:

- Due to a colder climate and generally better air quality relative to other countries, the potential downward pressure on fertility stemming from higher temperatures and air pollution are not expected to be significant. This conclusion is supported by a quantitative analysis presented in the next subsection.
- Climate change is a global problem and the potential impacts on global food production and water quality would also affect developed countries such as Canada, albeit to a lesser extent. Although there is some downside risk to fertility from this factor, at this point, it is not expected to be significant.

As mentioned, indirect risks stemming from climate change could create both downward and upward pressure on fertility. For Canada more specifically:

- The financial uncertainty related to transitioning to a low carbon economy as well as the psychological stress associated with climate risk have the potential to decrease fertility in the shorter term. These are factors that may be considered when setting OCA's fertility assumption for the next actuarial valuation cycle (31 December 2024). At this point, these factors would be considered on a qualitative basis and not explicitly quantified.
- Longer-term impacts depend heavily on the success of the design and implementation of global and Canadian climate policies for transition. At this point, given the high level of uncertainty related to the transition path in Canada and globally, the OCA is not ready to adjust its fertility assumption to reflect longer-term indirect risks stemming from climate change.

3.1.4 Quantitative analysis

The OCA conducted a quantitative analysis to estimate the potential impact of climate change on fertility in Canada. This section briefly describes the framework used for the analysis and its results along with comparisons to similar analysis performed by peers for other countries.

3.1.4.1 Framework

The methodology is based on a framework that takes a statistical analysis approach to assessing the relationship between environmental stressors and health impacts. It is a well-established and widely accepted framework in environmental epidemiology (Bhaskaran, Gasparrini, Hajat, Smeeth, & Armstrong, 2013).

The following list of environmental stressors were tested:

- Number of days per month above 30°C measured between eight and 15 months before birth,
- Number of days per month above 15°C, 20°C and 25°C measured nine months before birth,
- PM2.5 (air quality) measured nine months before birth, and
- Ozone levels (air quality) measured nine months before birth.

Additionally, combinations of environmental stressors were analyzed in relationship to number of live births or total fertility rates. The selected best fitted model based on various statistical metrics as well as the balance between complexity and goodness-of-fit, is shown below:

- Health impact: Live births, by month
- Environmental stressor: Number of days above 30°C per month measured nine months before birth
- Geography level: By individual province (and excluding territories)
- Generalized linear model: Poisson distribution with log-link function
- Control for seasonality and the long-term trend (to separate the short-term association between the environmental stressor and the outcome): Cubic spline with degree of freedom of six.

While air quality (PM2.5 and ozone levels) is a potential future driver for fertility, the available Canadian data may be insufficient to establish a relationship in Canada and as such it was excluded from the model. More specifically, it lacks consecutive days of significant exposure, as research suggests that studies of pollution effects need thousands of observation days with an average of tens of events per day to have credible precision and power (Bhaskaran, Gasparrini, Hajat, Smeeth, & Armstrong, 2013).

3.1.4.2 Data

The analysis relies on provincial fertility data from 1991 to 2022 from Statistics Canada[4] and on provincial environmental stressors data from ClimateData.ca[5] and Environment and Climate Change Canada[6]. Monthly data were used for the live births while monthly total

[4] Table: 13-10-0415-01 (formerly CANSIM 102-4502) and Table *13-10-0418-01* (formerly CANSIM 102-4505).
[5] Historical Station Data (accessed in 2023): Environment and Climate Change Canada and (climatedata.ca)
[6] National Air Pollution Surveillance (NAPS) Program - ECCC Data Catalogue

fertility rates were estimated from annual total fertility rates.

3.1.4.3 Results

Based on the model, each additional day above 30°C in a month would result in a relative decline in the number of births after nine months of 0.54%. Under the SSP5-8.5 scenario (IPCC scenario with the most severe physical impact), the number of days above 30°C is expected to increase on average by about 1.30 days per month by 2050, and 5.30 days per month by 2100. This would result in a relative reduction in the number of births of around 0.70% by 2050 and 2.85% by 2100.

Based on this analysis, the direct impact on births from increasing temperature alone is expected to be minimal in Canada. However, the impact of climate change is not limited to direct environmental impacts such as rising temperature. As discussed earlier, it could also negatively impact the general population's health and have important socio-economic implications which were not reflected in the model and may have a more significant impact on future births.

Finally, the relative decline of 0.54% for Canada is in line with the findings of comparable studies conducted in other countries, as summarized in Table 1 below (Keivabu, Cozzani, & Wilde, 2023). The last column illustrates the impact of climate change on fertility in terms of relative decline in birth rate for each additional day above a certain temperature threshold (column 3). Table 1 highlights consistent impacts across various regions, with declines in birth rates ranging from -0.18% to -0.90%, for each additional day above the temperature threshold selected in the study. While the magnitude of the impact varies slightly between countries, the potential effect of climate change on fertility is generally expected to be modest across diverse climates.

Table 1 Potential impact of climate change on fertility – summary of comparative researches

Study	Region	Temperature threshold (°C)	Impact on birth rate*
This study (OCA)	Canada	>30 (mean)	-0.54%
Keivabu et al. (2023)	Spain	>30 (mean)	-0.90%
Cho (2020)	South Korea	30-32 (max)	-0.24%
Barreca et al. (2018)	USA	>26.6 (mean)	-0.40%
Hajdu & Hajdu (2022)	Hungary	>25 (mean)	-0.18 to -0.85%

* Impact on birth rate is measured as the relative percentage change in number of newborns in a month, divided by the population, resulting from one additional day above the temperature threshold

3.1.4.4 Model assumptions/limitations

The framework represents a simplified version of quantifying the impact from environmental stressors based on historical data. Some underlying assumptions were made:

- The population (and fertility rates) are assumed to be constant going forward. While it does not account for some groups, such as older individuals, being more susceptible to climate change, it does allow for the isolation of the climate effects from other demographic trends.
- Geographical location and temperature at conception are assumed to be in the two cities with the highest population in the province (one city for Prince Edward Island and one for Newfoundland).
- The period of gestation is assumed to be nine months prior to birth for all individuals.
- The model assumes no adaptation (e.g., behaviour) or changes/access to technology

(e.g., increase in the number of individuals having an air conditioner).

3.2 Mortality

This section discusses the potential impacts of climate change on human mortality. Unlike the research on fertility, there is more information available on mortality that is specific to Canada; therefore, the various subsections have a more direct Canadian focus than for fertility.

It is important to note that this section focuses solely on the potential impacts on mortality from climate change in isolation. For example, stating that mortality could increase because of climate change does not mean that mortality would be expected to increase overall given that many other factors influence mortality.

The first subsection looks at the potential direct impacts on mortality arising from environmental channels associated with the physical risks of climate change. The second subsection explores potential indirect consequences of climate change on socio-economic and demographic factors that could influence mortality. Conclusions are provided in the third subsection, and the last subsection concentrates on examples of research papers that provide quantitative impacts.

3.2.1 Direct impacts

Climate change can impact future human mortality directly through various environmental channels. These channels include changes in temperature, changes in precipitation and pathogen patterns, increased air pollution and more frequent wildfires. This subsection discusses the impacts of climate change on mortality through these distinct channels. The interplays among different channels and their potential synergies can compound the possible overall impacts.

It is important to note that the impact on mortality from these direct channels can vary significantly depending on future emission levels. Although the directional impacts indicate potential increases in mortality, the extent of these increases depends heavily on the design and implementation of current and future climate policies.

3.2.1.1 Temperature change

One of the most apparent changes from climate change involves noticeable shifts in temperature across the globe. While global temperatures are generally rising due to climate change, the pace of warming and level of temperatures reached will vary from one region to the next, with Canada projected to warm at a faster pace than the global average[7]. In addition, some regions may experience colder winters due to complex interactions in the climate system. According to the Canadian Centre for Occupational Health and Safety, although it is expected that Canadian winters, on average, will have milder temperatures in the future, extreme cold events are still predicted to occur in Canada[8].

Increases in future mortality from climate change can arise from both hotter summers and extreme cold events (Masselot, et al., 2023) (Raimi, 2021). Many studies found evidence of excess mortality from increased heatwaves (Gasparrini, et al., 2015) (Luthi, et al., 2023)

[7] Expert insight: Canada is warming faster than anywhere else on earth - Western News (westernu.ca)
[8] Canadian Centre for Occupational Health and Safety: Climate Change: Extreme Weather - Cold

(Hajat & Kosatky, 2010) (Ryti, Guo, & Jaakkola, 2016). More extreme winter weather can also exacerbate health conditions such as respiratory and cardiovascular diseases (Seltenrich, 2015), and cause disruptions in infrastructure of healthcare services, transportation, and emergency response systems, ultimately leading to increased mortality. On the other hand, some studies suggest that decreases in mortality could arise as a result of warmer winters (Davis, Knappenberger, Michaels, & Novicoff, 2004) (Kinney, et al., 2015). An important question is whether these potential decreases in cold-related mortality would be sufficient to offset the potential increases from hotter summers and more extreme weather patterns.

The Canadian-specific research suggests that the increases in mortality may not be balanced by a decrease in cold-related deaths, especially under the higher-emission scenarios. This research supports predominantly increased mortality from temperature changes in Canada (Club Vita, 2018) (Gasparrini, et al., 2017) (Gosselin, Campagna, Demers-Bouffard, Qutob, & Flannigan, 2022) (Hebbern, et al., 2023) (Lavigne, 2020).

From a more regional perspective, a 2012 study of 15 Canadian cities estimates that four cities would see a net increase in mortality: London, Hamilton, Regina, and Montréal (Martin et al., 2012). Later studies also show that the net impacts of temperature on excess mortality appear to vary across geographic regions (Gasparrini, et al., 2017) (Gosselin, Campagna, Demers-Bouffard, Qutob, & Flannigan, 2022) (Hebbern, et al., 2023) (Lavigne, 2020).

3.2.1.2 Changing patterns of precipitation and pathogens

Climate change may alter the patterns of precipitation in Canada, which could contribute to an increased frequency and intensity of extreme weather events such as floods, storms, and droughts (Bonsal, Peters, Seglenieks, Rivera, & Berg, 219). These events can lead to direct physical injuries, long-term impacts on mental health, forced displacement and disruptions in healthcare services (Ebi, et al., 2022). These multifaceted consequences could lead to increased mortality, especially under high emissions scenarios.

Furthermore, gradual shifts in temperature and precipitation can impact urban ecosystems, causing shifts that enable insects to expand poleward. This increases the risks of vector-borne diseases such as West Nile virus and Lyme disease in North America (Portner, et al., 2022). Approximately 17% of all infectious diseases are caused by vector-borne diseases, resulting in over 700,000 deaths worldwide annually, according to the World Health Organization (WHO)[9].

3.2.1.3 Air pollution

Climate change is generally expected to degrade air quality in Canada (Egyed, et al., 2022) (Fiore, Naik, & Leibensperger, 2015). The degraded air quality can also exacerbate the impacts of climate change, as many air pollutant sources are also carbon dioxide emitters (Fiore, Naik, & Leibensperger, 2015). These interactions ultimately have both direct and indirect repercussions on human mortality and morbidity (Orru, Ebi, & Forsberg, 2017).

Air pollutants, especially from combustion, can adversely affect the respiratory system, leading to conditions such as asthma, chronic obstructive pulmonary disease, and other respiratory illnesses. Long-term exposure to these pollutants can also contribute to

[9] World Health Organization: Vector-borne diseases

cardiovascular diseases. Most of the literature has shown positive correlations of air pollution (and/or exposure to weather variables) with mortality and/or hospital admissions, especially related to respiratory and cardiovascular diseases (Abed Al Ahad, Sullivan, Demsar, Melham, & Kulu, 2020) (World Health Organization, 2013). In Canada, chronic exposure to fine particulate air pollution resulting from the burning of fossil fuels is responsible for 7,100 premature deaths and $53.5 billion in health-related costs per year (Howard, Rose, & Rivers, 2018).

Air pollutants can also affect mortality and morbidity indirectly, by boosting climate change. For instance, certain greenhouse gases like black carbon (soot) and methane can intensify extreme temperatures (Bunker, et al., 2016), and pollutants such as ozone can impact crop yields affecting food security and public health (McGrath, 2020) (Patz, Frumkin, Holloway, Vimont, & Haines, 2014). There is also the combined synergistic effect of high temperatures and air pollution on mortality, as elevated temperature and air pollution have been associated with increased mortality (Willers, et al., 2016).

3.2.1.4 Wildfires

Climate change may result in an increased frequency of heatwaves and greater variability in precipitation patterns, resulting in prolonged dry periods and intensified rainfall events. The amalgamation of extreme heat and drought escalates the occurrences of wildfires. Projections indicate heightened fire activity in numerous North American regions (Halofsky, Peterson, & Harvey, 2020) (Ranasinghe, et al., 2021), attributed to extended fire seasons (USGCRP, 2017), persistent warming (Villarreal, Haire, Iniguez, Cortes Montano, & Poitras, 2019) (Wahl, Zorita, Trouet, & Taylor, 2019) and increased lightning frequency (Chen, et al., 2021).

Wildfires, particularly wildland-urban interface fires, can exert detrimental effects on mortality, morbidity, and mental health, as delineated in the IPCC AR6. The release of substantial particulate matter, toxic gases, and volatile organic compounds during wildfires contribute directly to ground-level ozone formation. These wildfire smoke particulates can travel considerable distances, impacting air quality and health. They are found to elevate risk of cardiovascular disease, morbidity and mortality by increasing specific cardiovascular outcomes, such as cardiac arrests (Dennekamp, et al., 2015). Vulnerable populations, including children, the elderly, pregnant women, individuals with low socio-economic status, and first responders often experience these effects more acutely (Abbott & Chapman, 2018) (Agyapong, et al., 2018) (Ford, 2012) (Maguet, 2019). Notably, in northern Canada, reports highlight high levels of respiratory stress and disease among Inuit and First Nation communities in relation to wildfires (Howard, et al., 2021).

3.2.2 Indirect impacts

This subsection discusses the potential indirect impacts from climate change on mortality. Once again, the extent of the potential impacts depends heavily on the design and implementation of current and future climate policies.

3.2.2.1 Agricultural productivity impacts

Climate change may lead to increases in mortality through declining agricultural productivity, leading to lower caloric availability. Studies suggest this may increase underweight individuals and climate-related deaths in North America by 2050 (Springmann, Godfray, Rayner, &

Scarborough, 2016) (Springmann, et al., 2016) (Springmann, et al., 2018). While reduced caloric availability could decrease obesity-related deaths, research shows that the increases in mortality from decline in fruits and vegetable consumption are projected to more than offset the mortality reductions due to lower obesity-related deaths by 2050, especially in Canada and the USA (Springmann, Godfray, Rayner, & Scarborough, 2016) (Springmann, et al., 2016).

Nutrition impacts also vary within countries (Shannon, Kim, McKenzie, & Lawrence, 2015) (Zeuli, Nijhuis, Macfarlane, & Ridsdale, 2018). Alaska and Canada have already experienced challenges to nutrition security from climate-induced changes that have impacted locally harvested foods (Bunce, Ford, Harper, Edge, & IHACC Research Team, 2016) (Harper, et al., 2015) (Hupp, Brubaker, Wilkinson, & Williamson, 2015) (Lynn, et al., 2013) (Petrasek MacDonald, Harper, Cunsolo Willox, Edge, & Rigolet Inuit Community Government, 2012). First Nations coastal communities in western Canada are projected to face reduced access to traditionally harvested seafood by 2050 under scenarios RCP2.6 and RCP8.5, adversely affecting nutrition, particularly for many older adults (Marushka, et al., 2019).

3.2.2.2 Mental health

Climate change exerts a profound impact on mental health, manifesting through various direct and indirect pathways associated with extreme weather events, cumulative environmental changes, and anticipatory stressors (Cunsolo & Ellis, 2018) (Hayes, Blashki, Wiseman, Burke, & Reifels, 2018).

Specific climate hazards, including storms, floods, heatwaves, wildfires, and drought, have demonstrated significant adverse effects on mental health, with extensive research highlighting their correlation with conditions such as PTSD, anxiety, and depression (Charlson, et al., 2021) (Hayes, Blashki, Wiseman, Burke, & Reifels, 2018) (Obradovich, Migliorini, Paulus, & Rahwan, 2018). Within the context of North America, climate change is intricately linked to a spectrum of emotional responses, including depression, generalized anxiety, ecological grief, increased substance use, family stress, domestic violence, heightened suicide rates, and loss of cultural knowledge and place-based identities (Clayton, 2020) (Cunsolo & Ellis, 2018) (Dumont, Haase, Dolber, Lewis, & Coverdale, 2020).

Studies show that deteriorated mental health can exacerbate physical conditions, and subsequently increase mortality. Mental disorders are significant contributors to morbidity and mortality around the globe, and people with mental disorders have higher mortality rates than the population without mental disorders (Charlson, et al., 2021) (Hayes, Blashki, Wiseman, Burke, & Reifels, 2018) (Reisinger Walker, McGee, & Druss, 2015).

3.2.2.3 Socio-economic impact

Climate change could pose a multifaceted threat to public health in Canada. The increasing frequency of severe weather events could strain the existing healthcare systems and infrastructure (Felio, 2017) (Health Care Without Harm, 2018), potentially leading to increased healthcare costs, reduced access to healthcare, and worsened health conditions, ultimately increasing mortality.

Disadvantaged groups, who may already face greater challenges in mitigating and preventing climate-related risks (Islam & Winkel, 2017), are particularly vulnerable to the health impact of climate change. Vulnerability to health impacts of climate change is determined by the exposure to climate change hazards, the sensitivity to possible impacts, and the capacity to respond or adapt (Gosselin, Campagna, Demers-Bouffard, Qutob, & Flannigan, 2022). Populations that are disproportionately affected include Indigenous peoples, women, children, older adults, low-income individuals, people living with pre-existing physical and mental health conditions, and certain occupational groups.

3.2.2.4 Transition to a low-carbon emission economy

The transition to a low-carbon emission economy may have profound implications on mortality as societies adopt cleaner energy sources and sustainable practices. The transition towards a low-carbon emission economy, while potentially increasing mortality rates in the shorter term due to redirected research (from health to transition) and increased mental pressure, may bring promising benefits for minimizing the potential increases in mortality from all the factors mentioned in previous subsections, and in some cases lead to other indirect and independent decreases in mortality.

Studies published in The Lancet have shown that appropriate climate change mitigation strategies can have additional, independent, and largely beneficial effects on public health (Haines, 2017) (Watts, et al., 2018). A successful transition can improve the environment with better air quality and promote better lifestyles, which all reduce the prevalence of illnesses (Erickson, Griswold, Maghirang, & Urbaszewski, 2017) (Watts, et al., 2018). Increased emphasis on sustainable practices can also lead to enhanced water quality and availability, reducing waterborne diseases. Furthermore, investments in climate-resilient infrastructure have the potential to enhance healthcare systems and emergency response capabilities, ensuring better access to healthcare and timely responses to health emergencies. Additionally, the transition may contribute to stabilizing extreme weather events. Sustainable agriculture and improvements in food systems could also enhance food security and nutrition, thereby potentially improving overall mortality over time (Friel, et al., 2009) (McMichael, Powles, Butler, & Uauy, 2007).

