Actuarial Considerations Around Climate-Related Risks on Social Security

Climate Risk Task Force
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This paper was prepared by the Climate Risk Task Force of the International Actuarial Association (IAA) in collaboration with the International Social Security Association (ISSA).

The IAA is the worldwide association of professional actuarial associations, with several special interest sections and working groups for individual actuaries. The IAA exists to encourage the development of a global profession, acknowledged as technically competent and professionally reliable, which will ensure that the public interest is served.

The ISSA is the world’s leading international organization for social security institutions, government departments and agencies. The ISSA promotes excellence in social security administration through professional guidelines, expert knowledge, services, and support to enable its members to develop dynamic social security systems and policy throughout the world.

The role of the Climate Risk Task Force is to deliver on the Statement of Intent for IAA Activities on Climate-related Risks as adopted by Council on 7 May 2020.

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Executive Summary

Climate change is a global issue that poses significant risks worldwide. To mitigate its impact, it is imperative that experts from different fields collaborate and work together. This collaboration is crucial in developing science-based solutions that can help people and organizations cope with its potential consequences.

Actuaries are contributing to the understanding and implications of climate-related risks across a wide range of actuarial practice areas and countries. These actuarial contributions can also help inform risk management, policy recommendations and the decision-making of regulators.

This paper builds on the International Actuarial Association (IAA) climate risk paper series and is focused on how climate-related risks can impact social security. In particular, it is focused on the way social protection benefits are funded and designed, acknowledging that climate-related risks are likely to impact demographic and socioeconomic assumptions, in addition to assumptions regarding investment returns and financial market stability discussed in earlier papers. Actuaries involved in social security analysis, projections and valuations rely on a range of demographic, socioeconomic and investment-related assumptions that are being impacted by climate-related physical and transition risk. Thus, the consideration of practical scenarios is increasingly important for medium- and long-term projections. There are many uncertainties associated with the assumptions and scenarios discussed in this paper, particularly those associated with the responses of policymakers, financial markets, and the environment to climate risk. While it is challenging to estimate the probabilities of climate scenarios, there is still great value in these scenarios and risks being quantified through projections and valuations to better inform decision-making.

Although the focus of this paper is mainly on considerations for incorporating climate risk in actuarial projections, the role of social security actuaries as it relates to climate risk is much broader. It is important for actuaries to keep in mind that the ultimate goal is to work with other social security professionals to help ensure the design of climate-resilient and sustainable social security programs. An important first step to reach this goal is to enhance qualitative and quantitative analysis for incorporating climate risk in actuarial projections. In this paper we therefore primarily focus on how climate change affects three major assumption classes that are key to social security actuarial projections: demographic, economic and investment-related assumptions. In the Appendix we also illustrate different scenarios and the methods behind them, so that readers can easily adapt them to their own system.

To some extent, several economic and financial analyses address existing uncertainty by proposing plausible scenarios following economic and market equilibriums regarding the interaction between policymakers, financial and economic dynamics, and environmental responses. However, in most cases these analyses would benefit from solid probabilistic support. The authors of this paper hope that improved data, further research, and exploration of plausible scenarios will continue enhancing decision-makers’ understanding of the economic and financial costs associated with climate-related risks.
1. Introduction and Context

This paper is the seventh in the series of papers developed by the Climate Risk Task Force (CRTF) and published by the International Actuarial Association (IAA) on climate-related risks. This paper is a joint publication by the IAA and International Social Security Association (ISSA). Its main goal is to highlight the key effects of climate-related risks and appropriate climate scenarios that actuaries may keep in mind when working on social security and social insurance programs.

As in the previous papers of this series, readers are advised to read earlier IAA publications which provide useful information:

- Paper 1: Importance of Climate-Related Risks for Actuaries
- Paper 2: Introduction to Climate-Related Scenarios
- Paper 3: Climate-Related Scenarios Applied to Insurers and Other Financial Institutions
- Paper 4: Application of Climate-Related Risk Scenarios to Asset Portfolios
- Paper 5: Climate-Related Disclosures and Risk Management: Standards and Leading Practices
- Paper 6: The Climate Change Adaptation Gap: An Actuarial Perspective
- A joint IAA–Intergovernmental Panel on Climate Change (IPCC) paper titled Climate Science: A Summary for Actuaries – What the IPCC Climate Change Report 2021 Means for the Actuarial Profession.

As global temperatures continue to rise, climate change is becoming an increasingly pressing issue that touches many aspects of human life. One area that is particularly vulnerable to the risks of climate change is social security. Social security differs from country to country. It usually refers to a system of government programs that provide financial support to individuals due to, for example, retirement, disability, or other reasons.

These programs are wide-ranging and can include retirement pensions, disability benefits, employment insurance and work injury benefits, as well as healthcare coverage and disaster relief. Depending on the country or even the region we consider, social security systems can provide not only financial but also non-financial benefits, such as housing, medicine, and food. Social security is meant to provide a safety net for those in need, and it is subject to a range of climate-related risks that could threaten its ability to function effectively, as well as its sustainability and inclusiveness.

The important climate-related risks associated with social security are the acute physical risks such as extreme weather events, chronic physical risks such as increasing temperatures and sea-level rise, and the transition risk of moving to a low-carbon economy. Extreme weather events such as hurricanes, floods, wildfires, and other disasters can cause widespread damage and disruption, leading to loss of life, property damage and economic hardship. In the aftermath of these events, some social security systems may be overwhelmed by the demand for assistance from those affected. Depending on the type of support provided by the social security system, the costs of responding to physical risks can also strain social security budgets, leaving less funding available for other types of support. Transition risk can have widespread impacts, ranging from systemic changes affecting the whole economy and industries to specific impacts on the returns of assets and investments within social security and pension plans. Both physical and transition risks have implications for labour markets, and therefore a proportion of the working and non-working population. Consequently, both acute and chronic events may impact both the benefits of social security programs (i.e., their benefit.
payment side) and their financing (i.e., the contribution side). These are key considerations for social security and pensions actuaries.

Moreover, climate change affects in various ways the assumptions actuaries use when providing long-term projections. These assumptions may be affected by the physical, and transition aspects of climate risk. As a result, the modelling of these aspects in the future is subject to considerable uncertainty.

In addition to considering the financial impact on social security, we also discuss some possible consequences of climate change for the sustainability and inclusiveness of different social security systems. Related to those changes we also give possible alternative adaptive measures that governments might consider appropriate to mitigate the effects of climate change on sustainability and equity.

The body of this paper highlights the aspects actuaries may want to consider when they design relevant scenarios to reflect climate-related risks and opportunities in their social security analyses and advice. Please refer to the Appendix in this paper, as well as in Paper 2 (Introduction to Climate-Related Scenarios) and Paper 3 (Climate-Related Scenarios Applied to Insurers and Other Financial Institutions) in the CRTF paper series for information about how scenarios can be constructed using these considerations.

1.1. Purpose and Intended Audience

In this paper we primarily focus on how climate change affects three major assumption classes that are key to social security actuarial projections: demographic, economic and investment-related assumptions. Enhancing qualitative and quantitative analysis of how climate could affect actuarial projections is an important step in the ultimate goal of designing climate-resilient and sustainable social security programs.

There is a significant amount of uncertainty surrounding the potential impacts given that climate-related risks rely heavily on the transition path to a greener economy. The impacts will therefore depend on the timing and pace of this transition. Technological advances and mitigation policies can also have a strong influence on climate risks in the future and in the short term as they are also drivers of the timing and pace of the transition, which, in turn, are driven by technological advances and mitigation policies.

In considering social security systems, we also discuss some possible consequences of climate change for sustainability and inclusiveness, as introduced in the previous section. As mentioned above, we give possible alternative adaptive measures that governments might consider appropriate to mitigate the effects of climate change on sustainability and equity.

This paper is intended to serve a broad audience. It is expected that it will be of interest to experts working in social security or pensions-related fields. The goal is, in particular, to address the increased need for actuaries to consider climate-related risks in their current social security-related roles. This paper should also be of interest to a broader set of stakeholders and policymakers who are involved in social security matters: they may benefit from some simplified tables on risk analysis and possible scenarios.

1.2. What Do We Mean by “Social Security”?  

Usually, “social security” refers to a government-run program that provides social services or financial assistance and support to individuals at various stages of their lives. The coverage is usually quite broad, and eligibility is often tied to residence, income level and/or tax remittances (payroll or otherwise).

It ensures that eligible individuals and their families have access to a safety net or social services to help them meet their basic needs when they face financial hardship due to adverse
events or circumstances (e.g., disability, sickness, unemployment) as well as certain life events (e.g., retirement, death). Social security programs can also provide benefits to widows and children of beneficiaries, as well as healthcare services including universal health care (UHC).

In this paper we will not consider a particular social security system, nor will we define the type of benefits provided nor the way these benefits are financed by the system. The idea is to provide generic information that can be applied to most social security systems.

Social security systems are often characterized by their financing method: fully funded, partially funded or pay-as-you-go.

A fully funded social security program refers to a system where the benefits paid to beneficiaries are sourced mainly from the revenue of the trust fund (e.g., fully invested defined contribution plans).

A partially funded social security program is a program where only part of the benefits are financed by current workers’ contributions.

A pay-as-you-go social security program is a type of retirement program in which usually current workers pay contributions into the system, which are then used to provide benefits to current beneficiaries. The benefits paid out to beneficiaries depend on the amount of money contributed by workers generally over their lifetime.

In other words, under a pay-as-you-go system, current workers finance the benefits of beneficiaries today, and future generations of workers will finance the benefits of the beneficiaries of the future. This is different from a fully funded social security system, in which each worker would save a portion of their income throughout their career to pay for their own social security benefits.

This paper offers actuaries and technicians dealing with actuarial valuations on social security many different aspects of climate-related risks that they may need to consider. The goal is to allow social security experts to choose which of the proposed effects are relevant to the plan or program they are working with.

Climate-related risks affect social security programs in different ways depending on how the program is financed. For a pay-as-you-go program, changes in demographic and economic assumptions can have a significant impact, as population and economic growth heavily influence the financing source of the system. For a fully funded program any change in economic and investment assumptions can substantially affect the coverage of the system. Furthermore, changes in investment assumptions and practices may increase the risk exposure of existing infrastructure investments.

The following sections provide a more comprehensive explanation of how climate-related risks can be transferred to social security plans worldwide.

1.3. Glossary

Readers may wish to consult the Glossary of Defined Terms Used in IAA Climate-Related Risk Publications for definitions of terminology that may be used differently in a climate change context than in the typical usage in actuarial practice.

2. Main Climate-Related Risks that Affect Social Security Programs

There are several climate-change-related risks that can affect social security programs, including:

- *Financial impacts of climate-related events*: Extreme weather events, such as droughts, hurricanes, floods, wildfires, and coastal inundation, can damage infrastructure, disrupt
supply chains, engulf residential or cultivated lands, and cause financial losses, which can impact the financial stability of social security programs. In the long run, gradual changes in climate may have similar impacts, as regions and even whole countries may suffer financial losses from events such as rising sea levels or persistent droughts. It should also be noted that some positive outcomes may arise. Damaged infrastructure could lead to relocation, which incurs financial losses in the short term, but can be considered an opportunity for investment that could potentially lift long-term productivity.

- **Health impacts**: Climate change can lead to more frequent and severe extreme weather events, and vector-borne diseases and pandemics. All these risk factors present uncertainties that can exacerbate health problems for vulnerable populations, such as children, older adults and people with low income or disabilities. This can increase demand for health and social services, which can strain social security programs.

- **Migration and displacement**: Climate change can result in population displacement and migration (on a county, state, or country basis), which can strain social security programs. Regions with an increasing population will likely experience a higher demand for social security coverage, while areas with depopulation will see a reduction in social security financing.

- **Economic impacts**: Climate change can lead to economic disruptions, such as reduced productivity in certain sectors, increased energy costs and increased insurance premiums. These impacts can affect employment rates, wages and other economic factors that influence social security programs.

- **Regulatory and policy impacts**: Climate change can lead to legislative actions that can affect the social security system (e.g. adjustments to scopes and levels of benefits, contribution and tax rates, or retirement ages).

To address these risks, social security programs need to be designed to be resilient to the impacts of climate change and take into account the needs of vulnerable populations.

In cases of existing social security programs, there is a need to consider the above risks when making projections and long-term valuations. In this context, the ISSA–ILO (International Social Security Association–International Labour Organization) Guidelines on Actuarial Work for Social Security include a section that provides useful guidance on risk management practices, highlighting the importance of risk identification, measurement, and mitigation. The section also includes a guideline on actuarial input into the understanding of catastrophic risk, which is quite relevant in the case of climate-related risks.

This paper mainly presents the downside of the impacts discussed above. This is especially true for demographic impacts and damage related to natural disasters or sea-level rise (where applicable). It is possible to find some upsides for climate-change-related risks when studying transition risk. For example, the investments needed to implement an efficient transition may be expected to somewhat mitigate negative impacts or potentially even boost the employment rate, productivity, and gross domestic product (GDP).

### 3. Making Assumptions for Social Security Projections

Long-term projections of social security plans are evaluations of the financial health and sustainability of a country’s social security program(s) over an extended period typically spanning several decades into the future. They involve analyzing trends in such areas as demography (birth rate, mortality, migration), the economy (economic growth, inflation, labour force, wages) and investments (risk and returns), to assess the system’s ability to meet its obligations in terms of providing promised benefits (e.g., retirement, disability, and survivorship benefits).
Long-term projections are crucial for policymakers and administrators to anticipate potential challenges and develop strategies to ensure the long-term financial sustainability of the social security plan. These projections can help identify potential funding shortfalls, demographic shifts that impact the ratio of workers to beneficiaries, changes in life expectancy, or adjustments needed to maintain an adequate level of benefits or to restore financial sustainability.

Long-term projections enable governments to make informed decisions about adjusting contribution levels, retirement age, benefit formulas, investment strategies and other aspects of the social security system to address any predicted imbalances and secure its sustainability.

Actuaries have an important role to play in performing and adequately communicating these long-term projections to decision-makers. The ISSA–ILO Guidelines on Actuarial Work for Social Security highlight the importance of actuarial input in social security work and provide many examples of how actuaries, social security professionals and stakeholders can work together in the design, management, financing, and provision of social security benefits. They also include extensive guidance on performing actuarial valuations and long-term projections for social security programs.

To perform a long-term projection for a social security plan, several assumptions are typically needed. These may include:

- **Mortality and morbidity rates**: Assumptions about mortality and morbidity are needed to estimate the length of time for which an individual would receive benefits. Mortality and morbidity rates can vary based on factors such as age, gender, and health status.

- **Other demographic factors**: Assumptions about the birth rate and immigration rates are necessary as these factors can impact the future population and the financial stability of the social security system.

- **Inflation rate**: An assumption about the future inflation rate is required. Inflation affects the indexing of benefits and their purchasing power in the future.

- **Employment rates**: Assumptions about the future employment rates are required. Employment rates impact the number of contributors to the social security system and the amount of revenue generated. Employment rates can also have an impact on benefit eligibility and levels depending on the plan provisions.