3.2.3 Summary of conclusions

Based on the research performed, this subsection provides a summary of conclusions thus far, and how they could affect the OCA's assumption-setting process for mortality in Canada. This subsection is meant to represent the OCA's current views which will evolve as more research and data become available. For context, lower mortality leads to higher cost ratios for pay-as-you-go, fully funded and partially funded programs, and vice versa.

It is worth reiterating that that the section focuses solely on the potential impacts on mortality of climate change in isolation. While climate change is a factor potentially impacting future mortality, numerous other factors (e.g., advances in medical technology, increased access to healthcare, etc.) exert considerable influence on future mortality and mortality improvement rates.

The following is a summary of the OCA's current views on how climate change could impact mortality:

- Direct impacts, stemming from temperature change, changing patterns of precipitation and pathogens, air pollution and wildfires, collectively contribute to a predominantly negative outlook on mortality (upward pressure).

- Indirect impacts stemming from potential ramifications on agriculture productivity, mental health, and socio-economic factors could further compound this negative outlook.

- Amidst these various challenges posed by climate change, the transition to a low-carbon emission economy could help minimize or even reverse the potential climate-related mortality increases. Thus, the net future effect from climate change on mortality depends heavily on the success of climate transition both globally and in Canada.

- Despite the potential avenue for positive changes stemming from the transition, the overall impact of climate seems to be more skewed towards potential increases in mortality. The OCA may take this into account when setting the mortality assumption for the next actuarial valuation cycle (31 December 2024). At this point, it would be considered on a qualitative basis and not explicitly quantified.

3.2.4 Quantitative impact of climate change on mortality

Although the OCA did not conduct a quantitative analysis linking climate change and mortality, there are a number of studies available on the subject. This subsection provides a few examples of publicly available papers quantifying the potential impact of climate change on mortality.

3.2.4.1 Club Vita: hot and bothered?

The Club Vita paper (Club Vita, 2018) outlines three climate change longevity scenarios that pension plans in the United Kingdom (UK) can use to stress test their funding. While much of the existing work on climate change has been centered on financial markets and investment choices, this paper highlights the importance for trustees to ensure that pension plans are resilient to potential future outcomes, specifically with regards to life expectancy.

The scenarios presented in the paper are therefore meant to inform risk assessments as part of regular governance, or to feed into assumption-setting. Although probabilities are not assigned to each scenario, it is possible to look at the stress tests and assess the level of preparedness to each scenario.

The first scenario is referred to as the "Head in the Sand" scenario. This is an extreme case where there is a complete lack of response to resource and environmental risk. Under this scenario, the UK experiences food shortages and a surge in diseases that make their way from warmer climates. A decline in proper nourishment results in larger rates of cancer and cardiovascular diseases. Harsh flu epidemics are experienced every three years because of fluctuating temperatures. It is assumed that life expectancy will fall and that it will happen quickly.

The second scenario is referred to as the "Challenging Times" scenario. This is a more moderate case where some climate adaptation is achieved, but availability of oil becomes a constraint to economies in the future. This leads to severe funding issues with the national health system and increased cost of imported food stocks. This scenario assumes that a significant portion of lower income groups are unable to afford their basic needs, while higher income groups are less affected. It is assumed that life expectancy will stop improving for the lower income groups.

The final scenario is referred to as the "Green Revolution" scenario. This entails positive and successful adaptation to climate change, leading to improved longevity. Improvements in environmental conscience, legislation, and health education are all contributing factors under this scenario.

Table 2 below shows the impact on cohort life expectancy from age 65 for the three scenarios.

Table 2 Impact on cohort life expectancy from age 65 (in years) as at January 1, 2018

Scenario	Typical member	Current deferred, age 50	Current pensioner, age 65
Head in the sand	Men	-3.6	-1.1
	Women	-4.0	-1.4
Challenging times	Men	-1.2	-0.4
	Women	-1.7	-0.7
Green revolution	Men	+1.9	+0.9
	Women	+1.6	+0.8

3.2.4.2 Canadian Journal of Public Health: Future temperature-related excess mortality under climate change and population aging scenarios in Canada

The Canadian Journal of Public Health paper (Hebbern, et al., 2023) provides an evaluation of temperature-related mortality across Canada until 2099, accounting for changes in the age-structure of the population and scenarios of population growth relative to a baseline scenario, which uses 2010-2019 as the reference period. The authors used daily counts of non-accidental deaths from 2000 to 2015 for all 111 health regions across Canada (obtained from Statistics Canada) and conducted a two-part time series analysis of mean daily temperatures and mortality.

Three different SSP climate change scenarios are considered: SSP1-2.6, SSP2-4.5, and SSP5-8.5. The results show a positive correlation between temperature rising and heat-related mortality across SSP scenarios, with the largest increases occurring under SSP5-8.5, and the smallest increases occurring under SSP1-2.6. Cold-related mortality impacts are expected to decrease under the SSP1-2.6 scenario and increase under the other two scenarios.

The net increase in excess mortality in 2090-2099 is expected to range between 3.29% and 17.31% depending on the SSP scenario. Interestingly, results by broad age group show that younger age groups are expected to experience negative net excess mortality across all SSP scenarios, while those aged 65 and over are expected to experience positive net excess mortality across all SSP scenarios.

3.2.4.3 Canadian Institute for Climate Choices - The Health Costs of Climate Change: How Canada can adapt, prepare, and save lives

This paper (Clark, D. G., Coffman, & Beugin, 2021) analyzes potential health cost impacts of climate change for Canada under low (RCP 4.5) and high (RCP 8.5) global greenhouse gas emissions scenarios. It covers impacts on a wide range of variables such as morbidity and mortality outcomes, healthcare costs, the value of lost lives and lost quality of life as well as productivity losses and associated costs. This section focuses on the part of the analysis that covers heat-related deaths in Canada.

To estimate the potential mortality impact associated with higher temperatures under climate change scenarios, exposure-response functions (ERF) were coupled with socio-economic data and climate data, and results were compared to those under a baseline scenario. Canadian studies analyzing regional relationships between high-temperature days and health outcomes helped to produce these ERF. The baseline is a combination of 2016 socio-economic data and climate data for the period 1971-2000.

The ERF coefficients are obtained from Gasparrini et al. (Gasparrini, et al., 2015), a study that included 21 Canadian cities and analyzed all deaths between 1986 and 2009. Excess deaths are defined as deaths caused by temperatures above or below the "optimum" temperature (between the 2.5th and 97.5th percentiles of mean temperature).

Resulting modeling estimates from the paper show that by mid-century, an additional 400 heat-related deaths may occur annually in Canada under the high-emission scenario (RCP 8.5) compared with the baseline. That figure nearly doubles by the end of the century at 790 deaths per year. This represents about 1.1 additional deaths per 100,000 people annually by mid-century and 1.7 additional deaths per 100,000 annually by the end of the century.

3.3 Migration

This section discusses the potential impacts of climate change on migration patterns. When faced with climate change, including the potential economic uncertainty and political instability resulting from the changing climate, migration is one of the strategies that individuals and households may willingly or be forced to undertake to improve their well-being and livelihoods.

The first two subsections discuss various climate-related drivers of migration, which can be viewed in two groups: direct and indirect drivers of migration and displacement. It is important to underscore the broad and general scope of these drivers. Regional impacts can vary significantly, shaping migration patterns in diverse ways depending on the local conditions. The subsequent subsection investigates how these drivers may influence future migration patterns in Canada.

It is important to note that there remain a lot of uncertainties and more research is needed, as highlighted by the special IPCC report: "our understandings of the links of global warming to human migration are limited and represent an important knowledge gap" (Hoegh-Guldberg, et al., 2018).

3.3.1 Direct drivers of migration

The various direct climate drivers of migration and displacement can be broadly grouped into two categories.

First, there are the slow-onset changes, encompassing chronic physical risks such as shifts in temperature and precipitation patterns, sea-level rise, agricultural land salinization, desertification, etc. Changes in temperature and precipitation patterns can instigate migration through environmental displacement and agricultural challenges (Bohra-Mishraa, Oppenheimera, & Hsiang, 2014). Temperature rise can also contribute to the melting of glaciers and polar ice, causing sea-level rise. This has impacts on coastal areas and small islands, poses threats to habitation, food security, and economic growth. Tipping points related to sea-level rise, especially under high levels of warming, may increase the global population at risk of displacement (Ranasinghe, et al., 2021).

The second direct drivers of migration and displacement are related to the rapid-onset climate events, referred to as acute physical risks. Extreme storms, floods and wildfires are strongly associated with high levels of short- and long-term displacement, while droughts, extreme heat and precipitation anomalies are more likely to stimulate longer-term changes in migration patterns (Hoffman, Dimitrova, Muttarak, Crespo Cuaresma, & Peisker, 2020) (Kaczan & Orgill-Meyer, 2019). According to the Internal Displacement Monitoring Centre[10], based on data collected since 2008, the extreme storms and floods consistently top the list of weather-related drivers causing population displacements globally, emphasizing the significance of these events.

There are many empirical studies on the relationship between migration and climate and/or other environmental drivers. However, the direction and the extent to which the environmental factors influence migration are not clear. Environmental change has been found to contribute to increased human migration in some studies, whereas no effect or a decline in migration has been reported in others. The empirical results differ depending on the environmental factors considered, the data and scale of the analysis, the methodology employed, and the geographical contexts covered (Berlemann & Steinhardt, 2017) (Cattaneo, et al., 2019) (Hunter, Luna, & Norton, 2015).

Finally, environmental hazards and events are just one of many factors influencing the decision to migrate. The recent literature has emphasized the role of different macro-level conditions including economic, cultural and socio-political factors which can reinforce or suppress migratory responses to environmental shocks (Barnett & McMichael, 2018) (Cattaneo, et al., 2019) (Hoffman, Dimitrova, Muttarak, Crespo Cuaresma, & Peisker, 2020) (Kaczan & Orgill-Meyer, 2019) (McLeman, 2017).

3.3.2 Indirect drivers of migration

Migration decisions are often multi-causal, and the environmental stress is merely one of many underlying drivers of migration. Climate change may influence migration indirectly through political and socio-economic factors (Black, Bennett, Thomas, & Beddington, 2011). Different regions, countries and communities have different adaptive capacities. National and individual wealth plays an important role in determining the vulnerability to climate events, as they can reduce the risk of impacts from climate disasters as well as improve disaster education and responses (Brown, 2008).

3.3.2.1 Political factors

When faced with climate change challenges, governments may respond through the implementation of various policies. These could include measures to adapt to changing

[10] Home | IDMC - Internal Displacement Monitoring Centre (internal-displacement.org)

conditions, promote sustainable practices, or allocate resources more efficiently. However, if policies are inadequate or not effectively implemented, it can contribute to social and economic disparities, potentially fueling migration as people seek better opportunities in regions with more favourable policies (McLeman, 2017).

As the environmental shifts intensify, nations may increasingly face heightened competition for vital resources such as water and arable land. This competition can escalate into political tensions and conflicts, potentially displacing populations and setting the stage for cross-border migration (Raleigh, Linke, & O'Loughlin, 2014) (Stern N. , 2006). These factors could contribute to forced migration, including asylum seekers and refugees. Although climate refugees do not currently qualify as a "Convention refugee"[11], a country may decide to extend protection to individuals displaced due to climate change[12].

At the international level, several pertinent policy initiatives and agreements have been established to address potential challenges on migration governance[13]. These initiatives could influence the international migration outlook.

3.3.2.2 Socio-economic factors

Climate change is anticipated to drive global human migration and displacement through changes in various socio-economic factors (Portner, et al., 2022), including availability of job opportunities, access to social services and socio-economic inequality in the place of origin, which are all pertinent migration drivers (Massey, 1999) (Migali & Scipioni, 2019).

Climate change can impact an individual's access to healthcare, education, job opportunities, other social services, and infrastructure. This reduced access can in turn influence migration decisions. As climate change intensifies in the region of origin, residents may decide to migrate both internally, from rural to urban areas (Lustgarten, 2020) (Rigaud, et al., 2018), or internationally (Goodman, et al., 2021) (McLeman, 2017) (Reuveny & Moore, 2009). In general, individuals or families with greater financial resources and higher levels of education have greater capacity to adapt to the changing climate (Butz, Lutz, Sendzimir, & Andruchowitz, 2014) (Ocello, Petrucci, Testa, & Vignoli, 2014). They are also the ones who are better able to migrate internally or internationally (Adams & Kay, 2019) (Koubi, Schaffer, Spilker, & Böhmelt, 2022) (Kubik & Maurel, 2016) (Riosmena, Kuhn, & Jochem, 2017).

Furthermore, climate change could exacerbate social and economic inequality within a country, leading to increased migration (Burzynski, Deuster, Docquier, & Melo, 2019) (Islam & Winkel, 2017) (Mardhiori & Ingmar, 2009). This is due to the disproportionate impact of climate change on disadvantaged groups, including increased exposure to adverse effects, greater susceptibility to damage, and decreased ability to cope and recover (Islam & Winkel, 2017). Moreover, research shows that climate change can also increase global economic inequality, which could increase international migration (Diffenbaugh & Burke, 2019).

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[11] According to Article 1 of the 1951 Refugee Convention, a "Convention refugee" has a strict definition of someone outside their country of nationality or habitual residence that cannot return due to a well-founded fear of persecution for reasons of race, religion, nationality, membership of a particular social group or political opinion. (The 1951 Refugee Convention | UNHCR)

[12] Legifrance - CETA

[13] Global Compacts for Safe, Orderly and Regular Migration and for the protection of Refugees; the Warsaw International Mechanism of the UNFCCC; the Sustainable Development Goals; the Sendai Framework for Disaster Risk Reduction; and the Platform on Disaster Displacement (Portner, et al., 2022)

In summary, climate change may increase the number of international migrants to developed countries, but the potential scale and effect are still very uncertain. There are still knowledge gaps regarding the long-term effects of climate change on human migration and considerably more research is required (Portner, et al., 2022) (Stern N. , 2006).

3.3.2.3 Climate transition

The transition to a low-carbon economy introduces its own set of economic risks and opportunities that can influence migration dynamics. Job displacement in carbon-intensive industries may prompt individuals and families to migrate in search of alternative employment in emerging green sectors or regions with more resilient economies. Shifts in investment patterns and capital flows towards renewable energy and sustainable infrastructure can also impact migration as people move to areas with greater economic prospects (Bluedorn, et al., 2022).

On the contrary, effective climate policies and investments in sustainable development can contribute to reducing migratory pressure by addressing underlying vulnerabilities and enhancing resilience in communities facing climate-related challenges (World Bank, 2023).

3.3.3 Research and considerations specific to Canada and summary of conclusions

As mentioned above, the impact of climate change goes beyond environmental concerns, influencing both internal and international migration patterns, and can vary significantly by region. The research available for Canada is scarce, there is not always consensus on results, and in many cases, there is no clear conclusion on how climate change could affect migration patterns in Canada.

This subsection provides an overview of considerations and research that are relevant to Canada, as well as a summary of conclusions in the context of the OCA's assumption-setting process for migration in Canada.

3.3.3.1 Internal migration

There is very little research on potential climate-driven internal migration in Canada. OCA's assumption-setting process for both demographic and economic assumptions is performed at the macro-level and is focused mainly on a Canada-wide perspective[14]. At this point, the OCA is not ready to adjust demographic and economic assumptions to reflect the potential impact of climate-driven internal migration in Canada.

3.3.3.2 International migration

In Canada, international immigration consists of the following categories:

- Economic immigrants are individuals who have been selected for their ability to contribute to the Canadian economy.
- Immigrants sponsored by family are individuals who are granted permanent resident status through sponsorship by a family member who is a Canadian citizen or a permanent resident.
- Refugees are individuals who are granted permanent resident status based on a well-

[14] The only province for which separate assumptions are developed is Quebec because workers in that province do not contribute to the CPP.

founded fear of returning to their home country. In Canada, the definition of "refugee"[15] is limited in its application to specific legal categories. The individuals displaced by climate change can only qualify as refugees in Canada if other displacement drivers interact with climate change, for example, political violence resulting from conflicts over water access. Although Canada has mechanisms for addressing emergencies such as sudden-onset climate disasters, it lacks a designated immigration pathway for those forced to leave their countries due to long-term environmental degradation.

- Other immigrants include all other individuals who are granted permanent resident status.
- Non-permanent residents are individuals who have a work study or permit, or who are asylum claimants seeking refugee status.

Canada's future population growth will depend on immigration levels. Beyond the actual immigration levels, the composition of immigrants (age, gender, level of education, job skill, etc.) and the immigration category can also affect Canada's future economic growth. Climate change could have an impact on both the future levels of immigration in Canada and the composition of immigrants. Unfortunately, there is very little research on the subject. A summary of a few Canadian-specific references is provided below.

Studies show that international climate-related immigration is mainly observed between countries sharing borders (Hoffman, Dimitrova, Muttarak, Crespo Cuaresma, & Peisker, 2020) (Kaczan & Orgill-Meyer, 2019). This observation suggests that historical immigrants to Canada have been motivated by factors that are not directly related to climate issues, given Canada's sole border is with the United States. However, some studies underscore that environmental considerations can still play primary or secondary roles in motivating migration to Canada (McLeman, 2017) (Veronis & McLeman, 2014).

Like the refugee category, asylum claimants may also be affected by climate hazards, yet research on their international movements in Canada is limited. While some studies (Abel, Brottrager, Cuaresma, & Muttarak, 2019) (Missirian & Schlenker, 2017) suggest links between climate fluctuations and asylum-seeking migration in Europe and Middle East, contradictory findings also exist (Schutte, Vestby, & Jørgen Carling, 2021). The absence of Canadian-specific research and the lack of consensus among studies from other regions underscore the uncertainty regarding the correlation and directional impact between climate change and asylum claimants in the Canadian context.

3.3.3.3 Summary of conclusions

Despite the little research available, the OCA developed its own views and considerations on how the drivers of migration discussed in the first section could relate to Canada. These views and considerations are summarized below. They are not meant to be exhaustive, and future data and research will help further inform the OCA's thinking. For context, lower immigration levels lead to higher cost ratios for pay-as-you-go and partially funded programs, and vice versa.

In terms of the direct and indirect drivers of migration, Canada may experience relatively milder impacts due to its unique geographical landscape and stable socio-political

[15] The 1951 Refugee Convention | UNHCR

environment. This could make Canada a desirable destination for climate-related migrants worldwide and make it easier to attract and retain high-skilled immigrants who can contribute to the economy. At the same time, there may be some pressure for Canada to accept climate-related migrants from other immigration categories that may not contribute as quickly to the economy.