- **Capital markets**: For systems that rely on investment income as a type of financing, long-term capital market assumptions are required for different types of assets in order to project the value of invested assets.

- **Legislative changes**: Assumptions may also need to be made about future legislative changes to the social security system. These changes could include adjustments to the scopes and levels of benefits, contribution and tax rates, retirement ages or other important factors.

Variations for factors including economic conditions, events, regulation, and policy can lead to a range of outcomes and impact the valuation result.

In this paper, we consider these factors as well as the interactions among the factors. For example, demographic drivers could lead to changes in the inflation and economic factors. One key consideration for actuaries is also the modelling complexity to capture the impacts from these considerations and their dependencies.

It is important to note that climate-related events affect different social groups unevenly and can have both positive and negative impacts. Unfortunately, the most vulnerable members of society, such as children, older adults and those with low income or disabilities, tend to be the ones most negatively impacted. It needs to be emphasized that certain positive and negative
effects on the sustainability of a social security program cannot be considered as fully balancing each other out, as society may not find it acceptable to net out the impacts. For instance, if changes to the program benefit the wealthy at the expense of the poorest, this may not be seen as a fair trade-off. Therefore, it is crucial to consider both the technical aspects and the social implications when evaluating the sustainability of a social security program within an ESG (environmental, social, and governance) framework. Such considerations require the expertise and professional judgment of actuaries.

3.1. Demographic Issues

This section investigates demographic issues arising due to climate-related risks and implications for making social security projections. The aim of this section is to explore ways in which actuaries can allow for climate-related demographic risks when making assumptions or developing scenarios for social security projections.

Broadly, as introduced earlier, changes in climate-related risks impact human health through heightened physical risks (directly from the increased frequency and severity of extreme events, and indirectly from the gradual increase in temperatures, sea levels, ocean acidity and air pollution). Physical risks may also have second-order impacts on coastal erosion, and food and water supply. Climate-related risks also have broader impacts on social factors; for example, from a slow transition to a low-carbon economy. These tend to have socioeconomic impacts on the population’s overall health, safety, and quality of life, having implications for birth rates, mortality, and migration. Finally, the combination of these impacts translates to health impacts, differing by age, gender, and co-morbidities.

Demographic factors are key to projecting social security, from both a sufficiency and sustainability standpoint, and therefore it is important to consider the climate-related risk implications. Three factors are discussed in this section, separately and with consideration to their interaction: birth rate, mortality, and migration. For each factor, two angles are explored: how the factor impacts social security projections (in the context of different frameworks as introduced in the previous section), and how exposure to climate-related risks will impact the factor and its interactions.

3.1.1. Birth Rate

Future fertility patterns are a key determinant of future population size, which in turn impacts the economy and society through changes in the size and distribution of the workforce. Forecasts of global population indicate that the population is expected to peak before 2100, with different countries having different expected timing of the population peak, which is largely driven by the trajectory of fertility. Related issues around the ageing population can have significant implications for the work force and social security. Before considering the climate-related drivers, it is important to consider the implications of birth rate for social security.

The social security considerations around changes in birth rate differ depending on the social security framework. To illustrate, two contrasting examples are considered in detail.

For example, in a social security retirement system that is closer to pay-as-you-go, all else being equal, changes in birth rate directly impact the adequacy or affordability of the system for the current working population and for future generations. Shifts in the working to non-working ratio and a smaller population in the future may exacerbate issues around the sufficiency of social security.

One important factor to consider under this framework is the “old-age dependency ratio,” defined as the ratio of retirees to workers. As the birth rate falls, this ratio increases, making social security financing more difficult.
For a fully funded social security retirement system, given that there is a stronger link between contributions and benefits, a change in birth rate on its own has little impact on the system’s sustainability, though there may be related second-order impacts.

These kinds of implications can be generalized for social security overall. The next step is to consider climate drivers’ impacts on birth rate. It is worth noting, in the wider global context, that fertility is falling. In academic literature, it is widely accepted that population growth is a factor in the growth of greenhouse gases (GHGs), and directly contributes to the increase in climate-related risks. In some extreme examples, there are schemes that offer to offset carbon footprints through accepting donations which fund contraceptives. Studies show that an increased awareness of climate and environmental impacts has driven decreases in birth rate. Therefore, it is likely that the declining birth rate projections will continue to be exacerbated by climate-related concerns, and thus have implications for the future workforce and social security financing.

Second-order impacts from climate-related risks on birth rate arise through volatility in the economy from transition impacts, and uncertainty around physical impacts (temperatures rising, air pollution, food shortages, sea levels rising). There are increasing effects of global climate change on food supply through drought, floods, and heatwaves. The economic and transition impacts are likely to impact practical considerations around fertility, whereas the extensive physical ramifications from climate-related risks may have implications for health issues impacting fertility. Both factors can further decrease fertility (and/or increase infant mortality), with an implication that the future workforce will decrease.

An important factor for actuaries to consider when looking to understand future social security projections is the impact of migration on birth rate. While Section 3.1.3 delves into further detail around climate change and the impact of migration on social security, earlier research shows migration has an impact on birth rates, and differences in fertility arise based on the mothers’ birth places. Actuaries who are looking to forecast social security sufficiency also need to consider the possible changes in government policy offset by the impact from direct and indirect climate-related considerations.

### 3.1.2. Mortality Rate and Morbidity Impacts

As defined in the Introduction, “social security” usually refers to a system of government programs that provide financial support to individuals at various stages of their life, with coverage tied to age, disability, or other factors. Therefore, mortality changes and shifts in morbidity will impact the duration of financial support at an individual level, and the pattern of payments in the aggregate.

Some social security systems globally have considered and even established a link between retirement age and life expectancy. This directly motivates a better understanding of the impact of climate-related risks on mortality to inform assumptions for social security projections.

In addition to retirement and pensions, changes in mortality and morbidity due to climate-related risks pose additional considerations for actuaries working in social security from a disability income and support perspective. Research has indicated there may be long-term health implications, particularly post-disasters, and these implications can vary depending on the subset of the population. For example, studies have indicated that more vulnerable subgroups, including children and people living with disability, may be more impacted by the risks presented through climate change, regardless of whether these are event-based or slow-moving changes. Therefore, actuaries working in social security and disability income may consider the mortality and morbidity implications for subgroups of the population differently. For
morbidity both incidence (changes in the proportion of the population who require disability income support) and recovery (duration of support required) will need to be assessed separately. Actuaries may wish to consider the long-term implications of the changes in mortality and morbidity, and the increased uncertainty arising from climate-related risks.

As part of understanding the impact of climate-related risks on health, it is important to acknowledge the challenges around attribution as conclusively determining whether deaths or hospitalizations are climate-related is not always straightforward. One of the key challenges around attribution is the volatility over time introduced by climate-related risks. Impacts from climate-related risks tend to vary depending on the severity and frequency of extreme events, which exacerbates the challenges around attribution.\(^{17}\) In addition, there are typically co-morbidities and time lags that can further mask and distort the attribution exercise.

Events related to climate change and having an impact on mortality and morbidity can be grouped as short-term, long-term and second order. Examples of short-term events are wildfires, floods, and heatwaves. Examples of long-term events are the general rise in temperatures and sea levels. Examples of second-order events are food shortages, water insecurity and mental health challenges.

Table 1 captures only a small subset of examples in which climate-related risks can impact mortality and morbidity. The existing literature and research show there are significant variations in mortality incidence and morbidity implications by age.\(^{18}\) For social security projections, actuaries may wish to consider the exposure to these events, longer-term risks, and second-order impacts. Methods including compositional data analysis have also been used to model and forecast healthy life expectancy from a longevity perspective.\(^{19}\) Consideration of healthy life projections will be useful in understanding the implications for long-term care costs, and the potential trajectory of these costs. From a social security standpoint, a robust government social security plan and well-funded private pensions market can significantly contribute to ensuring positive outcomes for the population affected by increased morbidity due to climate-related risks.

Given the climate-related impacts on disability income and pensions, the projection of healthy life years becomes increasingly important for social security actuaries to consider. While life expectancy projections have been improving over the past few decades, recent seminal literature has suggested the improvements may be slowing down.\(^{20}\) Research on healthy life expectancy (HLE) projections has been emerging, with results indicating there are key differences between countries.\(^{21}\) Climate-related risks also impact geographies differently, and therefore are a key factor when social security actuaries are considering HLE projections. A recent UK study postulates that the increase in life expectancy may not lead to extended working lives due to changes in health and job opportunities.\(^{22}\) This paper projected the gap between healthy working life expectancy (HWLE) and the life expectancy at each age and found that the gap between HWLE and life expectancy is forecasted to increase. Understanding the factors relating to HWLE is key for social security projections.

A related consideration to projecting HLE and HWLE is unemployment. With climate risk driving changes in HLE and HWLE, actuaries may wish to consider the implications for the broader labour market and the long-term economic implications driven by changes in HLE. There is evidence that climate change and other forms of environmental degradation have negatively impacted work productivity (e.g., extreme weather impacting working hours and productivity\(^{23}\)) The trade-off between climate impacts on employment and productivity and adaptation measures could also impact the social security outcome, which may differ by subgroups of the population.

The next section explores climate-triggered migration; however, migration may indeed also be driven by indirect climate impacts on HWLE. In a similar vein, the Network for Greening the Financial System (NGFS) scenarios\(^{24}\) also include unemployment as a macroeconomic factor...
that is impacted by climate-related risks through carbon prices and interest rates. We elaborate on economic issues in Section 3.2.

**Table 1. Examples of Sources of Mortality/Morbidity Impact**

<table>
<thead>
<tr>
<th>Source of Mortality/ Morbidity Impact</th>
<th>Event-based triggers</th>
<th>Long-term changes</th>
<th>Second-order changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact on mortality/ morbidity</td>
<td>Wildfires: Impact of one-off events driven by climate risks can be adverse for mortality. Impacts differ by location and socioeconomic environment of countries. However, with the increase in wildfires, there is a more direct climate change risk. Air quality is the most significant environmental cause of deaths, which does not depend on socioeconomic level.</td>
<td>Temperature: Empirical studies show that increases in temperature (particularly in the range of temperature) increase mortality, particularly for older parts of the population. In the UK, studies show that gradual increases in temperature have implications for mortality through increases in cardiovascular and respiratory conditions, as well as in mental health complications. There are also offsetting impacts through fewer winter deaths in the older population. Some studies suggest the initial reductions in deaths due to milder winters are expected to be outweighed by increases in heat-related mortality. There are potential implications for mental health, where studies show a correlation between temperature change and violence, which can also impact mortality and morbidity.</td>
<td>Vector-borne diseases: • Location-based • Research into these impacts and attribution is in its infancy. Food shortages: Changes in temperature and sea levels drive changes in crop yields and fish populations</td>
</tr>
<tr>
<td>Impact on mortality/ morbidity</td>
<td>Heatwaves: Extremes in temperature can trigger adverse health responses from people with pre-existing conditions, which may increase mortality in the short term, and may increase the proportion of unhealthy lives requiring social security support.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact on mortality/ morbidity</td>
<td>Sea-level increases: These can be considered direct (drowning, as a result of flooding and cyclones) or indirect effects on human health.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact on mortality/ morbidity</td>
<td>Vector-borne diseases:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact on mortality/ morbidity</td>
<td>Food shortages:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Considerations for social security**

- Pay-as-you-go: sufficiency/surplus problems
- Fully funded: determining the level of contributions

- Volatility of first-order impact, and high interactions with co-morbidities (cancers, cardiovascular diseases)
- Implications for labour force migration

- Slower moving risks often have early warning signs. People living in vulnerable areas may choose to relocate, thus impacting the labour force migration, as well as the mortality of those who stay.

- Interactions with migration and changes in labour force, where migration includes international as well as internal.
Ultimately, mortality and morbidity impact from climate risks do not affect the population equally, and disparities exist between different segments of socioeconomic classes. The research paper Mortality by Socio-economic Class and Its Impact on the Retirement Schemes: How to Render the Systems Fairer? explores the impact on retirement schemes with different mortality by socioeconomic class. In a similar vein, actuaries considering social security implications from climate-related risks could consider the mortality and morbidity impacts on subgroups of the population. There is also the potential for favourable mortality or morbidity impacts to arise, which may offset some of the increase in mortality risk in the short term. Table 1 briefly indicates an example of reduction in mortality from cold-weather-related winter deaths, which could offset some of the higher mortality arising from exposure to climate-related risks. The time horizon of the projection is also a key factor when considering the implications of climate-related risks for mortality, as increases in short-term mortality may be offset by decreases in mortality in the future or decreases in disabled-life mortality. These interactions have different ramifications for a social security system and will lead to different decisions.

Finally, the sustainability of a given social security program cannot always be looked at in isolation, as it’s financing often depends on the government’s fiscal position and priorities. For example, climate-related increases in morbidity and/or in gaps between HWLE and life expectancy could put pressure on how governments manage their tax revenues and financing decisions.

3.1.3. Migration

The United Nations (UN) International Organization for Migration estimates that there could be as many as 1 billion climate change migrants in the next 30 years. Similarly, the World Bank’s Groundswell report concludes that climate change is an increasing driver of migration and could force 216 million people to migrate within their country, and amid this, natural disasters force an average of 21.5 million people from their homes around the world each year, according to the UN High Commissioner for Refugees. Shifts in the population inevitably drive changes in the labour force. Shifts in the labour force across countries lead to changes in the working population, which will have differing impacts depending on the social security framework.

“Climate refugees” is a term that has been used to describe migrants who have been forced to leave their traditional habitat because of marked environmental disruption. Parts of the global population who live in areas that are more exposed to climate risks also typically lack the resources to adapt and become more exposed to disaster displacement.

The surge in global temperatures and consequent sea-level rises may eventually cause some areas of the world to become uninhabitable. However, climate change may also make some places better able to sustain larger populations. For example, higher temperatures could extend growing seasons and reduce frost risk in mid- to high-latitude areas and reduce the concentration of CO₂.

International migration leads to changes in the workforce composition by age and industry. A better understanding of migration and labour flows will inform the future sufficiency and financing of social security frameworks. In the short term, unmitigated climate factors driving population migration will likely lead to new problems and outcomes. The risks introduced in earlier sections of this paper (extreme weather, sea-level rises, droughts, food, and water shortages) pose a threat to people’s lives and lead to an increase in migration. Over time, migration implications for GDP may lead to additional second-order impacts on future migration and workforces, and on the ability of a country to adapt to climate risks in the future. Long-term climate adaptation and sustainable development initiatives could work to offset these impacts and reduce the scale of migration by as much as 80%.