Canada's response to climate change, such as its commitment to sustainability and green initiatives, can also influence decisions to migrate to Canada. A successful climate transition could help attract and retain skilled workers, but the reverse is also true.

While climate change may influence the trend of international migration to Canada, the total number of immigrants primarily depend on the government's annual immigration targets. These targets[16] guide immigration policies, determine visa allocation, and shape the composition of the immigrant population, reflecting national priorities and societal needs.

The diversity in drivers, contexts and outcomes makes establishing a general relationship between climate change and migration challenging. The frequency, severity of damage, duration, and spatial reach of climatic drivers differ greatly, while the responses to migration are shaped by a complex interplay of cultural, demographic, economic, political, and social factors spanning different scales.

As it currently stands, there is too much uncertainty to even assess the potential directional impact of climate change on migration patterns in Canada. Although it is an important topic to monitor for the future, the OCA does not plan on making any adjustments to incorporate climate change in its assumption-setting process for migration for the next actuarial valuation cycle (31 December 2024).

[16] For example, the most recently published target for 2024-2026: Government of Canada: Notice- Supplementary Information for the 2024-2026 Immigration Levels Plan

4 Economic assumptions

Climate change has significant implications that may extend far beyond environmental concerns to impact key economic indices and result in both direct and indirect costs to the Canadian economy.

In the context of preparing actuarial reports for the CPP, the OAS program and public sector pension plans, the OCA develops assumptions for a wide range of Canadian macro-economic variables such as inflation, unemployment/employment rates, real wage increases, productivity growth, GDP growth, etc. This part of the study discusses key considerations when evaluating the potential impacts of climate-related risks on these economic assumptions. As the research available specifically focused on the Canadian economy is limited, some of the following analysis draws references from peer countries.

The first two subsections focus on two broad variables: inflation and economic growth. The last subsection discusses various considerations for developing a framework that translates potential climate change impacts on economic growth into variables that are relevant to OCA's models. The framework can be useful to illustrate potential impacts on the cost of the CPP, the OAS program and public sector pension plans.

4.1 Inflation

The Bank of Canada uses the consumer price index (CPI) to measure inflation[17]. The CPI tracks how much the average Canadian household spends, and how those spendings change over time. The average Canadian household spends on items such as food, shelter, transportation, household expenses, clothing, healthcare, etc. Among these items, food, shelter, and transportation receive relatively larger weights compared to the other items[18] when determining the CPI, totaling around 60%.

Potential climate change related impacts on inflation have received much attention lately, and they are being analyzed through different angles. For example, in a 2022 speech, European Central Bank's Executive Member Isabel Schnabel declared a "new age of energy inflation"[19] and brought up three types of inflation: "climateflation", which reflects price changes due to physical risks, "fossilflation", which reflects price changes due to cost fluctuations in fossil fuels and "greenflation", which reflects price changes due to the transition to a green economy. Although understanding these three types of inflation and their dynamics can be useful, most research examines potential future increases and decreases in inflationary pressure stemming from climate change on an aggregate level. This section applies a similar approach and explores the divergent pressures and their consequences through the lens of physical risks and transition risks.

4.1.1 Climate physical risks

Climate change can influence future inflation in Canada through climate-related physical risks. Many studies found empirical evidence of a positive relationship between temperature rise and the level of inflation in a country. As climate change brings more frequent and more severe weather shocks, the volatility and heterogeneity of inflation may increase, and hotter summers may result in more frequent and persistent upward pressures on inflation (Faccia,

[17] Bank of Canada: Understanding the consumer price index
[18] Statistics Canada: Basket weights of the Consumer Price Index, Canada, provinces, Whitehorse, Yellowknife and Iqaluit
[19] European Central Bank - A new age of energy inflation: climateflation, fossilflation and greenflation

Parker, & Livio, 2021) (Kotz, Kuik, Lis, & Nickel, 2024) (Li, Zhang, & He, 2023) (Mukherjee & Ouattara, 2021). In Canada, the average annual temperature is projected to increase between 1.8°C (RCP 2.6) and 6.3°C (RCP 8.5) by the end of the century, with variations by region and seasons[20]. Therefore, as hot summers become more frequent and more severe, stronger inflationary impacts may be expected in the future.

Climate-related events, such as heatwaves, droughts or storms, can impact agricultural productivity[21] (Cœuré, 2018) (Lesk, Rowhani, & Ramankutty, 2016), increase production costs for businesses (Rodrigues, Salish, & Salish, 2024) (Yu, Cai, Zhang, & You, 2022), and cause negative supply-side shocks worldwide (Batten, Sowerbutts, & Tanaka, 2020). Furthermore, climate-related events can damage infrastructure thereby increasing transportation costs or increase the need to import goods from abroad. This may cause upward pressures on prices and create spillover across countries (Klomp & Sseruyange, 2021) (Peersman, 2018). These spillover effects may pass the increased costs to Canadian consumers through higher prices for food and other goods, driving up inflation in the future.

On the other hand, climate physical risks can result in positive supply shocks in some locations and have deflationary effects in Canada. For example, according to Agriculture Canada[22], warmer winters and rising temperature may prolong and enhance the growing seasons in Canada, potentially improving agricultural output. Reconstructions after climate-related events may also increase investment and create positive effects on the supply-side (Batten, Sowerbutts, & Tanaka, 2020).

On the demand side, extreme climate-related events such as floods and wildfires can reduce wealth for households and businesses and lead to reduced consumption and investments. Climate-related events could also undermine business confidence and trigger a sharp sell-off in the financial markets, which in turn could increase the cost of funding new investments and thus reduce investment demand. These impacts on the demand-side are mostly deflationary, especially if the losses from these weather events are uninsured or underinsured (Batten, Sowerbutts, & Tanaka, Let's talk about the weather: the impact of climate change on central banks, 2016).

4.1.2 Climate transition risks

Climate transition risks have important implications on future inflation in Canada, and the magnitude of impact is heavily dependent on the transition pathways and climate policies.

There are typically three types of climate policies for reducing carbon emissions (Batten, Climate change and the macro-economy: a critical review, 2018). The first type achieves reductions by decreasing the energy intensity, as well as production and consumption of high carbon products. The second type of climate policies focuses on improving the energy efficiency of existing products and processes, and the third type focuses on transitioning to renewable energy sources.

The first type of climate policies can reduce economic growth, with everything else being equal (Batten, Climate change and the macro-economy: a critical review, 2018), which may

[20] Environment and Natural Resources Canada - Changes in Temperature
[21] Climate Atlas of Canada - Agriculture and Climate Change
[22] Agriculture and Agri-Food Canada - Climate change impacts on agriculture

result in upward pressure on inflation when analyzing from the supply side. The reduced supply of fossil fuel is expected to drive up its price, which usually has an immediate direct impact on the inflation, since energy goods feature substantially in inflation indices. Higher fossil fuel prices may also contribute to inflation indirectly over time as most goods and services require energy throughout the production and transportation process. On the demand side, lower foreign demand of fossil fuels may offset the cost-push effect of the carbon price increase under the first type of climate policies, resulting in downward pressure on inflation (Bank of Canada; Office of the Superintendent of Financial Institutions, 2022).

The second and the third types of climate policies can achieve carbon emission reductions through technological advancements on the supply side. If they are successful and any significant supply shock is avoided, the inflationary pressures from other climate-related channels are expected to be smaller (Batten, Sowerbutts, & Tanaka, Climate change: Macroeconomic impact and implications for monetary policy, 2020). Moreover, these types of climate policies could also decrease inflation in Canada. Some studies show that if the price increases caused by climate policies are offset by technological advancements in the energy sector, this could result in overall lower energy prices and downward influence on inflation (Apel, 2022) (Way, Ives, Mealy, & Farmer, 2022).

In practice, a combination of the different types of climate policies can be used to address climate change and their effectiveness will depend on policy characteristics as well as their mix (Burniaux, Château, Duval, & Jamet, 2008) (Stern N. , 2006). Different approaches to achieve low carbon emissions will impact energy and other prices differently. Some would provide more stable and predictable price outcomes, while others could be more volatile, increasing the future volatility of inflation (McKibbon, Morris, Wilcoxen, & Panton, 2017) (Molico, 2019).

4.1.3 Conclusion

The previous two subsections explored the different channels through which climate change can influence future inflation in Canada. They may introduce shocks on both the supply and demand side, which could result in opposing pressures on inflation. The net effect from climate change depends on the magnitude of future climate-related events as well as the design and implementation of climate policies.

Furthermore, the timing of potential climate change impacts on inflation varies with the type of risks involved. Acute physical risks can cause immediate shocks to the economy that may persist into the medium term, while the impacts of chronic physical risks unfold over the medium to long term. Additionally, the design and implementation of climate policies can influence the timing of the resulting inflation impacts. A gradual transition could spread the impact over time, whereas a delayed and abrupt transition may result in more significant and immediate shocks.

It is also important to note that although climate-related risks can have lasting economic implications, central banks possess a range of tools to manage inflation and aim to stabilize it around the long-term target (Batten, Sowerbutts, & Tanaka, Let's talk about the weather: the impact of climate change on central banks, 2016) (McKibbon, Morris, Wilcoxen, & Panton, 2017). These tools include incorporating climate change into their modeling and policy frameworks (Batten, Sowerbutts, & Tanaka, Climate change: Macroeconomic impact and implications for monetary policy, 2020) (Boneva, Ferrucci, & Mongelli, 2022) (Network for Greening the Financial System, 2020).

Based on the research performed, given the level of uncertainty around the future environmental and economic landscape, the OCA is not ready to incorporate the potential impact of climate change on inflation in its best-estimate assumptions for the next actuarial valuation cycle (31 December 2024). However, it is useful to look at future inflation projections under different climate scenarios, which is the purpose of the next subsection.

4.1.4 Quantitative analysis of projected inflation

While there exists many publicly available projections of future inflation by climate scenario globally, the focus on Canada is relatively sparse and yields inconsistent results.

This section illustrates potential inflation projections using the NGFS Climate Scenario Database[23]. For this purpose, three NGFS scenarios were selected, with each scenario representing different pathways of climate transition policies and physical impacts from 2022 to 2050:

- Below 2°C scenario: assumes a gradual increase of the stringency of climate policies to potentially limit global warming to below 2°C.
- Delayed Transition scenario: assumes annual emissions do not decrease until 2030; more disruptive and stringent climate policies are therefore needed to limit warming to below 2°C.
- Current Policies scenario: assumes that only the currently implemented policies are preserved, leading to high physical risks.

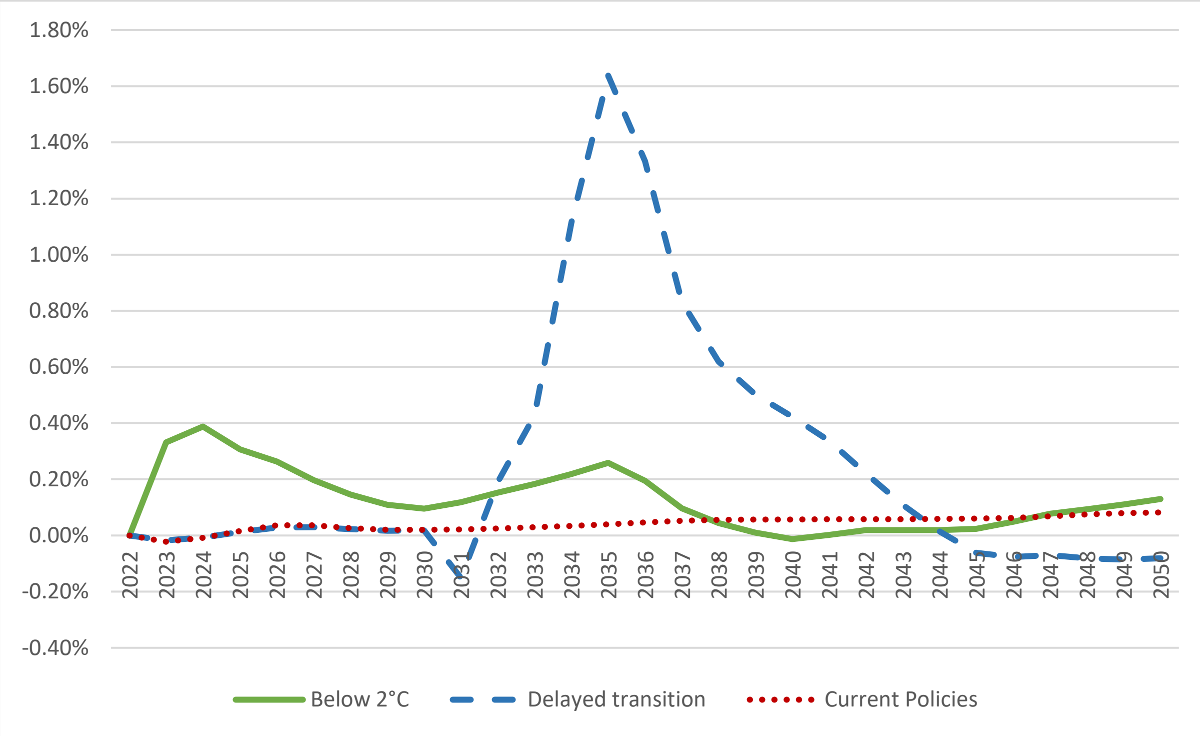
Charts 1 and 2 below show the projected inflation impact, measured as an absolute percentage change from the baseline scenario, for Canada and the USA, respectively. The baseline scenario is defined by NGFS as a hypothetical scenario with neither physical nor transition risks.

Both charts exhibit similar trends of inflation impact. Under the "Below 2°C" scenario, inflation is increased in the short to medium term, but the overall impacts are less substantial than in the "Delayed Transition" scenario where drastic increases in inflation can be observed shortly after the transition begins. Finally, the overall impact under the "Current Policies" scenario is the smallest among the different scenarios, since there is no impact from climate transition and the impacts shown are mainly from physical risks, which are projected not to be very significant in Canada and the USA between now and 2050.

Although projections beyond 2050 would be useful in assessing the impact on inflation of longer-term physical risks, especially for the current policies scenario, they are not directly available through the NGFS Climate Scenario Database.

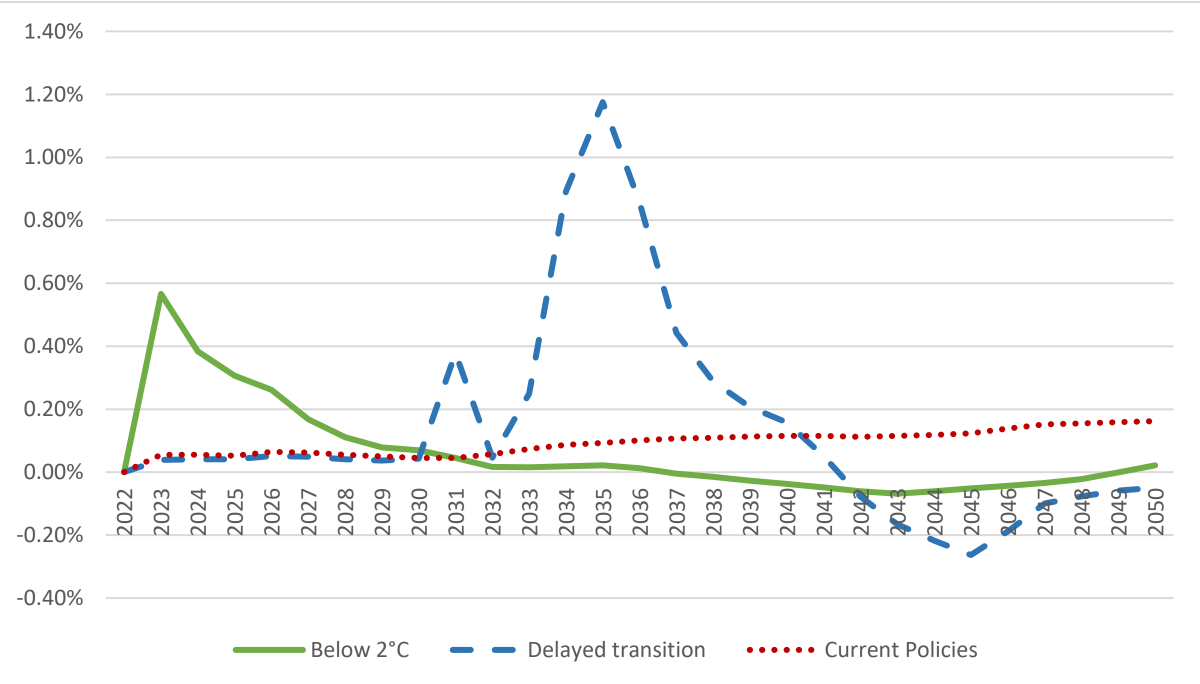
[23] The data used in this study is from the NGFS Scenarios Phase IV publication. Although a subsequent data refresh was released in the NGFS Scenario Phase V publication in the second half of 2024, it was not incorporated due to the timing of the study.

Chart 1 Inflation Impact – Canada (absolute % change from baseline)



Source: IIASA NGFS Climate scenario database (Phase IV publication), NiGEM model with REMIND inputs.

Chart 2 Inflation impact – USA (absolute % change from baseline)



Source: IIASA NGFS Climate scenario database (Phase IV publication), NiGEM model with REMIND inputs.

4.2 Economic growth

As mentioned above, climate-related risks can result in direct and indirect costs to the economy, affecting both productivity and economic growth. Economic growth can be measured using GDP, which determines the total value of goods and services produced within a country. Productivity growth can be measured using indicators like GDP per capita or GDP per hour worked, which gauges the efficiency of resources used in generating economic output. These macroeconomic indicators can be used to measure the aggregate economic costs from climate-related risks.

4.2.1 Acute climate physical risks

According to IPCC AR6, some regions in Canada have already been experiencing direct, indirect and non-market[24] economic damages from increasingly more frequent extreme events. For example, the 2023 Insurance Bureau of Canada fact book[25] shows that the average insured losses from catastrophes have been increasing. In 2022 Canadian dollars, they averaged about $0.4 billion between 1983 and 2000, $0.7 billion between 2001 and 2010, and $2.3 billion from 2011 to 2020. In addition, the total losses from extreme weather events in Canada can be estimated as double the amount of the insured losses (Boyd & Markandya, 2021).

Extreme climate-related events can cause long-term or permanent damage to lands, infrastructures, and productive capitals. They may also increase the rate of capital depreciation (Fankhauser & Tol, 2005) and divert the resources otherwise available for research and development (Sawyer, Ness, Clark, & Beugin, 2020), leading to reductions of productive capital accumulation (Batten, Sowerbutts, & Tanaka, Climate change: Macroeconomic impact and implications for monetary policy, 2020) and slower economic growth.

Acute climate physical risks could also disrupt international trade patterns, leading to slower economic growth. Changes in agricultural productivity, supply chain disruptions due to extreme weather events, or shifts in global demand for climate-sensitive goods can affect a country's ability to export and compete in international markets. Increased import costs due to climate-related risks, such as higher insurance premiums or transportation expenses, can further impact net exports negatively. Given that net exports accounted for 68% of Canada's GDP in 2022, these disruptions can pose a threat to economic stability and growth in Canada (Sawyer, Ness, Clark, & Beugin, 2020).

On the other hand, some studies support potential periods of faster economic growth in the aftermath of extreme events. For example, the surge in expenditures following climate-related events may provide stimulus to the economy and increase economic growth in the short term (Sawyer, Ness, Clark, & Beugin, 2020). Furthermore, the reduced supply of capital can raise its value if demand remains the same or increases. The higher capital value can attract investments for reconstruction and modernization, spurring economic activity. Labor and resources also shift towards rebuilding efforts, which can introduce new technologies and infrastructure. These activities can help enhance productivity and stimulate growth by

[24] Damages to intangible items not bought or sold in a traditional market and thus don't have a readily observable price (e.g., loss of human life, impact on human health, loss of ecosystem, threats on species, etc.) (Boyd & Markandya, 2021).
[25] Insurance Bureau of Canada - 2023 FACTS of the Property and Casualty Insurance Industry of Canada

optimizing resource use, driving innovation, and creating jobs, ultimately leading to a more efficient and dynamic economy (Hsiang & Jina, The Casual Effect fo Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones, 2014) (Skidmore & Toya, 2002) (Yang, 2008). In addition, replacing the outdated assets that were destroyed by climate-related events could boost economic growth in the longer term (Cuaresma, Hlouskova, & Oberteiner, 2008) (Hallegatte & Dumas, 2009) (Hsiang, Meng, & Cane, Civil conflicts are associated with global climate, 2011).

Overall, the literature on the economic impacts of natural disasters present mixed findings, but generally suggest negative short- to medium-term effects on economic growth, with the severity varying based on the disaster type, the country's development level and financial sector robustness (Botzen, Deschenes, & Sanders, 2019) (Cavallo, Becerra, & Acevedo, The Impact of Natural Disasters on Economic Growth, 2021) (Cavallo, Galiani, Noy, & Pantano, 2010).

4.2.2 Chronic climate physical risks

Similar to the acute physical impacts, chronic physical risks such as temperature rise and change in precipitation patterns may also reduce economic growth by causing lasting damages to the lands, infrastructures, and productive capitals (Revesz, et al., 2014) (Stern, 2013).

Additionally, as discussed in section 3.2 (Mortality), climate change may have long-term impacts on human health and mortality. This could reduce effective labour supply, productivity and economic growth. Studies show that climate change may have a long-term impact on the physical and cognitive performance of workers, especially in occupations in areas with environmental exposure and high temperatures (Aaron W. Tustin, et al., 2018) (Batten, Climate change and the macro-economy: a critical review, 2018) (Hsiang, et al., 2017) (Sawyer D. , Ness, Lee, & Miller, 2022) (Teasdale & Panegyres, 2023). For instance, a Canadian-focused study investigates the relationships between manufacturing output and extreme temperatures as measured by the number of days below -18°C or above 24°C. The study finds that in a typical year, extreme temperatures reduce annual manufacturing output by 2.2%. It also finds that taking predicted climate change into account would lead to manufacturing output losses ranging between 3.7% and 7.2% by the end of the century. (Kabore & Rivers, 2020). With manufacturing accounting for about 10% of Canada's GDP, even small output reductions can result in material productivity losses (Sawyer D. , Ness, Clark, & Beugin, 2020).

On the other hand, certain sectors in Canada may benefit from rising temperatures. For example, many studies show that prolonged growing seasons could increase Canada's agriculture outputs, with the largest gains being in the Prairie provinces (Amiraslany, 2010) (Ayouqi & Vercammen, 2014) (Ochuodho & Lantz, 2015) (Reinsborough, 2003) (Weber, 2003). Tourism is another example of industries in Canada that may benefit from the warming climate, with studies indicating that increased net tourism flows due to the warming climate may offset other climate-related economic losses, resulting in modest net gains for the Canadian economy (Development, 2015) (Lafakis, Ratz, Fazio, & Cosma, 2019) (Portner, et al., 2022)[26] (Scotta, Hall, & Gössling, 2019).

Studies on economic impacts from chronic physical risks are limited, very narrow in scope and sectoral coverage, and suggest mixed results (Boyd & Markandya, 2021). There are no clear conclusions on how they could impact economic growth in the future.

4.2.3 Climate transition risks

The climate transition risks have important implications on the future economic outlook in Canada, and the magnitude of impact is heavily dependent on the transition pathways and climate policies. As discussed in section 4.1 (Inflation), there are typically three types of climate policies for reducing carbon emissions (Batten, Climate change and the macro-economy: a critical review, 2018).

If the reduction in carbon emissions is to be achieved entirely via reductions in energy intensity and the demand for fossil fuel (first type of climate policies), the resulting decreases in output could be substantial. For example, (Smulders, Toman, & Withagen, 2014) shows that a 10% reduction in energy use decreases output by around 1%. Since Canada is a fossil fuel exporter, it may face significant costs from both reductions in domestic emissions and substantial decline in fossil fuel exports. A study by (Zhao, et al., 2022) shows that the costs of decline in fossil fuel exports could result in a cumulative GDP loss of more than 37% for Canada by 2100.

In addition, if climate policies focus solely on reducing energy intensity, the need for climate adaptation measures may increase. Funds would therefore be directed to repair and replacement and away from innovation and productive investment opportunities, potentially leading to negative growth in investment, lower productivity gains and lower economic growth (Pindyck, 2013); (Stern, 2013).

If the reductions in carbon emissions are achieved successfully and orderly through policies that focus on climate transition initiatives such as renewable energy infrastructure, energy efficiency programs, and climate resilience projects (second and third type of climate policies), it may contribute to higher economic growth in Canada. Increased investment in these climate transition initiatives can spur innovation and technological advancements, leading to productivity gains and cost reductions across industries. They can also create demand for goods and services, stimulate production and employment, and generate income for business and individuals, resulting in economic growth (Batten, Climate change and the macro-economy: a critical review, 2018).

Finally, investment in climate transition can also lead to environmental benefits such as reduced greenhouse gas emissions, better air and water quality, and improvement to the sustainability of the ecosystem and biodiversity, etc. (Batten, Climate change and the macro-economy: a critical review, 2018). These effects can have positive economic impacts by reducing healthcare costs, mitigating climate-related risks, and contributing to labour productivity growth, which may ultimately contribute to overall economic growth (Sawyer D. , Ness, Lee, & Miller, 2022) (Groosman, Muller, & O'Neill, 2009).

[26] Organisation for Economic Co-operation and Development (OECD, 2015). The Economic Consequences of Climate Change. OECD Publishing, Paris.

4.2.4 Conclusion

The previous three subsections explored potential climate change impacts on economic growth in Canada. Based on the research, it is difficult to draw firm conclusions on both the direction and magnitude of potential impacts. The competing pressures of various dynamics as well as the strong interconnection between physical and transition risks makes it difficult to quantify the net effect.

Similar to inflation, based on the research performed, the OCA is not ready to explicitly incorporate the potential impact of climate change on economic growth in its best-estimate assumptions for the next actuarial valuation cycle (31 December 2024). However, it is useful to look at future projections under different climate scenarios, which is the purpose of the next section.

4.3 Quantitative analysis

Over the last few years, many global organizations and regulators have been conducting climate scenario analysis in order to assess risk, and they have been publishing the results of their findings. The risk assessments focus on a range of variables under various climate path scenarios. The climate path scenarios are normally broadly based on the RPCs or SSPs used in the IPCC AR5 and AR6.

One important variable that is often analyzed in these publications is the GDP. It has the advantage of being a well understood and broadly used measure. Conceptually, it is also an overarching macroeconomic variable that can be used to adjust the future economic and investment environment.

In the 31st Actuarial Report on the CPP as at 31 December 2021 (CPP31 AR), the OCA presented three hypothetical climate scenarios with different pathways of Canadian nominal GDP growth rates relative to a baseline scenario[27] to illustrate potential impacts of climate change on the base CPP MCR. The hypothetical scenarios presented in the report are based on a review of public and private research papers that reflect different levels of exposures to physical and transition risks arising from climate change. Another important aspect is that the analysis focused on illustrating downside risk. The scenarios are therefore intentionally adverse and do not reflect the potential impact of new technologies and business opportunities related to a transition to a lower carbon economy.

Scenario 1 can be generally classified in the 'orderly transition' category of scenarios. It therefore assumes that successful climate policies are introduced early and gradually in order to limit global warming. Canadian nominal GDP growth rates are lower relative to the baseline scenario starting in 2020, mainly caused by disruption in the economy from the implementation of climate change policies. The cumulative difference in GDP projections relative to the baseline scenario grows to -10% by 2050, then stays constant until 2100.

Scenario 2 can be generally classified in the 'disorderly/delayed transition' category of scenarios. It assumes that climate change policies only start in 2030. There is therefore no impact on nominal GDP relative to the baseline scenario until 2030. However, late action

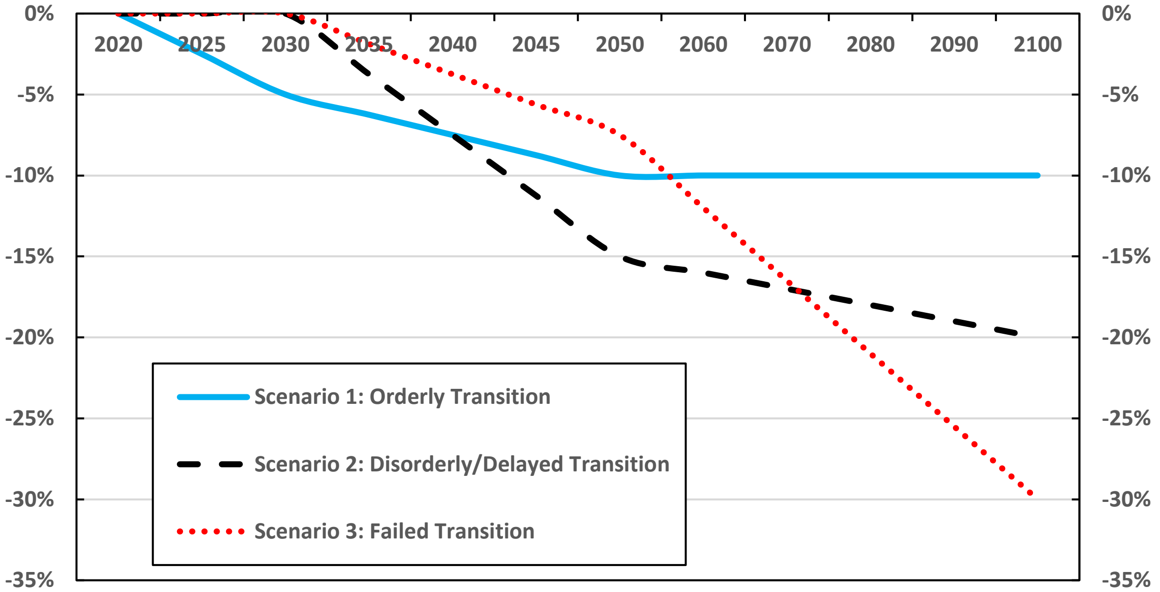
[27] The baseline scenarios in publicly available reports can vary and are not defined; therefore, they can't be assessed against the best-estimate assumptions of the CPP31 AR. For illustration purposes only, the differences relative to the baseline scenarios were applied to the best-estimate assumptions of the CPP31 AR.

leads to a stronger impact than scenario 1 after 2030. The cumulative difference relative to the baseline scenario is 0% by 2030, -15% by 2050 and -20% by 2100.

Scenario 3 can be generally classified in the 'failed transition' category of scenarios. It assumes that no further climate change policies are implemented. Although the difference relative to the baseline scenario is lower than the other scenarios through 2050, the compound physical risks resulting from no further climate action creates severe impacts between 2050 and 2100. The cumulative difference relative to the baseline scenario is 0% by 2030, -8% by 2050 and -30% by 2100.

Chart 3 shows the difference in Canadian nominal GDP growth rates relative to the baseline scenario for each scenario.

Chart 3 Illustrative climate scenarios – cumulative Canadian nominal GDP impact relative to baseline scenario



4.3.1 CPP31 AR framework for translating GDP impacts in other economic variables

Under OCA's current methodology, nominal GDP is assumed to grow at the same pace as total employment earnings. Total employment earnings are mainly derived through labour market assumptions (participation rates and unemployment/employment rates) as well as assumed real wage growth and inflation. In addition, the real wage growth assumption depends mainly on assumed labour productivity growth.

The impacts on GDP growth from the scenarios presented in Chart 3 can therefore be translated into OCA's models through changes in total employment earnings growth using a combination of changes in labour market assumptions, real wage growth and inflation. Unfortunately, there is not a lot of research available to separate GDP impacts between these components on a consistent basis, especially for a projection period of over 75 years.

In the CPP31 AR, a simplified approach was adopted. Changes in the nominal Canadian GDP growth by scenario were translated one-for-one into changes in total employment earnings through the real wage assumption. As part of the simplified framework, no changes were made to the number of jobs (labour markets) nor to the inflation assumption to reflect potential different employment and inflation paths by scenario.

4.3.2 Considerations for adjustments to CPP31 AR framework

Cascading all or a part of the changes in total employment earnings through adjustments to the labour force assumptions could also be considered. In lieu of reflecting the entire change in total employment earnings through reductions to the real wage growth assumption, all or a portion of the impact could be reflected through reductions in the projected number of jobs.

For example, under Scenario 2 (disorderly/delayed transition), if the entire impact flows through the real wage assumption, the average annual real wage growth over the 75-year period 2022-2096 stands at 0.52%, compared to the best-estimate assumption of 0.82%, while the average employment rate (18-69 for Canada less Quebec) over the same period stands at 72.6%. This is in line with the approach used in the climate scenarios presented in CPP31 AR. If the impact is shared equally between changes in real wage growth and the number of jobs, the average annual real wage growth over the 75-year period 2022-2096 stands at 0.67%, while the average employment rate (18-69 for Canada less Quebec) over the same period stands at 68.1%.

Given the lack of research on the subject, a lot of judgment would be required to separate the changes in total employment earnings between wages and the number of jobs. It is also important to keep in mind that any significant changes to the projected number of jobs would need to consider other variables including, for example, retirement behaviour and immigration. For example, a reduction in the number of jobs may lead individuals to take their CPP pension earlier and/or to lower immigration to Canada. Caution should therefore be exercised when the size of the labour market is adjusted to ensure overall consistency with other assumptions. Adding the dynamic of climate risk makes developing consistent scenarios even more complex.

Based on the above, the OCA continues to believe that the simplified framework of flowing changes in total employment earnings through wages only rather than a combination of wages and number of jobs remains appropriate. However, the OCA plans on conducting research to update its hypothetical climate scenarios based on more recently available information.

5 Investment assumptions

This part of the study reviews considerations when assessing the potential impact of climate-related risks on investment assumptions developed by the OCA, to prepare actuarial reports for the CPP and funded public sector pension plans. CPP Investments invests assets of the CPP that are not currently needed to pay for benefits, while PSP Investments plays a similar role for the public sector pension plans. Both investment managers hold diversified portfolios and invest globally in a wide range of asset classes such as public and private equities, corporate and sovereign bonds, and real assets.

An important challenge is that existing studies on the subject are limited and predominantly concentrated on shorter-term perspectives, while the OCA projections span a much longer period, extending to over 75 years. Another challenge is that since assets for both the CPP and public sector pension plans are invested in globally diversified portfolios, potential climate change impacts on investment assumptions must account for various asset classes across different geographies.

The first three sections focus on potential climate change impacts on the rates of return on fixed income, equities, and real assets. Although asset classes are considered individually in this study, it is recognized that they do not exist in isolation. It is possible that an impact on one asset class could indirectly affect another asset class as they compete for investor dollars.

When feasible, the sections address how the impacts could vary by region. The last section investigates considerations for developing a framework that the OCA can use to quantify the potential climate change impacts on overall rates of return. This last section focuses on the CPP given that it builds on the framework that was developed in the CPP31 AR.

5.1 Fixed income

This section explores the potential impacts from climate-related risks on various classes of fixed income investments. The research focuses on the impact on yields for sovereign bonds and the impact on the cost of borrowing for corporate bonds. Yields and costs of borrowing are negatively correlated with bond prices, meaning that all else equal, an increase in yield/cost of borrowing in a given year will result in a decrease in the rate of return for that year, and vice versa. That said, all else equal, a higher steady-state yield results in a higher steady-state rate of return, and vice versa. The average returns on fixed income over a longer timeframe therefore also depend on the extent and duration of yield changes, as well as whether the changes are temporary or permanent.

As noted in section 4.1 (Inflation), the timing and magnitude of the impact of climate change on inflation is unclear. When considering fixed income return assumptions in this section we are focused on nominal yields and returns. However, if inflation increases because of climate change, then the return and yield of fixed income investments in real terms will decrease. Investors would therefore often require higher yields to compensate for inflation and central banks would typically increase nominal policy rates to combat inflation. It should be noted that these changes in yields and rates do not necessarily occur one-for-one with inflation.

Although there is not a lot of research providing direct insights into the impact of climate change on Canadian fixed income yields and returns, research for other geographies can be useful and sometimes apply to Canada.

5.1.1 Sovereign bonds

Many factors can influence sovereign bond yields, including the dynamics between supply and demand, inflation expectations and fiscal and monetary policies. Climate change can have an important and diverse effect on economies, including potentially influencing the fiscal and monetary policies of governments and central banks around the world. For example, after a climate-related event, interest rates could be influenced by monetary policy efforts to address economic stability in the country. Changes in interest rates would have a direct impact on fixed income yields and rates of return.

Another factor that directly influences a country's sovereign bond yields is its sovereign risk, and there are several transmission channels between climate risks and sovereign risk. Taken in isolation, an increase in sovereign risk would normally result in higher yields, and vice versa.

First, the depletion of natural capital[28] due to climate change can potentially increase sovereign risks (Pinzón, Robins, McLuckie, & Thoumi, 2020). According to Pinzon et al. (2020), the value of sovereign bonds partially depends on the country's management of their natural capital. This dependency may often be overlooked or undervalued in the sovereign government markets, which may lead to mispricing of sovereign bonds, misrepresenting their true value and risk in the face of environmental challenges. This could eventually result in higher yields. Canadian sovereign bonds are susceptible to the impacts of natural capital depletion given the economy's reliance on natural resources. In 2021, more than 50% of Canada's total exports constituted natural resources products[29], contributing 1.6 million jobs and 17% of the GDP. Globally, this implication is especially relevant for countries in emerging markets that rely more heavily on natural capital for economic growth.