A related additional challenge to isolate the impact from climate-related risks on migration is around attribution. When people are forced to migrate as a result of extreme events (e.g.,
hurricanes), the climate impact is clearer. However, there are longer-term trends caused by climate-related risks, which can cause disruption to society or the economy, and drive migration as people look for work. This includes political instability, as reports suggest the physical effects from climate-related risks could "exacerbate geopolitical flashpoints."\(^\text{37}\)

Notwithstanding the attribution to climate-related risks, from a social security projection standpoint actuaries may wish to consider the impact of migration between countries with differing levels of GDP and development, and what this means for skills and training, as well as the burden on the health system and other government-sponsored support. Conversely, there could be potential upsides from migration, since those who are younger and healthier are usually more mobile. This could positively impact the working tax base, and potentially benefit the social security systems in the countries where migrants arrive while causing serious problems in the countries from which they leave. With differing levels of exposure to physical risks (briefly introduced in the previous section), implications arise around increased inequality. As migration is forecast to rise due to an increase in climate-related risks, especially towards countries with higher GDPs and more stable economies, social security projections should also reflect the likely changes and expectations.

With migration, there are also likely shifts in industry and the economy, which we explore further in Section 3.2.2 of this paper. Additional considerations regarding the working population include changes to industries and productivity as retraining may place an additional burden on social security. Additionally, in Appendix A.3 of this paper, we explore some ways in which migration scenarios have been explored in literature.

### 3.2. Economic Issues

Climate change could disrupt many areas of life, exacerbating existing challenges to prosperity posed by deteriorating infrastructure, stressed ecosystems, and economic inequality. Its consequences touch many aspects of our economy, with the potential of cascading damages and unprecedented systemic risk to globally interconnected economic systems. From a social security perspective, changes to a country's economic conditions stemming from climate change can affect the revenues that are used to fund social security programs. At the same time, climate change can increase demand for financial support or services, which can create further strain on social security programs and government finances.

This section explores potential economic impacts from climate-related risks, potential implications for social security programs and considerations with respect to certain economic assumptions used when making social security projections. Section 3.2.1 discusses the impacts on economic assumptions from physical risks. Persistently rising temperature, changes in precipitation patterns and more extreme weather events can have long-term macroeconomic effects by damaging property and infrastructures, adversely affecting labour forces and productivity, and slowing investments. Section 3.2.2 discusses economic impacts from transitioning into a low-carbon emission economy. Disruptions caused during transitions may impact the labour market, the value of assets, the cost of living and economic growth.

#### 3.2.1. Physical Risk

**Damage to Property and Infrastructure (or Physical Capital)**

Physical risks affect the economic system through direct losses or indirect damage. This section focuses on direct losses, which include damages to properties, inventories, raw materials, extractable natural resources, and physical infrastructure. As the frequency and severity of the extreme weather and climate-induced events increase,\(^\text{38}\) damage to assets affects the longevity of physical capital through an increased speed of capital depreciation.\(^\text{39}\)
Furthermore, the growing costs of damaged properties can threaten the solvency of households, businesses, and financial institutions, especially for the non-insured losses.

For the insured losses, the higher costs could be felt in the form of higher insurance premiums. As climate change impacts worsen, insurance companies may go as far as to refuse to provide insurance coverage. This limited insurability of catastrophe risk places the burden of post-disaster reconstruction and recovery on homeowners and taxpayers who are funding disaster relief spending from governments. This will also raise a challenge for governments who may need to underwrite and/or mitigate the risk of damage. With damaging weather events predicted to increase in the coming years, the risk tipping point of uninsurability is becoming a critical concern around the world.40

The existing infrastructure was designed for historical climate conditions and may be more vulnerable to changing climate conditions and future extreme climate events. Without adaptation, climate change may continue to degrade infrastructure performance over the rest of the century, with the potential for cascading impacts that threaten our economy, national security, essential services, and health and well-being. We also consider the investment implications in Section 3.3 of this paper.

On the other hand, these climate-related investments may also present new business opportunities. According to the 2019 Carbon Disclosure Project,41 about 80% of the world’s biggest companies believe climate change could generate more than US$2.1 trillion in new business prospects. There will be more opportunities in sectors related to clean renewable energy and green buildings. The production of hybrid and electric vehicles is expected to grow,42 and the construction of green infrastructure and more resilient coastal infrastructure could create many new career opportunities.

**Labour Force, Productivity and Economic Output**

The economies and industries that depend on natural resources and favourable climate conditions, such as agriculture, tourism, and fisheries, will become more vulnerable due to physical risks associated with climate change. Labour forces and productivity will be affected directly by climate change. In fact, climate change effects on labour forces are among the most important drivers of the total economic costs of climate change.43

More specifically, climate change can affect the labour force by reducing labour supply, in terms of working hours, especially in working conditions that are highly exposed to the climate (e.g., in the agriculture sector). As discussed in Section 3.1.2, climate change has the potential impact of increasing mortality and morbidity, which reduces the labour supply as well.

Climate change also affects labour productivity by diminishing performance during working hours. Heat stress, determined by high temperature and humidity, lowers working speed, increases the need for breaks and increases the occurrence of accidental injuries at work. Although outdoor workers are especially affected, indoor workers with poor or non-existent air-conditioning systems are also at risk (e.g., factory workers).

As heatwaves become more frequent and/or longer in many parts of the world, it is also important to note that studies have demonstrated a cumulative effect of successive workdays in the heat on thermoregulatory function.44 In addition, warmer nights impact how people recover from heat exposure during the day and can affect sleep, leading to a greater risk of fatigue. The cumulative effects of successive hot days/night not only result in higher risk for heat-related illnesses and dehydration but may result in worker fatigue and diminished work performance on subsequent days, resulting in increased accidental injuries.45

The temperature effects on labour productivity vary widely between countries.46 The impact of heat stress on labour productivity in different countries is highly dependent on their industrial compositions and age profiles.
For example, the workforces in less-developed nations, where a larger share of labour is concentrated in agricultural activity, have a greater risk of exposure to extreme heat than the workforces of more-developed nations that rely more on services. Countries with high labour shares in industries such as construction and mining are also likely to experience productivity losses related to extreme heat exposure.

Finally, the economic output may be reduced due to resources diverted from investment in productive capital and innovation to climate change adaptation. The damages to assets, as mentioned in the previous section, affect the longevity of physical capital through an increased speed of capital depreciation.\(^\text{47}\) Even if the relevant capital stocks might survive, efficiency might be reduced, and some areas might have to be abandoned.\(^\text{48}\) In general, many studies suggest that productivity decreases as temperature increases beyond a country’s historical average.\(^\text{49}\)

In general, climate change is expected to have a long-term impact of uneven magnitude on economic output and the projected magnitude varies significantly among available literatures. Most studies in the literature conjecture uneven macroeconomic effects of climate change. The negative short- and medium-term consequences are more concentrated in countries with hot climates, many of which are also low-income countries.\(^\text{50}\) A test case on a climate change scenario analysis done for Canada can be found in Appendix A.2 to illustrate the wide ranges of potential cumulative GDP impact from climate change for different climate pathways.

**Monetary Instability (or Inflation)**

Three types of energy inflation were introduced in a speech by Isabel Schnabel,\(^\text{51}\) a member of the Executive Board of the European Central Bank, at a panel on monetary policy and climate change: climateflation, fossilflation and greenflation. This section will focus on the long-term inflation impacts from climate change, “climateflation,” which link directly to the costs of climate change itself, where extreme weather events might disrupt supply chains and jeopardize the energy transition by making it more expensive.

As the number of natural disasters and severe weather events is rising, so is their impact on economic activity and prices. When supplies dwindle, demand naturally rises, bringing price increases.

Climate-related risks are likely to affect monetary policy (or inflation) through supply- and demand-side shocks. Supply-side shocks include resource shortages involving such areas as agricultural products and energy, which increases inflation. Higher temperatures, higher atmospheric concentrations of CO\(_2\) and changes in precipitation patterns will directly impact global crop yields. Without adaptation, agricultural productivity will likely decrease, which results in higher global food inflation. Similarly, energy supply may shrink as the efficiency of existing power stations is compromised due to a more extreme climate.\(^\text{52}\)

As discussed in previous sections, climate change can also cause supply-side shocks through reduced stock of physical and human capital, resulting in lower productivity and less output.