Second, as discussed in section 4.2 (Economic growth), acute physical risks such as floods, wildfires, and other climate-related natural disasters can negatively impact economic growth. The fiscal consequences of such events can in turn impact sovereign risk and bond yields. Although there is potential for spurts of economic growth after extreme events, the literature generally suggests negative short- to medium- term effects on economic growth. This can adversely affect the country's tax and other public revenues (Schuler, Oliveira, Mele, & Antonio, 2019), and have detrimental effects on the cost of sovereign borrowing, potentially increasing yields. Lower levels of economic development and growth prospects can also lead to investor flight, thereby increasing sovereign bond yields (Beirne, Renzhi, & Volz, 2020).

A country's increased vulnerability and lower resilience to climate-related risks can lead to increases in their sovereign risk and bond yields. Between the two factors, vulnerability to climate-related events has a greater effect on the sovereign bond yields than the level of climate resilience (Beirne, Renzhi, & Volz, 2020). The impact arising from vulnerability to climate-related risks is less pronounced for advanced economies than for the emerging economies. The latter are particularly exposed to climate change and have a weaker capacity

[28] Natural capital is defined as the stocks of natural assets, both renewable and non-renewable, which include geology, soil, air, water and all living things.
[29] Natural Resources Canada - 10 Key Facts on Canada's Natural Resources

for climate adaptation and mitigation (Beirne, Renzhi, & Volz, 2020) (Cevik & Jalles, 2020). For example, according to Beirne et al. (2020), the premium on sovereign bond yields from increased climate risk vulnerability is highest for a group of countries more exposed to climate-related events[30], standing at 275 basis points, compared to 155 basis points for the Association of Southeast Asian Nations and 113 basis points for Europe and the Middle East.

The third channel through which sovereign bond risks and yields are impacted, is through the fiscal implications of implementing climate change adaptation and mitigation policies. The climate adaptation strategies may affect the public budgets directly on the expenditure side, while the climate mitigation policies can affect the public budgets on the revenue side (Bachner & Bednar-Friedl, 2019). There are still a lot of uncertainties around these transition policies, and there might be variations in public budgets in the short to medium-term, which influence the sovereign risks. But overall, successful climate adaptation and mitigation may reduce sovereign risks and bond yields (Beirne, Renzhi, & Volz, 2020) (Cevik & Jalles, 2020).

Developed and developing countries differ in their ability to reduce emissions due to several factors. With lower borrowing costs, higher GDP per capita, and greater economic stability, developed countries can more easily adopt clean energy and reduce reliance on fossil fuels. Developing countries could face challenges due to financial constraints and economic volatility, necessitating external support and technology transfers. Despite the potential for long-term economic growth from clean energy, developing countries may be compelled to prioritize shorter-term debt repayment, due to the uncertain external support, which could prompt investors to demand higher yields to offset perceived risks (Eicke, Weko, Apergi, & Marian, 2021). Additionally, the high natural resource rents in developing countries make the shift to clean energy less appealing compared to advanced economies, where favorable conditions and policies may better support low-carbon transitions (Collender, Gan, Nikitopoulos, Richards, & Ryan, 2022).

There are few studies quantifying the effects of climate policies on sovereign bond yields, although one recent paper shows varied results for developed markets and emerging markets. The study focuses on the impacts of climate transition risks on sovereign yields and spreads. It suggests that carbon dioxide emissions are positively related to sovereign bond yields and spreads, a relation that holds for both advanced and developing countries (Collender, Gan, Nikitopoulos, Richards, & Ryan, 2022). The same study shows that advanced countries with reduced natural resources and increased renewable energy consumption have lower sovereign borrowing costs, while the developing countries with similar energy consumption may have higher borrowing costs (Collender, Gan, Nikitopoulos, Richards, & Ryan, 2022).

5.1.2 Corporate bonds

As discussed in the previous section, climate change can have impacts on the sovereign bond markets through various channels, including the broader economic environment. Similarly, corporate bond performances can also be impacted by these effects. Moreover, corporate bonds are exposed to additional potential adverse effects of climate change from both transition and physical risks. Companies with higher exposure to these risks may have the

[30] Japan, the Netherlands, the Republic of Korea, Sri Lanka, Singapore, the Philippines, Viet Nam, Thailand, Indonesia, and India (Beirne, Renzhi, & Volz, 2020).

ratings attached to their bonds lowered resulting in increased costs of borrowing. Ultimately, the worst-case scenario would be a corporate bankruptcy and an issuer defaulting on its obligations.

In terms of climate physical risks, the geographical location of a business determines the company's exposure and vulnerability to climate-related events. High exposure and vulnerability areas can impact financial stability through potential damages, business disruptions, higher insurance premiums, and disrupted supply chains (e.g., (Bocchio, et al., 2023)). These risks can increase the corporate financing costs and affect access to finance (Javadi & Masum, 2021) (Kling, Volz, Murinde, & Ayas, 2021), which taken in isolation, would increase the cost of borrowing. In practice though, assessing the impact of climate vulnerability on corporate bond yields is challenging, as firms can reduce physical risks exposure by choosing less risky areas or relocating when costs rise. The findings on relocation decisions are however mixed (Indaco, Ortega, & Taspinar, 2019) (Kocornik-Mina, McDermott, Michaels, & Rauch, 2015). Moreover, firms may also diversify by operating in multiple locations, balancing relocation costs with maintaining networks of customers, suppliers, and investors (Jiang, Wei Li, & Qian, 2019).

Regarding climate transition risks, companies are faced with a range of challenges that can significantly affect their credit risks and costs of borrowing. One major impact arises from the evolving regulatory environment as part of the climate transition. Companies that fail to adapt to these changes or invest in sustainable practices may face higher regulatory and legal risks, leading to higher costs of borrowing (Carbone, et al., 2021) (Mueller & Sfappini, 2022). Moreover, technological advancements, shifts in consumer preferences and market dynamics toward sustainability may result in reduced market share and revenue to companies whose business models are not adjusted. Finally, investor and lender expectations are evolving, with growing emphasis on Environmental, Social and Governance (ESG) factors in their investment decisions. Companies perceived as lagging in managing their climate transition risks may face higher costs of borrowings (Seltzer & Starks, 2022).

Research quantifying potential climate change impacts on corporate bonds is limited. A recent study found that corporate bond market prices and credit spreads currently do not systematically reflect the risk of the transition to a low-carbon economy, nor do they consistently reflect physical climate risk. The expected climate change cost could potentially pose a risk to the asset value of firms, and losses might be large enough to adversely affect the value of bonds, even in a less aggressive 3°C target temperature scenario (Mastouri, Mendiratta, & Giese, 2022).

5.1.3 Climate-related opportunities in fixed income markets

Even though climate change presents additional risks to the fixed income market it also brings opportunities for growth and increased returns. For instance, impact investing through issuance of thematic bonds such as green bonds[31] can bring positive impacts to the social well-being and broader economy (Bisultanova & Aza, 2023); (Mattais & Nykvist, 2020) (Nenonen, Koski, Lassila, & Lehikoinen, 2019). They may also stimulate technological innovation and create jobs in emerging sectors like clean energy and green infrastructure, leading to new industries and economic opportunities (Rao, Chen, Shen, & Shen, 2022) (Ren,

[31] World Economic Forum - What are green bonds and why is this market growing so fast?

Cheng, & Dai, 2024). Both governments and companies can issue green bonds.

Despite the relatively short historical return period, investments in green bonds often achieve competitive returns, which can sometimes exceed those of traditional bonds. While research on the financial performance of green bonds shows mixed results (Flammer, 2018) (Karpf & Mandely, 2017) (Larcker & Watts, 2019), growing investor interest indicates that green bonds represent a viable and potentially rewarding investment option[32].

5.1.4 Conclusion

Based on the research conducted, the outlook for the impact of climate change on sovereign bonds is uncertain. As a result of physical risks there is a possibility of rising yields that would affect fixed income investments in both developed and emerging markets, with the latter likely exposed to more severe impacts. However, transition risk is more uncertain and will depend on the climate policies adopted. Without effective climate policies, emerging markets may experience more pronounced financial strain than developed markets. For corporate bonds, the impact could be exacerbated through broader economic instability and company-specific risks.

Impact investing such as green bonds offer a constructive pathway by funding environmentally beneficial projects, which can help manage climate-related financial risks while offering long-term socio-economic benefits.

Despite the growing awareness of these risks and opportunities, it is difficult to assess whether current bond markets are pricing them in and to what extent. This makes it difficult to decide if and how to adjust the OCA's assumption-setting process to explicitly incorporate climate change on fixed income yields and returns. Given these complexities and uncertainties, at this point, conducting scenario analysis is the OCA's preferred approach compared to adjusting best-estimate assumptions.

5.1.5 Quantitative analysis of projected bond yields

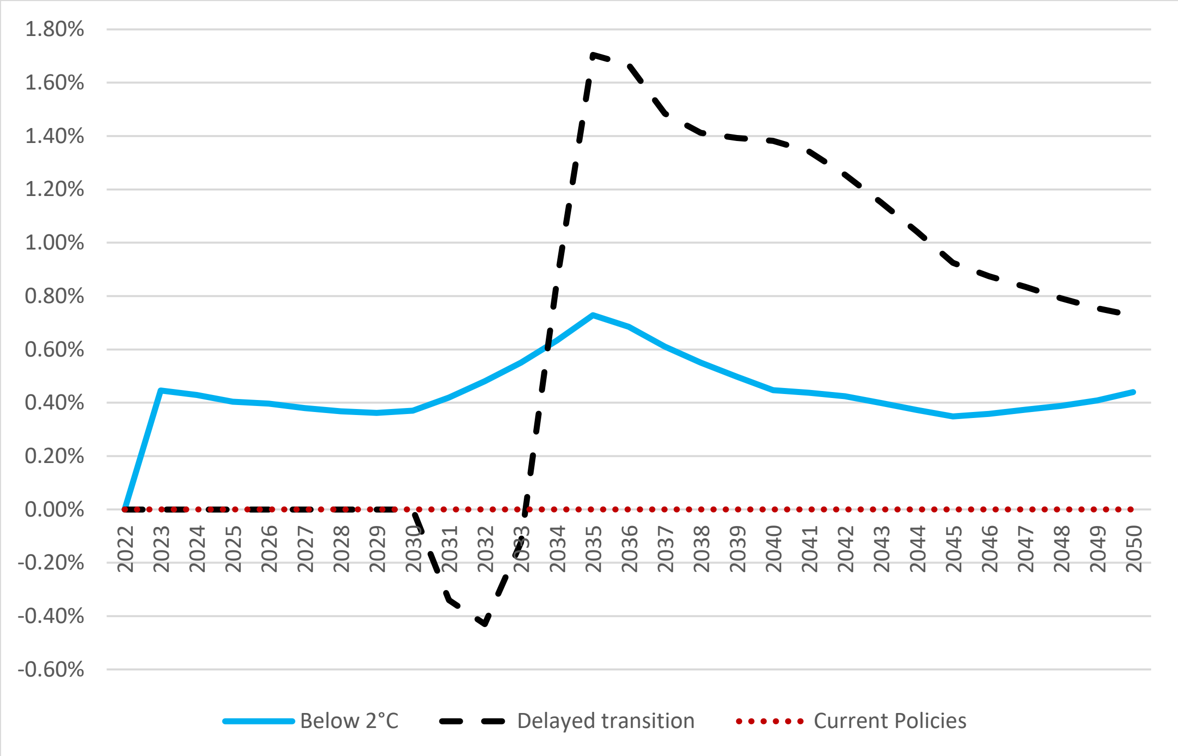
This section illustrates potential climate change impacts on the projections of Canadian nominal policy rates using the NGFS Climate Scenario Database[33]. Nominal policy rates are deemed to be a reasonable proxy for long-term government bond yields in Canada, as it reflects the Bank of Canada's stance on monetary policy, which influences interest rates in the economy.

The same NGFS scenarios were selected as in section 4.1 (Inflation): "Below 2°C" scenario, "Delayed Transition" scenario and "Current Policies" scenario. Charts 4 below shows the NGFS projected impact on future Canadian nominal policy rates, measured as the absolute percentage change from the baseline scenario. The baseline scenario is defined by NGFS as a hypothetical scenario with neither physical nor transition risks.

[32] Green bonds: Is doing good compatible with doing well in fixed income? | J.P. Morgan Asset Management (jpmorgan.com)

[33] The data used in this study is from the NGFS Scenarios Phase IV publication. Although a subsequent data refresh was released in the NGFS Scenario Phase V publication in the second half of 2024, it was not incorporated due to the timing of the study.

Chart 4 Nominal policy rates – Canada (absolute % change from baseline)



Source: IIASA NGFS Climate scenario database (Phase IV publication), NiGEM model with REMIND inputs.

Under the "Below 2°C" scenario, the nominal policy rates increase in the short to medium term, while much more substantial swings are projected under the "Delayed Transition". Under this scenario, there are no deviations from the baseline scenario until 2030. Then as the transition begins, a brief decrease is followed by a spike, then a gradual decline to an ultimate level higher than under the "Below 2°C" scenario". Finally, there are no impacts on the nominal policy rates under the "Current Policies" scenario since there is no impact from climate transition and the chronic physical impacts are only felt past 2050.

Similar to Section 4.1 (Inflation), data from the NGFS is only available up to 2050 and the OCA's investment assumption projection period is over 75 years.

5.2 Equities

Many studies suggest negative impacts on equity returns with increased exposure to both physical and transition climate-related risks as well as increased risk of financial losses due to stranded assets. The impacts by region will differ, with emerging markets projected to be the most impacted. Conversely, climate change can introduce new opportunities in sectors related to renewable energy and energy efficiency technologies.

The uncertainty surrounding whether climate change impacts are currently priced into equity returns adds another layer of complexity to assess the future impact of climate change on equity returns. This section explores these themes in more detail.

5.2.1 Physical and transition risks

The increasing frequency and severity of climate-related events are likely to increase costs associated with repairing damaged assets and higher insurance premiums[34], which could lead to lower equity returns. These events could also disrupt operations and supply chains, leading to revenue losses and inefficiencies (Bocchio, et al., 2023), while necessitating significant investment in resilience measures that divert capital from other growth opportunities (Batten, Sowerbutts, & Tanaka, Climate change: Macroeconomic impact and implications for monetary policy, 2020).

Many studies show that equity returns vary with the physical climate change exposure of firms in a predictable manner. Firms with high climate change exposures and high sensitivity to temperature changes are predicted to experience lower subsequent stock returns (Kumar, Xin, & Zhang, 2019), (Pankratz, 2018) (Sun, Xu, & You, 2022).

Furthermore, regulatory and compliance costs associated with new climate policies may add financial burdens, reducing profitability and future rates of return (Darnall, 2009) (Hengge, Panizza, & Varghese, 2023). Stranded assets[35], defined as those that suffer from unanticipated or premature write-downs, devaluations, or conversions into liabilities, add asset valuation risk as they may become obsolete or less valuable due to climate-related regulations. A study showed that to limit warming to below 2°C, one-third of current oil reserves, half of current gas reserves, and four-fifths of current coal reserves globally need to remain underground and unused until 2050 (McGlade & Ekins, 2015). Evaluating these climate transition risks is especially pertinent for developed markets. Historically, they were generally the world's top carbon emitters[36] and may face major transformations as the world moves away from fossil fuels.

5.2.2 Pricing in physical and transition risks

Studies suggest that climate-related physical risks are not fully priced into equity prices, or that they are mispriced (Brunetti, et al., 2021) (Eren, Merten, & Verhoeven, 2022). Equity investors are challenged with limited information when pricing the anticipated increase in physical risk into their equity portfolios. They also need to form views on the likelihood of various climate scenarios and their implications for physical risk across the world, based on ever-evolving climate science, expected climate mitigation and adaptation policies. Even if investors can correctly price climate physical risk, the time horizon over which this change is likely to unfold may be longer than the investment horizon of most investors, including institutional investors (Brunetti, et al., 2021) (Deghi, et al., 2020).

From a transition risk perspective, recent research suggests that climate transition risks are increasingly being priced into equity returns, but the degree of integration varies across markets and sectors (Broeders, Schouten, Tiems, & Verhoeven, 2023) (Giese, Nagy, & Rauis, 2021) (Reboredo & Ugolini, 2020). Moreover, European markets exhibit greater sensitivity to climate transition risks than the US market, where European investors are more likely to reduce the value of companies with high transition risk exposure (Reboredo & Ugolini, 2020).

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[34] Climate Risk Management - Office of the Superintendent of Financial Institutions (osfi-bsif.gc.ca)
[35] International Renewable Energy Agency - Stranded Assets and Renewables
[36] Developed Countries Are Responsible for 79 Percent of Historical Carbon Emissions | Center For Global Development (cgdev.org)

In the US equity market, only the climate transition risks related to climate policies are priced in, with the evidence being more pronounced over 2012-2018 (Faccini, Matin, & Skiadopoulos, 2021).

A recent Canadian-focused study by the International Monetary Fund (Yang, Huang, & Zhang, 2023) shows that climate transition risks are partially priced into stock prices. More specifically, the responses of stocks in the oil and gas sector to positive and negative news about mitigation policies are asymmetrical. An ease in climate mitigation constitutes a favourable shock to oil and gas companies but tighter mitigation policies do not necessarily signal a negative shock. The study also suggests that climate transition risks are partially priced into the current equity returns in Canada.

5.2.3 Emerging markets

The emerging markets are projected to be the most impacted by climate change, with Africa, Asia-Pacific, the Middle East and Latin America expected to suffer larger losses in real GDP terms compared to Western Europe and North America[37]. These GDP losses could result in lower equity returns.

Emerging market equities may be more vulnerable to climate-related risks than developed market equities, since countries in emerging markets generally have higher exposure to physical climate risks such as extreme weather events, sea-level rise, and water scarcity (IPCC AR6). These risks can directly impact companies' operations, supply chains, and infrastructure, leading to disruptions in production, increased costs, and potential asset damage. They may also have lower capacity to adapt and to recover from these events, as emerging markets may have limited financial resources, infrastructure, and institutional capacity compared to developed markets (Khan and Huq, 2023; Saeed et al., 2023). This can exacerbate the impacts of climate-related risks on companies' operations and financial performance.

Furthermore, developing countries have higher reliance on natural resources. As shown in the previous section, depletion of natural capital can increase sovereign risks (Pinzón, Robins, McLuckie, & Thoumi, 2020), increasing the risk perception of the costs of capital overall. Many emerging markets also rely heavily on climate-sensitive sectors such as agriculture, forestry, fishing, and natural resource extraction. These sectors are particularly vulnerable to climate variability and change, affecting companies' revenues, profitability, and stock performance (Portner, et al., 2022).

As discussed in section 3.3 (Migration), developing countries may face higher risks associated with migration, increased inequality, and conflict, which may cause disruption to their domestic markets.

5.2.4 Climate-related opportunities in equities

While presenting significant challenges, addressing climate change, and transitioning into a more sustainable, low carbon economy, may also offer various investment opportunities across different sectors in the equity markets (Miller & Swann). The *World Investment Report*

[37] RBC - The future of emerging markets: Climate change

2023: Investing in Sustainable Energy for All[38] stated that the total assets under management of sustainable funds have been increasing, indicating the growing opportunities climate change brings. Key areas of growth include renewable energy, green infrastructure, and energy efficiency technologies.