On the demand side, climate change could translate into demand shocks, by reducing household wealth and consumption.\(^\text{53}\) Some climate-related shocks may also turn into adverse demand shocks. Rising sea levels, for example, could lead to abrupt repricing of real estate prices in some exposed regions, causing large negative wealth effects.\(^\text{54}\)

In summary, the impacts of climate change on inflation are unclear as climate supply and demand shocks may pull inflation and output in opposite directions. And to the extent that climate change and the associated policy responses affect productivity and long-run economic growth, there may be implications for the long-run neutral level of the real interest rate, which is a key consideration in monetary policy.\(^\text{55}\)
Economic Impacts of Migration

Having discussed climate-related-risk impacts on migration in Section 3.1.3, it is worth acknowledging the economic implications of climate-driven migration for both international and internal migration within a country.

Internal migration would have important implications for future earners and earning distributions, which may increase the uncertainty in projections for social security programs. As discussed in more detail in the next subsection (Increased Difference Within Countries), people in disadvantaged groups might not be able to migrate after climate-related events, due to financial and liquidity constraints. Studies show that migration due to changed environmental conditions is also particularly pronounced in places with a dependency on agriculture.\(^5^6\)

In low-income countries and for individuals who are near subsistence level, a lower income worsens their liquidity constraint, implying potential migrants have a reduced ability to pay migration costs. In this case, global warming may trap very poor rural workers who become unable to leave agriculture, worsening their poverty. To the contrary, in countries in which individuals are not extremely poor, a decline in agricultural income may provide incentives to migrate to cities or abroad.

For international migrations, the emigration rates vary depending on the economic level of the origin countries as well as the financial situation of the potential migrants. Emigration rates are generally higher in middle-income countries compared to low- and high-income countries.

Mass migration disrupts production systems, and the loss of “human capital” in the form of the labour force and investment in education undermines economic growth. This leads to changes in the labour market, workforce composition and wage growth. These will all directly impact the sufficiency and overall financing of social security programs.

In addition, other considerations around migration relate specifically to vulnerable subgroups, who could be impacted differently by climate-related risks. In a similar vein, subgroups of the population could migrate differently. For example, the International Federation of Red Cross and Red Crescent Societies (IFRC) produced a case study that illustrates the risk climate change poses to indigenous communities in Australia, which goes beyond the loss of homes and livelihoods assets and extends to the loss of “cultural heritage grounded in a visceral sense of place attached to ancestral lands where the environment itself resonates with culturally symbolic meaning.”\(^5^7\) From a social security standpoint, considerations could therefore extend beyond provision of homes and livelihoods. Climate migration could also affect health and welfare; rapidly increasing urbanization and population densities can result in epidemic disease and put stress on medical care services. This could ultimately put more burdens on health-care-related social security programs.

Increased Differences Within Countries

Climate change has been one of the factors that has increased economic differences among countries since the 1960s.\(^5^8\) Moreover, poorer countries or individuals are more negatively affected by a changing climate, either because they lack the resources for climate protection\(^5^9\) or because they tend to be in warmer regions where additional warming would be detrimental to both productivity and health.\(^6^0\)

For the purposes of this paper, the focus will be on differences within a country as it has larger impact on an individual country’s social security programs and actuarial work related to social security than the differences between countries. The differences considered here are based on demographic characteristics, income level and access to public resources (i.e., healthcare, education, financing, etc.). In the UN Department of Economic and Social Affairs publication Climate Change and Social Inequality,\(^6^1\) the authors identified three channels through which the aggravating effect of climate change on economic differences materializes.
First, disadvantaged social groups tend to have more exposure to climate-related events, such as flood, erosion, drought, and water scarcity. Many studies show that disadvantaged groups are particularly exposed to climate hazards. Furthermore, economic, and administrative restrictions may lead to the concentration of larger numbers of disadvantaged groups living in areas that are more exposed to climate-related events. Finally, gender and income inequality impact individuals’ location of occupation and type of tasks performed, which determine their exposure to climate-related events.

Second, given the exposure level, the disadvantaged groups are more susceptible to damage caused by climate-related events. For example, people with houses constructed with less sturdy material suffer more from damage from flood or hurricane, and people without air conditioning are more susceptible to health damage from excessive heatwaves. Studies show that the disadvantaged groups are more susceptible to deterioration of health due to climate-related events, which undermines their income and asset position further.

Third, differences decrease these groups’ relative ability to cope with and recover from the damage they suffer. The disadvantaged groups suffer slower recovery from climate-related event damages, due to lack of property or health insurance. Furthermore, the disadvantaged groups are more prone to decrease their future income-earning ability due to climate-related events. For instance, without insurance, the household suffering from disease caused by a climate-related event might be forced to sell physical assets to meet health care expenses. Children from disadvantaged groups may have to withdraw from school to help their family, which further jeopardizes their future earning potential.

All this may put more pressure on the nation’s social security programs such as health care, disability, and unemployment insurance. For social security programs, depending on the funding structure, increased inequality may pose a considerable threat to the health of the plan. In addition, the uncertainty around earners and earning distribution increases volatility when making projections on social security programs. Finally, the need for additional targeted programs may arise.

3.2.2. Transition Risk

Moving towards clean energy sources (energy transition) and reducing the intensive use of fossil fuels (net-zero transition) is a socio-ecological transition that involves transforming the current model of how economic, social, and political systems interact with nature into a more sustainable one. Given the complexity of this task, regulators and sectors involved must carefully evaluate potential risks of their transition and mitigation policies, as they could have important economic and financial implications. The devaluation of financial assets, the increase in financial risks, the instability of consumer prices and the slowdown in economic growth are some of the main concerns about the effects of the energy transition. This type of risk has been addressed in the existing literature as a transition risk.

There are three primary drivers of transition risk to the economy and financial sectors. The first driver is through climate change mitigation policies. Ineffective or disorganized policies could result in financial losses and premature asset devaluation, ultimately causing companies exposed to carbon-heavy industries to experience credit rating downgrades. Two main policies have been proposed for sharing the expenses of transitioning to cleaner energy sources: tradable emission permits and carbon taxes. The aim of these policies is to reduce the amount of GHG emissions by increasing prices and placing limitations on the production of fossil fuels. This will help to ensure that the costs of climate change are shared mainly between fossil-fuel producers and secondary sectors benefiting from carbon emissions. The second driver is technological advancements. Changes in machinery, infrastructure and labour can affect production costs and market value for certain industries. Finally, the third driver is shifts in public
sentiment, demand patterns, preferences, and expectations. Such changes could cause reputation risk for companies related to carbon-intensive sectors.

Social security systems, whether they rely on pay-as-you-go or funded financing systems, are exposed to transition risk. Pension savings in funded systems could face increased market risk due to the extensive decarbonization of investment portfolios. However, an orderly low-carbon transition (in which financial markets efficiently allocate capital, assess, and transfer risks, and facilitate price discovery) would reduce risk to pension savings by reducing long-term climate physical risk, helping to manage exposures to stranded assets and obsolete processes. Furthermore, Investment opportunities for financing projects that promote adaptation and mitigation to climate change could offer attractive options in terms of diversification and profitability in the medium and long term.

The macroeconomic effects of the energy transition might also affect the sustainability and adequacy of public pension systems: the decline of carbon-intensive sectors and the rise of green industries could lead to income and human capital redistribution throughout the economy. If stabilization policies are ineffective, the slowdown in economic growth caused by climate-related physical damage and transition policies could result in lower incomes, higher consumer prices and lower interest rates. These effects could jeopardize social security systems’ sustainability, adequacy, and inclusiveness.

There are two channels through which transition policies can impact social security systems. The first is through economic and financial factors such as investment profitability, productivity growth, income, and labour force. These factors are crucial for ensuring the sustainability of the system. The second channel is through household welfare vulnerability. Transition policies can affect real wages, capital taxes, employment rates, prices, and consumption. These factors can impact the adequacy and intergenerational justice of social security systems. Therefore, it is crucial for social security planners to define appropriate contributions and benefit adjustments such as those linked to inflation and capital taxation. If inflationary pressures and other taxes do not keep up with income growth and benefit payments, social security systems may suffer from a depressed labour force with less incentive to contribute to the public pension system. Figure 1 provides a description of these effects.

**Figure 1. Transmission of transition risk drivers of climate change to social security**

<table>
<thead>
<tr>
<th>Economic and financial effects</th>
<th>Social effects</th>
<th>Intergenerational Justice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sustainability</strong></td>
<td>Adequacy</td>
<td>Intergenerational differences in income, labour taxes, contributions, and retirement benefits.</td>
</tr>
<tr>
<td>Reduced output and incomes in vulnerable economic sectors - income redistribution.</td>
<td>Increasing cost of living: higher burden for contributors and retirees.</td>
<td>Intergenerational differences in income, labour taxes, contributions, and retirement benefits.</td>
</tr>
<tr>
<td>Persistent inflation pressures and insufficient wage incomes.</td>
<td>New labor regulations on income, working hours, and labour taxation.</td>
<td>Increased burden on employees during transition: higher prices, lower income, and job instability.</td>
</tr>
<tr>
<td>Job creation and destruction - sectoral unemployment.</td>
<td>Growing need for social protection: unemployment Insurance and public employment schemes.</td>
<td>The elderly and households with low to middle income are at a higher risk of vulnerability.</td>
</tr>
<tr>
<td><strong>Pay-as-you-go systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divestment and stagnation of carbon assets - financial instabilities.</td>
<td>Increasing cost of living: higher inflation on funded savings.</td>
<td>Intergenerational differences in risks and expected returns.</td>
</tr>
<tr>
<td>Asset devaluation, increases in production costs, and disruption of business continuity in several sectors.</td>
<td>Employees may face higher market risk exposure during the transition period.</td>
<td>Mixing of financial benefits with ecological benefits during transition.</td>
</tr>
<tr>
<td>Financial losses from environmentally sustainable investment practices.</td>
<td>Limitations of fiduciary duties with respect to green investments.</td>
<td>Retirees may not receive any extra compensation from economic growth in the mature stages of the transition.</td>
</tr>
</tbody>
</table>

Source: Authors’ own work
**Impacts of Transition Risk on Labour Markets**

As the ILO pointed out, our current socioeconomic systems are unsustainable. The current path of exploiting natural resources and climate change is leading to shortages of water, food, energy, and other essential products, while reducing income and job security. Moreover, transitioning to alternative green energy sources could impact income, employment, and consumption on a global scale. Failure to take action to reduce emissions will lead to increased poverty and inequality, especially in developing countries where low-income households’ budgets could be severely affected by rising prices. As a result, there is a growing concern about whether transition and stabilization policies are fair and just. To address these concerns, the concept of a just transition is gaining momentum among governments and academics. According to the ILO, the goal of a just transition is to balance the benefits of climate action with effective social dialogue and respect for labour principles and rights. In this way, in addition to promoting more ecologically sustainable growth, a just transition also provides opportunities to address other social objectives, including social inclusiveness, poverty reduction and the creation of decent job opportunities.

Investing in innovation, energy efficiency, green activities such as reforestation, and physical risk mitigation can simultaneously create economic and social growth opportunities while mitigating climate risk. Three opportunities can be highlighted within an organized energy transition framework: creating new high-quality jobs, reducing poverty through job creation, and improving income, and promoting social inclusion by increasing access to clean energy and energy efficiency in housing and transportation. However, three challenges also arise. First, with the upcoming socioeconomic restructuring, it is likely that specific primary and energy sectors will experience job losses. This is due to the rising use of automation, changes in the employment composition and the limited adaptability of some labour sectors. As a result, certain qualified human capital may become marginalized. The second challenge is adapting to the physical damage caused by climate change, which is destroying jobs and assets in all economies. Lastly, transition policies must strive to compensate affected parties fairly while avoiding regressive social effects. Therefore, in order to benefit from emerging opportunities and confront the mounting challenges of climate change, societies must implement a well-organized and ambitious energy transition.

As mentioned above, the most significant impacts of the transition to a low-carbon economy occur in scenarios of abrupt changes. If the labour market supply does not keep pace with the new demand for skilled workers for the growing new industries, a depression in domestic employment could be expected. Several projections for 2030 based on scenario analysis show a relatively optimistic outlook in the labour market during the transition to a low-carbon economy. If the necessary investment for the transition is met, there is potential for increased productivity and a decrease in import costs of fossil fuels. This could lead to a rise in employment not just within clean energy industries, but also within their supply chains and secondary sectors, such as construction and manufacturing. Significant increases in these sectors imply a consequent increase in low- and medium-wage labour. One example of countries/entities that may experience these positive effects is the European Union (EU). The increase in prices of fossil fuels may not have a significant negative impact in comparison to the benefits of reducing import costs through investment in energy efficiency and domestic renewable energy sources. The opposite effect could be expected in the United States, where the oil and gas production drop could reduce its GDP.

Changes in employment can only occur gradually, leading to the identification of three-time stages regarding the potential impact of climate policies on labour markets. In the short term, naturally, jobs are destroyed, and new ones will appear as a direct consequence of technological innovation and production changes. Since transitioning to a low-carbon economy requires significant investment and job creation, green energy production may not be as profitable as fossil-fuel-based energy production in the short term. This underscores the need for competitive
and mature renewable energy technologies to achieve higher levels of efficient productivity. Consequently, rising demand for jobs in emerging industries could increase expenses relative to earnings. Moreover, the short-term limited labour mobility to adapt existing workers to new required skills could also cause a negative impact on both employment and production in the short term. In the medium term, climate policies have an impact on employment creation and destruction through changes in the value chain of affected sectors, which include secondary industries, clean energy suppliers and fossil-fuel producers, and mining. In general, several projections conclude that the medium-term effect remains positive, as job losses might be compensated for by an increasing demand for labour in other sectors. However, if climate regulations are not enforced uniformly across the world, industries with high carbon emissions might move from countries with strict regulations to those with lighter regulations or those that are not yet regulated, leading to job losses in countries that are committed to meeting climate agreements. Finally, in the long term, innovation in production processes is expected to have positive effects, leading to increased investment, economic growth and, therefore, more employment opportunities.

**Impacts of Transition Risk on Inflation and Economic Growth**

Following the ideas in Schnabel’s 2022 speech, the increase in energy and commodity prices triggered by actions to mitigate climate change and transition to renewable energy sources has resulted in two types of global inflation, namely fossilflation and greenflation. Fossilflation refers to the effects of policies aimed at reducing the use of fossil fuels and promoting low-carbon energy sources. Greenflation, on the other hand, is an additional source of inflation caused by scarcity and eventual price increases of raw materials needed by green energy sectors (e.g., minerals and metals). In order to address rising inflation and reduce carbon emissions, it may be necessary to implement fiscal policies and legislation that incentivize clean energy production, energy efficiency, and domestic supply chains. An example of such measures is the Inflation Reduction Act (IRA) launched by the United States in 2022. With a budget of approximately US$370 billion allocated to climate and clean energy investments, the IRA aims to lower energy costs and promote clean energy production, including the use of electric vehicles. It is anticipated that the IRA will reduce GHG emissions by around 40% in comparison to 2005 levels.