Moreover, firms integrating ESG criteria into their operations often experience higher valuations due to increased investor interest in sustainable and ethical investments. Proactive compliance with emerging climate regulations can enhance market reputation and may reduce potential future liabilities, contributing positively to equity valuation (Baz, Cathcart, Michaelides, & Zhang, 2023) (Di Febo, Angelini, & Le, 2024)).

5.2.5 Conclusion

Based on the research, the OCA's conclusions for how climate change could impact equity returns are as follows:

- Although there are opportunities stemming from innovation and green technologies, the outlook of climate change on equity returns is generally negative, with lower returns.
- Emerging markets are more at risk.
- It is difficult to assess whether equity markets are pricing in current risks and opportunities and to what extent.
- The impact on returns will depend on the design and implementation of global climate policies.
- Scenario analysis is the OCA's preferred approach compared to adjusting best-estimate assumptions.

5.3 Real assets

The real assets asset class broadly consists of real estate, infrastructure, and natural resources. It has been impacted globally by the physical risks of climate change as the frequency and severity of climate-related events have been noticeably increasing. This section discusses the potential impact of climate-related risks and opportunities on the value of real assets. Changes in the value of real assets have a direct impact on the rates of return.

5.3.1 Acute climate physical risks

First, acute physical risks, represented by extreme weather events such as flooding, hurricanes, wildfires, etc., not only cause immediate damages and loss of value, but can also have implications for future damages. Studies show that extreme weather events can reduce the value of real estate in high-risk areas. The impacts can be short-term (Fisher & Rutledge, 2021), or a permanent price discount (Addoum, Eichholtz, Steiner, & Yonder, 2021).

More specifically, increasing urbanization and rising temperatures are intensifying heavy precipitation, leading to increased inland flooding. This exacerbates damage to real estate and infrastructure, as well as disrupts commodity supply chains (Carlin, Arshad, & Baker, 2023). The global insured losses from inland flooding between 2011 and 2020 more than doubled from the previous decade and amounted to approximately US$80 billion (Bevere &

[38] United Nations Conference on Trade and Development - World Investment Report 2023 Investing in Sustainable Energy for All

Finucane, 2022). Wildfires are another potential hazard that have grown more intense and widespread due to climate change. Areas historically safe from such fires are now at risk, with significant examples including the destruction of 99,594 structures in the U.S. from 2,616 wildfires between 2005 and 2022[39], and the unprecedented burn area during Canada's 2023 wildfire season[40].

In addition to causing physical damages to real assets, increases to the frequency and severity of extreme weather events could lead to higher insurance premiums, higher costs for rebuilding and maintenance, and lower tourist numbers in affected areas. These can all have a negative impact on the values of the real assets.

However, as discussed in section 4.2 (Economic growth), there could be short-term opportunities after extreme weather events. For example, investments in the reconstruction of infrastructure following climate-related disasters and in climate adaptation infrastructure can generate economic activity and add value to the assets (Hsu & Chao, 2022) (Kelly & Molina, 2023). This includes funding recovery projects and incorporating resilience measures to reduce future risks.

5.3.2 Chronic climate physical risks

The chronic physical risks such as sea-level rise, subsidence, and temperature change may also have similar negative impacts on real assets. These impacts include direct repair and maintenance costs, increased insurance premiums, decreased real estate values (Contat, Hopkins, Mejia, & Suandi, 2024) supply chain disruptions in commodities and natural resources, and broader economic consequences (Bocchio, et al., 2023).

Globally, many cities are exposed to a rise in the sea-level and chronic flooding, and this is expected to worsen. A study by Climate Central (Climate Central, 2019) shows that land now home to 300 million people will be below the average annual coastal floods by 2050 due to sea level rise. Additionally, climate change contributes to subsidence, where ground beneath structures sinks, compromising foundations and destabilizing buildings[41].

5.3.3 Transition risks and opportunities

The climate transition, which includes climate mitigation or adaptation policies or both, and shifting market preferences, can significantly impact the value of real assets (Sawyer D. , Ness, Lee, & Miller, 2022). Investors may also increasingly favor assets aligned with ESG criteria, potentially influencing the availability and cost of capital for certain real assets.

For real estate, stricter building codes and energy efficiency standards can increase the costs for developers and property owners but may also enhance the value of compliant properties. Moreover, the preference for more sustainable and energy-efficient buildings may grow with the transition to a low-carbon emission economy (Contat, Hopkins, Mejia, & Suandi, 2024). This shift may drive demand for green buildings, retrofits, and properties in climate-resilient locations. Investors could benefit from premium rents, higher property values, and

[39] Wildfires destroy thousands of structures each year - Headwaters Economics
[40] Canadian Wildland Fire Information System | National Wildland Fire Situation Report (nrcan.gc.ca)
[41] Maps show the real threat of climate-related subsidence to British homes and properties - British Geological Survey (bgs.ac.uk)

government incentives associated with these sustainable assets.

Similarly, existing infrastructure may require significant investment to meet new environmental standards or to adapt to the changing climate conditions, potentially affecting the assets' value. However, the climate transition may also present opportunities[42], such as renewable energy infrastructure including solar, wind, and hydroelectric projects. Additionally, resilient infrastructure developments, such as flood defenses and upgraded transportation systems, are critical for climate mitigation and adaption and can offer attractive investment returns. Finally, the rise of electric vehicles also creates demand for supporting infrastructure like charging networks[43] and public transit enhancements[44].

In terms of natural resources and commodities, fossil fuels may see reduced demand and price volatility as economies shift towards renewables, potentially leading to stranded assets. However, commodities such as metals and minerals critical for renewable energy technologies (e.g., lithium, cobalt, copper, etc.) may appreciate due to increased demand for batteries and other green technologies (Hafner & Tagliapietra, 2020). Climate change can also alter agricultural productivity and land use patterns, impacting the value of agricultural commodities and land based on the changing conditions (Quaye, Nadolnyak, & Hartarska, 2018).

5.3.4 Conclusion

Both physical risks and transition risks of climate change impact real assets. Research suggests that physical risks point towards negative impacts of climate risk on real asset returns. The impact from transition risks is less clear. While the climate transition appears to present opportunities, factors such as physical damages from extreme weather events, increased construction costs due to carbon pricing, higher insurance premiums, and evolving regulatory policies present potential negative impacts. The combined effects of physical and transition risks on real assets are uncertain. For these reasons, the OCA is not ready to incorporate potential impacts of climate change on the rates of return for real assets in its best-estimate assumptions. In the OCA's view, scenario analysis would be a preferable approach.

5.4 Considerations for building a framework supporting quantitative analysis

This section explores the various considerations for assessing quantitative impacts of climate-related risks on investment assumptions as a part of the OCA's climate scenario analysis. The first subsection provides a brief summary of OCA's methodology used in the climate scenario analysis included in the CPP31 AR. The second subsection discusses considerations for improving the methodology for the next actuarial valuation cycle.

5.4.1 CPP31 AR framework for adjusting investment assumptions in climate scenario analysis

As shown in section 4.3, in the CPP31 AR, three hypothetical climate scenarios with different pathways of Canadian nominal GDP growth rates relative to a baseline scenario[45] were used

[42] CDP - World's biggest companies face $1 trillion in climate change risks
[43] For example, Canada Invests in Cross-Country Electric Vehicle Fast-Charging Network - Canada.ca
[44] For example, Government of Canada investing to electrify transit systems across the country - Canada.ca
[45] The baseline scenarios in publicly available reports can vary and are not defined; therefore, they can't be assessed against the best-estimate assumptions of CPP31 AR. For illustration purposes only, the differences relative to the baseline scenarios were applied to the best-estimate assumptions of this report.

to illustrate the potential impacts of climate change on the CPP MCR. As a reminder, the analysis focused on illustrating downside risk. The scenarios are therefore intentionally adverse.

For economic assumptions, changes in the nominal Canadian GDP growth by scenario were translated one-for-one into changes in total employment earnings through the real wage assumption. A simplified approach was also adopted to account for the impact of climate change on investment assumptions.

For context, the first building block to determine best-estimate rates of return for equities in OCA's actuarial reports is to develop an assumption for public developed market equities. The returns for other equity asset classes (emerging, private equity, small caps) are modelled through premiums relative to developed markets. The expected rate of return on developed market equities is comprised of expected income return (dividend and buyback yields), expected earnings growth and a repricing adjustment if markets are deemed to be undervalued or overvalued at the valuation date. The earnings growth component is proxied by projected GDP per capita, which creates a direct link to GDP in the methodology used to develop best-estimate equity returns. The OCA therefore used this GDP link to adjust equity returns under each climate scenario.

Under the simplified approach, changes in global GDP growth are proxied by changes in Canadian GDP growth. These changes in GDP were then incorporated in the assumed investment returns through changes in the growth in earnings component. Returns for all equity-linked assets were therefore adjusted to reflect different GDP paths under the different climate scenarios. However, for asset classes where the return is assumed not to have a direct link to GDP growth, fixed income for example, no climate change impact was included in the rates of return.

5.4.2 Considerations for next valuation cycle

As mentioned in section 4.3.2, the OCA plans on conducting research to update its hypothetical climate scenarios based on more recently available information. The OCA is also looking into building on the CPP31 AR framework to improve how the investment assumptions are adjusted in the climate scenario analysis. The priorities for the next valuation cycle are to investigate potential impacts on returns for fixed income asset classes, as well as to incorporate GDP impacts by different markets for adjusting equity returns.

5.4.2.1 Fixed income

For context, the first building block to determine best-estimate rates of return for fixed income asset classes in OCA's actuarial reports is to develop an assumption on the evolution of the long-term (10 years and plus) Government of Canada (GoC) bond yield. Historical yield spreads between various bond durations/types/geographies and the long-term GoC bond yield are then analyzed for setting the yield assumptions for the different fixed income portfolios. Rates of returns are then computed based on these yield projections.

An approach that the OCA is considering for incorporating fixed income impacts in its climate scenario analysis is to obtain projected GoC bond yields by climate scenario and determine the expected rate of return on the bond portfolios based on these yield paths.

However, there is limited information available to obtain such yield paths by climate scenario, especially over a projection period that spans over 75 years. In many cases, the projection period only extends to 2050, and does not give a full picture for physical risks, nor does it illustrate the interconnection between physical and transition risk.

5.4.2.2 Equities

In the scenario analysis presented in the CPP31 AR, changes in global GDP growth are proxied by changes in Canadian GDP growth. Given that CPP Investments and PSP Investments invest assets globally, the OCA is planning on refining its approach by expanding the GDP impact analysis to include countries other than Canada. The impact on equity returns would therefore be more in line with the geographical distribution of both investors' holdings.

5.4.2.3 Real Assets

Given the uncertainties of physical and transition risks on real assets, the OCA is reflecting on the appropriate treatment in its climate scenario analysis of the impact on real assets through changes in the GDP growth component.

6 Conclusion

The research presented in this study highlights the complexities and uncertainties surrounding the impacts of climate change on the OCA's assumption setting process. While the data is incomplete and sometimes contradictory, the study underscores the importance of scenario analysis as a tool to understand and illustrate these evolving climate-related risks.

Direct climate change risks are expected to decrease global fertility and increase mortality, though Canada's colder climate and better air quality may lessen these effects. Indirect climate risks could reduce fertility in the short term and raise mortality, but the long-term impacts are uncertain and depend on the climate policy successes. As for migration, there is too much uncertainty to even assess the potential directional impact of climate change on migration patterns in Canada. The OCA is not ready to explicitly incorporate the potential impacts of climate change on best-estimate demographic assumptions into its next actuarial valuation cycle.

Climate change may impact future inflation and economic growth in Canada through both supply and demand shocks, with effects varying depending on the type and timing of climate-related events and the nature of climate policies. Acute physical risks can cause immediate inflationary shocks, while chronic risks may have longer-term effects. Similarly, the impact on economic growth is uncertain due to the interplay of climate physical and transition risks. The OCA is not ready to explicitly incorporate the potential impacts of climate change on best-estimate economic assumptions into its next actuarial valuation cycle.

The impact of climate change on investment assumptions also remains uncertain. For fixed income, physical risks might lead to rising yields and financial strain, especially in emerging markets, while the impact of transition risks depend on climate policies. For equities, climate change generally suggests lower returns, with emerging markets at higher risks. However, it's unclear if climate risks are fully priced in. Real assets face negative impacts from physical risks and uncertain effects from transition risks. The OCA is not ready to explicitly incorporate the potential impacts of climate change on best-estimate investment assumptions into its next actuarial valuation cycle.

The OCA continues to believe that scenario analysis is a sound approach to understanding and illustrating risk. This study recommends, for climate scenario analysis in the upcoming actuarial valuations, to exclude demographic assumptions due to insufficient Canada-specific data. The scenario analysis for economic assumptions, as presented in the CPP31 AR, remains relevant but requires periodic updates to account for ongoing climate developments. Finally, the study recommends additional refinement to the scenario analysis for investment assumptions by incorporating new variables, including potential climate impacts on fixed income returns, as well as varying GDP impacts by different markets.

Appendix - A References

Aaron W. Tustin, M., Glenn E. Lamson, M., Brenda L. Jacklitsch, P., Richard J. Thomas, M., Sheila B. Arbury, M., Dawn L. Cannon, M., . . . Michael J. Hodgson, M. (2018, July 6). Evaluation of Occupational Exposure Limits for Heat Stress in Outdoor Workers — United States, 2011–2016. *Centres for Disease Control and Prevention - Morbidity and Mortality Weekly Report*, pp. 733-737.

Abbott, G., & Chapman, M. (2018). *Addressing the New Normal: 21st Century Disaster Management in British Columbia.* Victoria: BC Flood and Wildfire Review.

Abed Al Ahad, M., Sullivan, F., Demsar, U., Melham, M., & Kulu , H. (2020). The effect of air-pollution and weather exposure on mortality and hospital admission and implications for further research: A systematic scoping review. *PLOS ONE*, 1-24.

Abel, G. J., Brottrager, M., Cuaresma, J. C., & Muttarak, R. (2019). Climate, conflict and forced migration. *Global Environmental Change*, pp. 239-249.

Adams, H., & Kay, S. (2019). Migration as a human affair: Integrating individual stress thresholds into quantitative models of climate migration. *Environmental Science and Policy*, pp. 129-138.

Addoum, J. M., Eichholtz, P., Steiner, E., & Yonder, E. (2021, March). Climate Change and Commercial Real Estate: Evidence from Hurricane Sandy. SSRN.

Agyapong, V. I., Hrabok, M., Juhas, M., Omeje, J., Denga, E., Nwaka, B., . . . Li, X.-M. (2018, July). Prevalence Rates and Predictors of Generalized Anxiety Disorder Symptoms in Residents of Fort McMurray Six Months After a Wildfire. *Frontiers in Psychiatry*, pp. 1-12.

Amiraslany, A. (2010). *The Impact of Climate Change on Canadian Agriculture: A Ricardian Approach.* Saskatoon: University of Saskatoon.

Apel, M. (2022). *How does the climate transition affect inflation?* Sveriges Riksbank.

Ayouqi, H., & Vercammen, J. (2014). *EVALUATING THE IMPACT OF CLIMATE CHANGE ON CANADIAN PRAIRIE AGRICULTURE.* University of Alberta.

Bachner, G., & Bednar-Friedl, B. (2019). The Effects of Climate Change Impacts on Public Budgets and Implications of Fiscal Counterbalancing Instruments. *Environmental Modeling & Assessment*, pp. 121-142.

Bank of Canada; Office of the Superintendent of Financial Institutions. (2022). *Using Scenario Analysis to Assess Climate Transition Risk.* Ottawa: Bank of Canada; Office of the Superintendent of Financial Institutions.

Barnett, J., & McMichael, C. (2018). The effects of climate change on the geography and timing of human mobility. Australia: School of Geography, The University of Melbourne.

Batten, S. (2018, January). Climate change and the macro-economy: a critical review. *Staff Working Paper No. 706*. England: Bank of England.

Batten, S., Sowerbutts, R., & Tanaka, M. (2016, May). Let's talk about the weather: the impact of climate change on central banks. *Staff Working Paper No. 603*. England: Bank of England.

Batten, S., Sowerbutts, R., & Tanaka, M. (2020). Climate change: Macroeconomic impact and implications for monetary policy. In *Ecological, Societal, and Technological Risks and the Financial Sector.* Bank of England.

Baz, S., Cathcart, L., Michaelides, A., & Zhang, Y. (2023, March 31). Firm-Level Climate Regulatory Exposure. SSRN.

Beine, M., Docquier, F., & Schiff, M. (2009). *International Migration, Transfers of Norms and*

Home Country Fertility. The World Bank Development Research Group Trade Team.
Beirne, J., Renzhi, N., & Volz, U. (2020). *FEELING THE HEAT: CLIMATE RISKS AND THE COST OF SOVEREIGN BORROWING.* Tokyo: Asian Development Bank Institute.
Berlemann, M., & Steinhardt, M. F. (2017). Climate Change, Natural Disasters, and Migration—a Survey of the Empirical Evidence. *CESifo Economic Studies*, pp. 253-385.
Bevere, L., & Finucane, J. (2022, September 01). Economic Insights Flood: new risk-based pricing capabilities, new opportunities to close protection gaps. *Swiss Re Institute - Sigma research*.
Bhaskaran, K., Gasparrini, A., Hajat, S., Smeeth, L., & Armstrong, B. (2013, June 12). Time series regression studies in environmental epidemiology. *International Journal of Epidemiology*, pp. 1187-1195.
Bisultanova, & Aza. (2023). Green" bonds: historical aspects of implementation. *International Scientific Conference Energy Management of Municipal Facilities and Environmental Technologies*, 8.
Black, R., Bennett, S. R., Thomas, S. M., & Beddington, J. R. (2011, October 27). Migration as Adaptation. *Nature*, pp. 447-449.
Bluedorn, J., Hansen , N.-J., Noureldin, D., Shibata, I., Tavares, M. M., Newman, S., & Nyakeri, C. (2022). A GREENER LABOR MARKET: EMPLOYMENT, POLICIES, AND ECONOMIC TRANSFORMATION. In *International Monetary Fund.* 67-86.
Bocchio, C., Giamalaki, K., Giezek, M., Grevenbrock, N., Zayat, A., & Zemcik, P. (2023, March). Quantifying the Impact of Climate on Corporate Credit Risk. *Moody's Analytics*. Moody's.
Bohra-Mishraa, P., Oppenheimera, M., & Hsiang, S. M. (2014, July 8). Nonlinear permanent migration response to climatic variations but minimal response to disasters. *Proceedings of the National Academy of Sciences*, pp. 9780-9785.
Boneva, L., Ferrucci, G., & Mongelli, F. P. (2022, February). Monetary policy and the green transition. *SUERF Policy Brief No 268*. Vienna, Austria: SUERF The European Money and Finance Forum.
Bonsal, B. R., Peters, D. L., Seglenieks, F., Rivera, A., & Berg, A. (219). Changes in freshwater availability across Canada. In E. Bush, & D. S. Lemmen, *Canada's Changing Climate Report* (pp. 261-342). Ottawa: Government of Canada.
Botzen, W. J., Deschenes, O., & Sanders, M. (2019, Summer). The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies. *Review of Environmental Economics and Policy*, pp. 167-188.
Boyd, R., & Markandya, A. (2021). *Costs and Benefits of Climate Change Impacts and Adaptation; Chapter 6 in Canada in a Changing Climate: National Issues Report, (Eds.) F.J. Warren and N. Lulham.* Ottawa: Government of Canada.
Broeders, D., Schouten, B., Tiems, I., & Verhoeven, N. (2023, January 01). Pricing of climate transition risks across different financial markets. *Journal of Risk Management in Financial Institutions*, pp. 102-115.
Brown, O. (2008). *Migration and Climate Change.* International Organization for Migration.
Brunetti, C., Dennis, B., Gates, D., Hancock, D., Ignell, D., Kiser, E. K., . . . Tabor, N. K. (2021). Climate Change and Financial Stability. *FEDS Notes*.
Bunce, A., Ford, J., Harper, S., Edge, V., & IHACC Research Team. (2016, September 01). Vulnerability and adaptive capacity of Inuit women to climate change: a case study from Iqluit, Nunavut. *Natural Hazards*, pp. 1419-1441.
Bunker, A., Wildenhain, J., Vandenbergh, A., Henschke, N., Rocklov, J., Hajat, S., & Sauerborn,

R. (2016). Effects of Air Temperature on Climate-Sensitive Mortality and Morbidity Outcomes in the Elderly; a Systematic Review and Meta-analysis of Epidemiological Evidence. *EBio Medicine*, 258-268.

Burniaux, J.-M., Château, J., Duval, R., & Jamet, S. (2008, December 17). The Economics of Climate Change Mitigation: Policies and Options for the Future. *OECD Economics Department Working Papers No. 658*. Organisation for Economic Co-operation and Development.

Burzynski, M., Deuster, C., Docquier, F., & Melo, J. d. (2019). Climate Change, Inequality, and Human Migration. Louvain-la-Neuve, Belgium: Institut de Recherches Economiques et Sociales de l'Université catholique de Louvain.

Butz, W. P., Lutz, W., Sendzimir, J., & Andruchowitz, S. (2014). *Education and Differential Vulnerability to Natural Disasters.* International Institute for Applied Systems Analysis.

Carbone, S., Giuzio, M., Kapadia, S., Kramar, J. S., Nyholm, K., & Vozian, K. (2021). *The low-carbon transition, climate commitments and firm credit risk.* Frankfurt am Main: European Central Bank.

Carlin, D., Arshad, M., & Baker, K. (2023). *Sectoral Risk Briefings: Insights for Financial Institutions - Climate Risks in the Real Estate Sector.* UN Environment Programme.

Casey, G., Shayegh, S., Moreno-Cruz, J., Bunzl, M., Galor, O., & Caldeira, K. (2019). *The Impact of Climate Change on Fertility.*

Casey, G., Shayegh, S., Moreno-Cruz, J., Bunzl, M., Galor, O., & Caldeira, K. (2019, February). The Impact of Climate Change on Fertility.

Cattaneo, C., Beine, M., Fröhlich, C. J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., . . . Piguet, E. (2019). Human Migration in the Era of Climate Change. European Institute on Economics and the Environment.

Cavallo, E., Becerra, O., & Acevedo, L. (2021). *The Impact of Natural Disasters on Economic Growth.* Inter-American Development Bank.

Cavallo, E., Galiani, S., Noy, I., & Pantano, J. (2010). *Catastrophic Natural Disasters and Economic Growth.* Inter-American Development Bank.

Cella, W., Baia-da-Silva, D. C., Cardoso de Melo, G., Tadei, W. P., de Souza Sampaio, V., Pimenta, P., . . . Monteiro, W. M. (2019, March 08). Do climate changes alter the distribution and transmission of malaria? Evidence assessment and recommendations for future studies. *Journal of the Brazilian Society of Tropical Medicine*, pp. 1-9.

Cevik, S., & Jalles, J. T. (2020). *This Changes Everything: Climate Shocks and Sovereign Bonds.* International Monetary Fund.

Charlson, F., Ali, S., Benmarhnia, T., Pearl, M., Massazza, A., Augustinavicius, J., & Scott, J. G. (2021, April 23). Climate Change and Mental Health: A Scoping Review. *International Journal of Environmental Research and Public Health*.

Chen, Y., Romps, D. M., Seeley, J. T., Veraverbeke, S., Riley, W. J., Mekonnen, Z. A., & Randerson, J. T. (2021, May). Future increases in Arctic lightning and fire risk for permafrost carbon. *Nature Climate Change*, pp. 404-410.

Clark, D. G., R. N., Coffman, D., & Beugin, D. (2021, June). The Health Costs of Climate Change: How Canada can adapt, prepare, and save lives. *Canadian Institute for Climate Choices*. Canadian Institute for Climate Choices.

Clayton, S. (2020, August). Climate anxiety: Psychological responses to climate change. *Journal of Anxiety Disorders*.

Climate Central. (2019). *Climate Central*. Retrieved from Study triples global estimates of population threatened by sea level rise: https://www.climatecentral.org/press-release-flooded-future

Club Vita. (2018). *Hot and Bothered - How climate change might affect UK longevity.* London: Club Vita.

Cœuré, B. (2018). Monetary policy and climate change. *BIS Central Bankers' Speeches*.

Collender, S., Gan, B., Nikitopoulos, C. S., Richards, K.-A., & Ryan, L. (2022, November 29). Climate Transition Risk in Sovereign Bond Markets.

Contat, J., Hopkins, C., Mejia, L., & Suandi, M. (2024). When climate meets real estate: A survey of the literature. . *Real Estate Economics*, pp. 618-659.

Cuaresma, J. C., Hlouskova, J., & Oberteiner, M. (2008, April). Natural Disasters as Creative Destruction? Evidence from Developing Countries. *Economic Inquiry*, pp. 214-226. Retrieved from https://www.reasearchgate.net/.

Cunsolo, A., & Ellis, N. R. (2018, April). Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change*, pp. 275-281.

Darnall, N. (2009, May). Regulatory Stringency, Green Production Offsets, and Organizations' Financial Performance. *Public Administration Review*, pp. 418-434.

Davis, R. E., Knappenberger, P. C., Michaels, P. J., & Novicoff, W. M. (2004, April 19). Seasonality of climate - human mortality relationships in US cities and impacts of climate change. *Climate Research*, pp. 61-76.

Deghi, A., Feng, A., Gan, Z. K., Khadarina, O., Suntheim, F., Yizhi, X., . . . Qureshi, M. (2020). *Global Financial Stabilty Report: Markets in the time of Covid -19. Chapter 5 - Climate Change - Physical Risk and Equity Prices.* The International Monetary Fund.

Dennekamp, M., Straney, L. D., Erbas, B., Abramson, M. J., Keywood, M., Smith, K., . . . Tonkin, A. M. (2015, October). Forest Fire Smoke Exposures and Out-of-Hospital Cardiac Arrests in Melbourne, Australia: A Case-Crossover Study. *Environmental Health Perspectives*, pp. 959-964.

Development, O. f.-o. (2015). *The Economic Consequences of Climate Change*. Retrieved from OECDiLibrary: https://doi.org/10.1787/9789264235410-en

Di Febo, E., Angelini, E., & Le, T. (2024, August 13). European Non-Performing Exposures (NPEs) and Climate-Related Risks: Country Dimensions. *Risks*.

Diffenbaugh, N. S., & Burke, M. (2019, March 22). Global warming has increased global economic inequality. *Proceedings of the National Academy of Sciences*, pp. 9808-9813.

Dumont, C., Haase, E., Dolber, T., Lewis, J., & Coverdale, J. (2020). Climate change and risk of completed suicide. *The Journal of Nervous and Mental Disease*, 559-565.

Ebi, K. L., Vanos, J., Baldwin, J. W., Bell, J. E., Hondula, D. M., Errett, N. A., . . . Berry, P. (2022, April 17). Extreme Weather and Climate Change: Population Health and. *Annu Rev Public Health*, pp. 293-315.

Egyed, M., Blagden, P., Plummer, D., Makar, P., Matz, C., Flannigan, M., . . . Xi, G. (2022). Health of Canadians in a Changing Climate: Advancing our Knowledge for Action. In P. Berry, & R. Schnitter, *Air Quality* (pp. 287-365). Ottawa: Government of Canada.

Eicke, L., Weko, S., Apergi, M., & Marian, A. (2021). Pulling up the carbon ladder? Decarbonization, dependence, and third-country risks from the European carbon border adjustment mechanism. *Energy Research & Social Science*.

Eren, E., Merten, F., & Verhoeven, N. (2022). *Pricing of climate risks in financial markets: a summary of the literature.* Bank for International Settlements.

Erickson, L. E., Griswold, W., Maghirang, R. G., & Urbaszewski, B. P. (2017). Air Quality, Health and Community Action. *Journal of Environmental Protection*, pp. 1057-1074.

Faccia, D., Parker, M., & Livio, S. (2021). *Feeling the heat: extreme temperatures and price stability.* Frankfurt: European Central Bank.

Faccini, R., Matin, R., & Skiadopoulos, G. (2021, July 12). Dissecting Climate Risks: Are they Reflected in Stock Prices?

Fankhauser, S., & Tol, R. S. (2005). On climate change and economic growth. *Resource and Energy Economics*, pp. 1-17.

Felio, G. (2017). *Climate Change Impacts on Water and Wastewater Infrastructure at Akwasasne.* Ontario First Nations Technical Services Corporation.

Fiore, A. M., Naik, V., & Leibensperger, E. M. (2015). Air Quality and Climate Connections. *Journal of the Air & Waste Management Association*, 645-685.

Fisher, J. D., & Rutledge, S. R. (2021, March 22). The impact of Hurricanes on the value of commercial real estate. *Business Economics*.

Flammer, C. (2018). Corporate Green Bonds. *GEGI Working Paper*.

Ford, J. D. (2012, July). Indigenous Health and Climate Change. *American Journal of Public Health*, pp. 1260-1266.

Friel, S., Dangour, A. D., Garnett, T., Lock, K., Chalabi, Z., Roberts, I., . . . Haines, A. (2009, December 12). Public health benefits of strategies to reduce greenhouse-gas. *The Lancet*, pp. 2016-2025.

Gaskin, A. J., Fong, K. C., Awad, Y. A., Di, Q., Minguez-Alarcon, L., Chavarro, J. E., . . . Laden, F. (2019). Time-varying Exposure to Air Pollution and Outcomes of In Vitro Fertilization among Couples from a Fertility Clinc. *Environmental Health Perspectives*, 077002-1- 8.

Gasparrini, A., Guo, Y., Sera, F., Vicedo-Cabrera, A., Huber, V., Tong, S., . . . Armstrong, B. (2017, November 13). Projections of temperature-related excess mortality under. *Lancet Planet Health*, pp. e360-367.

Gasparrini, A., Guo, Y., Hashizume, M., Lavinge, E., Zanobetti, A., Schwartz, J., . . . Armstrong, B. (2015, May 21). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet*, pp. 369-375.

Giese, G., Nagy, Z., & Rauis, B. (2021). Foundation of Climate Investing: How Equity Markets Have Priced Climate-Transition Risks. *The Journal of Portfolio Management - Novel Risks*.

Goodman, S., Guy, K., Maddox, M., Hansen, V. V., Sending, O. J., & Iselin Németh Winther. (2021). *Climate Change and Security in the Arctic.* The Center for Climate and Security, Council on Strategic Risks, and Norwegian Institute of International Affairs.

Gosselin, P., Campagna, C., Demers-Bouffard, D., Qutob, S., & Flannigan, M. (2022). Health of Canadians in a Changing Climate: Advancing our Knowledge for Action. In P. Berry, & R. Schnitter, *Natural Hazards* (pp. 114-225). Ottawa: Government of Canada.

Groosman, B., Muller, N. Z., & O'Neill, E. (2009). *The Ancillary Benefits from Climate Policy in the United States.* Middlebury: MIDDLEBURY COLLEGE.

Ha, S., Sundaram, R., Buck Louis, G. M., Nobles, C., Seeni, I., Sherman, S., & Mendola, P. (2018, January). Ambient air pollution and the risk of pregnancy loss: a prospective cohort study. *Fertil Steril.*, pp. 148-153.

Hafner, M. (., & Tagliapietra, S. (. (2020). The Geopolitics of the Global Energy Transition. In *Lecture Notes in Energy.* Springer Open.

Haines, A. (2017, April). Health co-benefits of climate action. *The Lancet*, pp. e4-e5.

Hajat, S., & Kosatky, T. (2010). Heat related mortality: a review and exploration of heterogeneity. *Epidemiol Community Health*, pp. 753-760.

Hajdu, T., & Hajdu, G. (2021). Temperature, climate change, and fertility. *GLO Discussion*

Paper, No. 896.

Hallegatte, S., & Dumas, P. (2009). Can natural disasters have positive consequences? Investigating the role of embodied technical change. *Ecological Economics*, pp. 777-786.

Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, 1-26.

Harper, S. L., Edge, V. L., Ford, J., Cunsolo Willox, A., Wood, M., IHACC Research Team, . . . McEwen, S. A. (2015). Climate-sensitive health priorities in Nunatsiavut, Canada. *BMC Public Health*, pp. 1-18.

Hayes, K., Blashki, G., Wiseman, J., Burke, S., & Reifels, L. (2018). Climate change and mental health: risks, impacts and priority actions. *International Journal of Mental Health Systems*.

Health Care Without Harm. (2018). *Safe Haven in the Storm.* Reston: Health Care Without Harm.

Hebbern, C., Gosselin, P., Chen, K., Chen, H., Cakmak, S., MacDonald, M., . . . Lavigne, E. (2023, June 12). *Future temperature-related excess mortality under climate change.* Retrieved from Canadian Journal of Public Health: https://doi.org/10.17269/

Hengge, M., Panizza, U., & Varghese, R. (2023). *Carbon Policy and Stock Returns: Signals from Financial Markets.* International Monetary Fund.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., . . . Zhou, G. (2018). Impacts of 1.5°C of Global Warming on Natural and Human Systems. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. Shukla, . . . T. Waterfield, *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,* (pp. 175-311).

Hoffman, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., & Peisker, J. (2020). A Meta-Analysis of Country-Level Studies on Environmental Change and Migration.

Howard, C., Rose, C., & Rivers, N. (2018). *Lancet Countdown 2018 Report: Briefing for Canadian Policy Makers.* November.

Howard, C., Rose, C., Dodd, W., Kohle, K., Scott, C., Scott, P., . . . Orbinski, J. (2021). SOS! Summer of Smoke: a retrospective cohort study examining the cardiorespiratory impacts of a severe and prolonged wildfire season in Canada's high subarctic. *British Medical Journal Open*, pp. 1-10.

Hsiang, S. M., & Jina, A. S. (2014). *The Casual Effect fo Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones.* Cambridge: National Bureau of Economic Research.

Hsiang, S. M., Meng, K. C., & Cane, M. A. (2011, August 25). Civil conflicts are associated with global climate. *Nature*, pp. 438-441.

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., . . . Houser, T. (2017, June 30). Estimating economic damage from climate change in the United States. *Science*, pp. 1362-1369.

Hsu, K.-W., & Chao, J.-C. (2022). The Impact of Urban Green-infrastructure Development on the Price of Surrounding Real Estate: A Case Study of Taichung City's Central District. *IOP Conference Series: Earth and Environmental Science*.

Hunter, L. M., Luna, J. K., & Norton, R. M. (2015). The Environmental Dimensions of

Migration. *Annual Review Sociology*, pp. 377-397.

Hupp, J., Brubaker, M., Wilkinson, K., & Williamson, J. (2015). How are your berries? Perspectives of Alaska's environmental managers on trends in wild berry abundance. *International Journal of Circimpolar Health*.

Indaco, A., Ortega, F., & Taspinar, S. (2019). *Hurricanes, Flood Risk and the Economic Adaptation of Businesses.* Bonn: IZA Institute of Labor Economics.

Islam, N., & Winkel, J. (2017). *Climate Change and Social Inequality.* New York: United Nations - Department of Economic & Social Affairs.

Javadi, S., & Masum, A. A. (2021). The impact of climate change on the cost of bank loans. *Journal of Corporate Finance*.

Jiang, F., Wei Li, C., & Qian, Y. (2019). *Can firms run away from climate-change risk? Evidence from the pricing of bank loans.*

Kabore, P., & Rivers, N. (2020). *Manufacturing Output and Extreme Temperature: Evidence from Canada.* Ottawa: University of Ottawa.

Kaczan, D. J., & Orgill-Meyer, J. (2019, November 7). The impact of climate change on migration: a synthesis of recent empirical insights. *Climatic Change*.

Karpf, A., & Mandely, A. (2017, February 24). *Does it pay to be green? A Comparative Study of the Yield Term Structure of Green and Brown Bonds in the US Municipal Bonds Market*. Retrieved from SSRN: https://dx.doi.org/10.2139/ssrn.2923484

Keivabu, R. C., Cozzani, M., & Wilde, J. (2023, May). Temperature and Fertility: Evidence from Spanish Register Data. *IZA Institue of Labor Economics*. Bonn, Germany: IZA - Institute of Labour Economics.

Kelly, D. L., & Molina, R. (2023, Novmeber). Adaptation Infrastructure and Its Effects on Property Values in the Face of Climate Risk. *Journal of the Association of Environmental and Resource Economists*, pp. 1405-1438.

Khan, A. E., Scheelbeek, P. F., Shilpi, A. B., Chan, Q., Mojumder, S. K., Rahman, A., . . . Vineis, P. (2014, September 30). Salinity in Drinking Water and the Risk of (Pre)Eclampsia. *PLoS ONE*, p. e108715.

Kinney, P. L., Schwartz, J., Pascal, M., Petkova, E., Le Tertre, A., Medina, S., & Vautard, R. (2015, June). Winter Season Mortality: Will Climate Warming Bring Benefits? *Department of Health and Human Services USA*. Department of Health and Human Services USA.

Kling, G., Volz, U., Murinde, V., & Ayas, S. (2021). The impact of climate vulnerabilty on firms' cost of capital and access to finance. *World Development*.

Klomp, J., & Sseruyange, J. (2021). Earthquakes and Economic Outcomes: Does Central Bank Independence Matter? *Open Economies Review*, pp. 335-359.

Kocornik-Mina, A., McDermott, T., Michaels, G., & Rauch, F. (2015). *Flooded City.* Centre for Climate Change Economics and Policy; Grantham Research Institute on Climate Change and the Environment.

Kotz, M., Kuik, F., Lis, E., & Nickel, C. (2024). Global warming and heat extremes to enhance inflationary pressures. *Communications Earth and Environment*.

Koubi, V., Schaffer, L., Spilker, G., & Böhmelt, T. (2022). Climate events and the role of adaptive capacity for (im-) mobility. *Population and Environment* , pp. 367-392.

Kubik, Z., & Maurel, M. (2016, January). Weather Shocks, Agricultural Production and Migration: Evidence from Tanzania. *The Journal of Development Studies*, pp. 665-680.

Kumar, A., Xin, W., & Zhang, C. (2019, February). Climate Sensitivity and Predictable Returns.

Lafakis, C., Ratz, L., Fazio, E., & Cosma, M. (2019, June). The Economic Implications of Climate

Change. *Moody's Analytics*.

Larcker, D. F., & Watts, E. M. (2019). Where's the Greenium? *Journal of Accounting and Economics*.

Lavigne, E. (2020). *Temperature-related mortality under climate change scenarios in health regions of Canada [Video].* Retrieved from Air Health Science Division of Health Canada. Presented at the NOAAECCC webinar: https://www.youtube.com/watch?v=JD-3rVL_5lY

Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production.

Li, C., Zhang, X., & He, J. (2023, August 31). Impact of Climate Change on Inflation in 26 Selected Countries. *Sustainability*.

Lustgarten, A. (2020). THE GREAT CLIMATE MIGRATION. The New York Times, Pro Publica, Pulitzer Center.

Luthi, S., Fairless, C., Fischer, E. M., Scovronick, N., Armstrong, B., De Sousa Zanotti Stagliorio Coelho, M., . . . Vicedo-Cabrera , A. M. (2023, August 24). *Rapid increase in the risk of heat related mortality.* Retrieved from Nature Communications: https://doi.org/10.1038/s41467-023-40599-x

Lynn, K., Daigle, J., Hoffman, J., Lake, F., Michelle, N., Ranco, D., . . . Williams, P. (2013). The impacts of climate change on tribal traditional foods. *Climate Change*, pp. 545-556.

Maguet, S. (2019). *Public Health Planning for Wildfire Smoke.* Health Canada's Water, Air and Climate Change Bureau.

Mahalingaiah, S., Hart, J. E., Laden, F., Farland, L. V., Hewlett, M. M., Chavarro, J., . . . Misser, S. A. (2016, January 2). Adult air pollution exposure and risk of infertility in the Nurses' Health Study II. *Human Reproduction*, pp. 638-647.

Mardhiori, L., & Ingmar, S. (2009, April). WHEN NATURE REBELS: INTERNATIONAL MIGRATION, CLIMATE CHANGE AND INEQUALITY. PALAISEAU CEDEX, France: ECOLE POLYTECHNIQUE CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE.

Marushka, L., Kenny, T.-A., Batal, M., Cheung, W. W., Fediuk, K., Golden, C. D., . . . Chan, H. M. (2019, February 27). Potential impacts of climate-related decline of seafood harvest on nutritional status of coastal First Nations in British Columbia, Canada. *PLOS ONE*.

Masselot, P., Mistry, M., Vanoli, J., Schneider, R., Iungman, T., Garcia-Leon, D., . . . Gasparrini, A. (2023, March 16). Excess mortality attributed to heat and cold: a health impact assessment study in 854 cities in Europe. *Lancet Planet Health*, pp. e271-e281.

Massey, D. S. (1999, June). International Migration at the Dawn of the Twenty-First Century: The Rolde of the State. *Population and Development Review*, pp. 303-322.

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P., . . . (eds.), T. W. (2019). *IPCC, 2018: Global Warming of 1.5°C.* Intergovernmental Panel on Climate Change.

Mastouri, A., Mendiratta, R., & Giese, G. (2022, October). Corporate Bonds and Climate Change Risk. *The Journal of Portfolio Management*.

Mattais, A., & Nykvist, B. (2020). Understanding the role of green bonds in advancing sustainability. *Journal of Sustainable Finance & Investment*.

McGlade, C., & Ekins, P. (2015, January 5). *The geographical distribution of fossil fuels unused when limiting global warming to 2 °C.* Retrieved from The Open University: https://core.ac.uk/

McGrath, J. (2020, March). Climate, pollution and California's crops. *Nature Food*, p. 153.

McKibbon, W. J., Morris, A. C., Wilcoxen, P. J., & Panton, A. J. (2017, November 30). Climate

Change and Monetary Policy: Dealing with Disruption. *Climate and Energy Economics Discussion Paper*. Washington, DC, USA: The Brookings Institution.
McLeman, R. (2017). *How Will International Migration Policy and Sustainable Development Affect Future Climate-Related Migration?* Migration Policy Institute.
McMichael, A. J., Powles, J. W., Butler, C. D., & Uauy, R. (2007, October 6). Food, livestock production, energy, climate change, and health. *The Lancet*, pp. 1253-1263.
Migali, S., & Scipioni, M. (2019). Who’s About to Leave? A Global Survey of Aspirations and Intentions to Migrate. *International Migration*, pp. 181-200.
Miller, A. S., & Swann, S. A. (n.d.). CLIMATE CHANGE & THE FINANCIAL SECTOR A TIME OF RISKS & OPPORTUNITIES. SSRN.
Mills, J. N., Gage, K. L., & Khan, A. S. (2010, November). Potential Influence of Climate Change on Vector-Borne and Zoonotic Diseases: A Review and Proposed Research Plan. *Environmental Health Perspectives*, pp. 1507-1514.
Missirian, A., & Schlenker, W. (2017, December 22). Asylum applications respond to temperature fluctuations. *Science*, pp. 1610-1614.
Molico, M. (2019, November 19). Researching the Economic Impacts of Climate Change - Implications for monetary policy and financial stability. Ottawa, Ontario, Canada: Bank of Canada.
Mueller, I., & Sfappini, E. (2022). *Climate Change-Related Regulatory Risks and Bank Lending.* Frankfurt am Main: European Central Bank.
Mukherjee, K., & Ouattara, B. (2021). Climate and monetary policy: do temperature shocks lead to inflationary pressures? *Climatic Change*.
Nenonen, S., Koski, A., Lassila, A., & Lehikoinen, S. (2019). Towards low carbon economy – green bond and asset development. *IOP Conference Series: Earth and Environmental Science*.
Network for Greening the Financial System. (2020). *Climate Change and Monetary Policy Initial takeaways.* Banque de France; NGFS Secretariat.
Oberlin, A. M., & Wylie, B. J. (2023). Vector-borne disease, climate change and perinatal health. *Seminars in Perinatology*, 1-7.
Obradovich, N., Migliorini, R., Paulus, M. P., & Rahwan, I. (2018, October 23). Empirical evidence of mental health risks posed by climate change. *Proceedings of the National Academy of Sciences*, pp. 10953-10958.
Ocello, C., Petrucci, A., Testa, M. R., & Vignoli, D. (2014, December). Environmental aspects of internal migration in Tanzania. *Population and Environment*.
Ochuodho, T. O., & Lantz, V. A. (2015, March 13). Economic impacts of climate change on agricultural crops in Canada by 2051: A global multi-regional CGE model analysis. *Environmental Economics*, pp. 113-125.
O'Kelly, B., & Lambert, J. S. (2020, June 15). Vector-borne diseases in pregnancy. *Sage Journals*, pp. 1-27. Retrieved from journals.sagepub.com/home/tai.
Orru, H., Ebi, K. L., & Forsberg, B. (2017). The Interplay of Climate Change and Air Pollution on Health. *Curr Envir Health Rpt*, 504-513.
Pankratz, N. M. (2018, Novmeber 14). Climate Change, Firm Performance & Investor Surprises. Maastricht, The Netherlands: Maastricht University, Department of Finance and European Center for Sustainable Finance (ECCE).
Patz, J. A., Frumkin, H., Holloway, T., Vimont, D. J., & Haines, A. (2014, October 15). Climate Change: Challenges and Opportunities for Global Health. *Journal of the American Medical Association*, pp. 1565-1580.

Peersman, G. (2018). International Food Commodity Prices and Missing (Dis)Inflation in the Euro Area. National Bank of Belgium.

Petrasek MacDonald, J., Harper, S. L., Cunsolo Willox, A., Edge, V. L., & Rigolet Inuit Community Government. (2012). A necessary voice: Climate change and lived experiences of youth in Rigolet, Nunatsiavut, Canada. *Global Environmental Change*.

Pindyck, R. S. (2013). *CLIMATE CHANGE POLICY: WHAT DO THE MODELS TELL US?* Cambridge: NATIONAL BUREAU OF ECONOMIC RESEARCH.

Pinzón, A., Robins, N., McLuckie, M., & Thoumi, G. (2020). *The sovereign transition to sustainability: Understanding the dependence of sovereign debt on nature.* London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, and Planet Tracker.

Portner, H.-O., C, R. D., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegria, A., . . . Rama, B. (. (2022). *IPCC, Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the.* Cambridge: Cambridge University Press.

Quaye, F., Nadolnyak, D., & Hartarska, V. (2018). Climate Change Impacts on Farmland Values in the Southeast United States. *Sustainability*.

Raimi, D. (2021). *Effects of Climate Change on Heat- and Cold-Related Mortality: A Literature Review to Inform Updated Estimates of the Social Cost of Carbon.* Mountain View: Creative Commons.

Raleigh, C., Linke, A., & O'Loughlin, J. (2014, February). Extreme temperatures and violence. *Nature and Climate Change*, pp. 76-77.

Ranasinghe, R., Ruane, A. C., Vautard, R., Arnell, N., Coppola, E., Cruz, F. A., . . . Zaaboul, R. (2021). 2021: Climate Change Information for Regional Impact and for Risk Assessment. In V. P. Masson-Delmotte, *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1767-1926). Cambridge and New York: Cambridge University Press.

Rao, H., Chen, D., Shen, F., & Shen, Y. (2022). Can Green Bonds Stimulate Green Innovation in Enterprises? Evidence from China. *Sustainability*, 14.

Reboredo, J. C., & Ugolini, A. (2020). Climate transition risk, profitability and stock prices.

Reinsborough, M. J. (2003, February). A Ricardian model of climate change in Canada. *The Canadian Journal of Economics / Revue canadienne d'Economique*, pp. 21-40.

Reisinger Walker, E., McGee, R. E., & Druss, B. G. (2015, April). Mortality in Mental Disorders and Global Disease Burden Implications: A Systematic Review and Meta-analysis. *Journal of the American Medical Association Psychiatry*, pp. 334-341.

Ren, P., Cheng, Z., & Dai, Q. (2024). Can green bond issuance promote enterprise green technological innovation? *The North American Journal of Economics and Finance*.

Reuveny, R., & Moore, W. H. (2009, September). Does Environmental Degradation Influence Migration? Emigration to Developed Countries in the Late 1980s and 1990s. *Social Science Quarterly*, pp. 461-479.

Revesz, R. L., Howard, P. H., Arrow, K., Gouder, L. H., Kopp, R. E., Livermore, M. A., . . . Sterner, T. (2014, April 10). Improve economic models of climate change. *Nature*, pp. 173-175.

Rigaud, K., Kanta, A. d., Jones, B., Bergmann, J., Clement, V., Ober, K., . . . Midgley, A. (2018). *Groundswell: Preparing for Internal Climate Migration.* Washington: The World Bank.

Riosmena, F., Kuhn, R., & Jochem, W. C. (2017, February). Explaining the Immigrant Health

Advantage: Self-selection and Protection in Health-Related Factors Among Five Major National Origin Immigrant Groups in the United States. *Demography*, pp. 175-200.

Rodrigues, P. M., Salish, M., & Salish, N. (2024, January 8). Saving for sunny days: The impact of climate (change) on consumer prices in the euro area.

Ryti, N. R., Guo, Y., & Jaakkola, J. J. (2016, January). Gloval Association of Cold Spells and Adverse Health Effects: A Systematic Review and Meta-Analysis. *Environmental Health Perspectives*, pp. 12-22.

Sawyer, D., Ness, R., Clark, D., & Beugin, D. (2020). *Tip of the Iceberg: Navigating the Known and Unknown Costs of Climate Change for Canada.* Canadian Institute for Climate Choices.

Sawyer, D., Ness, R., Lee, C., & Miller, S. (2022). *Damage Control: Reducing the costs of climate impacts in Canada.* Canadian Climate Institute.

Schuler, P., Oliveira, L. E., Mele, G., & Antonio, M. (2019). *Fiscal Policies for Development and Climate Action - Managing the Fiscal Risks Associated with Natural Disasters.* World Bank.

Schutte, S., Vestby, J., & Jørgen Carling, H. B. (2021). Climatic conditions are weak predictors of asylum migration. *Nature Communications*.

Scotta, D., Hall, C. M., & Gössling, S. (2019, June 05). Global tourism vulnerability to climate change. *Annals of Tourism Research*, pp. 49-61.

Segal, T. R., & Giudice, L. C. (2022, August). Systematic review of climate change effects on reproductive health. *Fertility and Sterility*, pp. 215-223.

Seltenrich, N. (2015, November). Between Extremes Health Effects of Heat and Cold. *Environmental Health Perspectives*, pp. A275-A280.

Seltzer, L., & Starks, L. T. (2022). *Climate Regulatory Risks and Corporate Bonds.* Federal Reserve Bank of New York.

Shannon, K. L., Kim, B. F., McKenzie, S., & Lawrence, R. S. (2015). Food System Policy, Public Health, and Human Rights in the United States. *Annual Review of Public Health*, pp. 151-173.

Skidmore, M., & Toya, H. (2002, October). DO NATURAL DISASTERS PROMOTE LONG-RUN GROWTH? *Economic Inquiry*, pp. 664-687.

Slama, R., Bottagisi, S., Solansky, I., Lepeule, J., Giorgis-Allemand, L., & Sram, R. (2013, November). Short-Term Impact of Atmospheric Pollution on Fecundability. *Epidemiology*, pp. 871-879.

Smith, D. M., Sales, J., Williams, A., & Munro, S. (2023). Pregnancy intentions of young women in Canada in the era of climate change: a qualitative auto-photography study. *BMC Public Health*, 1-13.

Smulders, S., Toman, M., & Withagen, C. (2014). Growth theory and 'green growth'. *Oxford Review of Economic Policy*, pp. 423-446.

Springmann, M., Godfray, H. C., Rayner, M., & Scarborough, P. (2016, April 12). Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences*, pp. 4146-4151.

Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Godfray, H. C., Gollin, D., . . . Scarborough, P. (2016, May 7). Global and regional health effects of future food production under climate change: a modelling study. *The Lancet*, pp. 1937-1946.

Springmann, M., Wiebe, K., Mason D'Croz, D., Sulser, T. B., Rayner, M., & Scarborough, P. (2018, October). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *The Lancet*, pp. e451-e461.

Stern, N. (2006). Stern Review: The Economics of Climate Change. *Cambridge University Press*.

Stern, N. (2013). The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models. *Journal of Economic Literature*, pp. 838-859.

Strobl, E. (2008). *The Economic Growth Impact of Hurricanes: Evidence from US Coastal Counties.* Bonn: Institute for the Study of Labor.

Sun, C., Xu, J., & You, Y. (2022, March). Physical Climate Change Exposure and Stock Returns.

Teasdale, N., & Panegyres, P. K. (2023). Climate change in Western Australia and its impact on human health. *The Journal of Climate Change and Health*.

Turner, M. C., Jerrett, M., Pope, C. A., Krewski, D., Gapstur, S. M., Diver, W. R., . . . Burnett, R. T. (2016, May 15). Long-Term Ozone Exposure and Mortality in a Large Prospective Study. *American Journal of Respiratory and Critical Care Medicine*, pp. 1134-1142.

USGCRP. (2017). *Climate Science Special Report: Fourth National Climate Assessment, Volume I.* Washington, DC, USA: U.S. Global Change Research Program.

Veronis, L., & McLeman, R. (2014). Environmental influences on African migration to Canada: focus group findings from Ottawa-Gatineau. *Poulation Environment*, pp. 234-251.

Villarreal, M. L., Haire, S. L., Iniguez, J. M., Cortes Montano, C., & Poitras, T. B. (2019). Distant neighbors: recent wildfire patterns of the Madrean Sky Islands of southwestern United States and northwestern Mexico. *Fire Ecology*, 1-20.

Wahl, E. R., Zorita, E., Trouet, V., & Taylor, A. H. (2019). Jet stream dynamics, hydroclimate, and fire in California from 1600 CE to present. *Proceedings of the National Academy of Sciences*, 5393-5398.

Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., . . . Colstello, A. (2018, February 10). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *The Lancet*, pp. 581-630.

Way, R., Ives, M. C., Mealy, P., & Farmer, J. D. (2022, September 21). Empirically grounded technology forecasts and the energy transition. *Joule*, pp. 2057-2082.

Weber, M. H. (2003). A Regional Analysis of Climate Change Impacts on Canadian Agriculture. *Canadian Public Policy - Analyse de Politiques*, pp. 163-180.

Wesselink, A. K., Wang, T. R., Ketzel, M., Mikkelsen, E. M., Brandt, J., Khan, J., . . . Hatch, E. E. (2022, January). Air pollution and fecundabiity: Results from a Danish preconception cohort study. *Paediatr Perinat Epidemiol*, pp. 57-67.

Willers, S. M., Jonker, M. F., Klok, L., Keuken, M. P., Odink, J., van den Elshout, S., . . . Burdorf, A. (2016). High resolution exposure modelling of heat and air pollution and the impact on mortality. *Environment International*, 89-90, 102-109.

World Bank. (2023). *World Development Report 2023: Migrants, Refugees and Societies.* Washington.

World Health Organization. (2013). *Review of evidence on health aspects of air pollution - REVIHAAP Project.* Copenhagen: WHO Regional Office Europe.

Yang, D. (2008). Coping with Disaster: The Impact of Hurricanes on International Financial Flows, 1970-2002. *The B.E. Journal of Economic Analysis & Policy*, p. Article 13.

Yang, Y., Huang, C., & Zhang, Y. (2023). *Decomposing Climate Risks in Stock Markets.* International Monetary Fund.

Yu, S., Cai, C., Zhang, S., & You, P. (2022, August 11). Does climate change affect enterprises' ability to sell their products? *Frontiers in Ecology and Evolution*.

Zeppel, M. J., Wilks, J. V., & Lewis, J. D. (2014, June 13). Impacts of extreme precipitation and seasonal changes in. *Biogeosciences*, pp. 3083-3093.

Zeuli, K., Nijhuis, A., Macfarlane, R., & Ridsdale, T. (2018, October 24). The Impact of Climate Change on the Food System in Toronto. *Environmental Research in Public Health*, pp. 1-15.

Zhao, M., Huang, X., Kjellstrom, T., Lee, J. K., Otto, M., Zhang, X., . . . Cai, W. (2022). Labour productivity and economic impacts of carbon mitigation: a modelling study and benefit–cost analysis. *Lancet Planet Health*, pp. e941-948.

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