The persistence of climate-related shocks on prices is a primary concern for social security. It not only affects one of its main objectives of ensuring that the elderly have a decent standard of living but also has implications for balancing the active population’s consumption, personal savings, and contributions to the pension system. Extreme weather can damage infrastructure, livestock, and crops, causing supply shocks that decrease production and increase prices. Central banks face challenges dealing with these shocks as monetary policies to stabilize high inflation may further reduce output. Even though stabilizing the economy through monetary policies can work in the short term, frequent and severe weather events are causing inflationary pressures to persist. This could lead to a repeated weakening of output and ultimately limit the effectiveness of such policies.

As Semenova suggests, implementing fiscal policies that promote renewable energy production and energy efficiency can aid in reducing climate change and restoring financial stability in the medium and long term. However, such policies may require a reduction in economic growth to be effective. This is because meeting the demand for renewable energy to sustain economic growth may require extensive mining, resulting in severe ecological harm. Furthermore, some minerals necessary for replacing fossil fuels are scarce, so intensive energy production could lead to inflationary shocks or “greenflation,” as noted by Schnabel.

In line with the above ideas, two primary and sometimes opposing trends of transition policies have emerged. On the one hand, the first group of policies advocates for a just transition, aiming to reduce carbon emissions and achieve socioeconomic objectives such as economic growth, the creation of quality jobs and more significant social equity. Examples of these policies
include the Green New Deal, policies of the European Green Party and the Pact for a Green New Deal, launched in the United States, the EU and Canada, respectively. On the other hand, the other trend of policies opposes the ambitious economic growth targets of the first group. Instead, some economists suggest a degrowth perspective as a more realistic way to achieve carbon emission reduction targets. Using the Kaya identity, which shows that carbon emissions are proportional to the growth of output multiplied by the carbon intensity of energy production (renewable or not), degrowth advocates emphasize the need to reduce the rate of economic growth to achieve carbon emission reduction targets quickly.³⁶

Many countries that have successfully decreased their carbon emissions support the idea of economic degrowth. Le Quéré et al.³⁷ present an example of a group of 18 countries that contribute 28% of global carbon emissions and were able to achieve an average annual reduction of 2.4% between 2005 and 2015. This reduction was due not just to renewable energy production, but also decreased energy consumption, partly as a result of slower GDP growth. The degrowth transition framework involves a profound economic and social transformation of practices to increase energy efficiency and decrease consumption. Although this initiative leads to a decrease in GDP, it is justified by the belief that lower GDP growth can coexist with adequate quality-of-life standards.

### 3.3. Investment Returns and Market Effects

Making projections for social security plan assumptions on market and investment returns plays a relevant role. This issue will not be treated in this paper exhaustively since the IAA has already published Paper 4 in this series, which explicitly applies climate-related risk scenarios to asset portfolios. The paper, Application of Climate-Related Risk Scenarios to Asset Portfolios, illustrates the integration of physical, transition and reputational climate risks into the work of actuaries. For this reason, we recommend referring to that paper to understand better the effects of climate-related risks on markets and investments.

In this section, we will explore how public and private pension systems can contribute to a greener financial market. We will also discuss the opportunities and barriers to achieving both financial and environmental benefits.

**Impact of Transition Risk on Fund Assets**

As highlighted in most of the existing literature, effective policies aimed at reducing carbon emissions should prioritize the development and expansion of low-carbon industries while phasing out or transforming industries that rely on fossil fuels. This process should be carefully managed, considering that a significant portion of the economy currently depends on fossil fuels. An uncontrolled transition could potentially lead to financial instabilities and crises. It is important to note that not only the decline of carbon-intensive industries but also the possible accelerated growth of green industries can have significant financial impacts, such as the rise of financial bubbles.³⁹

It is becoming increasingly important to consider both financial and environmental benefits when making investment decisions. Recent studies have shown that climate change and sustainable investments can significantly impact investment performance due to physical and transition risk. While investing in carbon-intensive assets can increase the physical risks associated with climate change, implementing rigorous net-zero-carbon-emissions policies can raise transition risks. In other words, portfolios with a high carbon allocation can pose long-term physical risks, and without an appropriate divestment strategy, they are also exposed to transition risks. Following ESG practices, numerous investors address this issue by measuring the financial performance and the environmental damage their investments could promote. Another sustainable investment practice is Socially Responsible Investment (SRI), where investors exclude assets that are harmful to the environment or society for ethical considerations. As a result, divestment from carbon-intensive industries and carbon footprint
disclosures are gaining momentum among pension funds and other institutional investors driven by increasing implications from climate and sustainability risks, and global changes in regulatory requirements around disclosures.

As major asset owners responsible for ensuring intergenerational equity, both public and private pension funds may have a crucial role to play in promoting ESG and SRI practices worldwide. However, fiduciary duties and solvency constraints create financial and regulatory barriers that prevent pension funds from fully utilizing their investment power in ESG and SRI. Sustainable investments may not be allowed unless fiduciary duties allow for non-financial benefits that offset a potential reduction in profitability. Although mitigating climate change may be a non-financial benefit that enhances the welfare of the beneficiaries, there is an ongoing debate about whether pension funds should adapt their fiduciary duties to allow for environmental benefits in response to climate change and other sustainable goals.

Renewable energy projects can provide pension funds and other institutional investors with substantial financial benefits due to their low correlation with other financial assets and their potential to mitigate inflation. However, short-term regulatory constraints make investing in long-term innovative projects challenging for pension funds. While some analyses suggest that pension funds should adapt their prudential regulatory framework to long-term investment objectives, other analyses, such as that developed by Polzin and Sanders (2020), suggest that investment strategies for innovation projects could also be addressed through the so-called “innovation-finance-policy-chain”. This approach acknowledges that innovation projects involve different stages of risk and return, which may align with the risk and return profiles of different types of investors. Typically, the optimal financing for institutional investors involves the last stage, which is related to the diffusion of mature technologies through public and private equity, project financing, and infrastructure.

The involvement of pension systems in promoting the transition towards cleaner energy sources can be crucial in reducing transition risk effects on other social protection areas. The financial instability of carbon-based industries, if left unchecked, can result in increased production costs across various sectors, leading to reduced incomes, higher consumption prices, unemployment, low investment returns, and property devaluation among households. These effects can severely hamper people’s ability to adapt and meet their financial obligations. However, the active participation of pension systems can help mitigate these risks and also reduce the physical effects of climate change, potentially resulting in a reduction in social protection costs, including expenses related to unemployment benefits, healthcare, and disability pensions.

3.4. Future Uncertainties and Opportunities

Future Uncertainties

As discussed in earlier sections, climate-related physical risks include, among other things, more frequent and severe weather events. These events could damage existing infrastructure, disrupt supply chains, harm agricultural production, and exacerbate resource scarcity. They may lead to economic instability and increase the uncertainties in predicting and assessing the economic issues related to social security programs. For example, depending on the transition pathway, climate change could have significant impact on morbidity through heatwaves, disease vectors and air pollution, potentially reducing labour productivity and increasing healthcare costs. Climate-induced migration and conflicts over resources can disrupt economies and create geopolitical uncertainties. Increased climate-related physical risks may also lead to higher insurance premiums and liability costs for individuals, business, and government.
In addition to physical risks, transition to a low-carbon emission economy could also increase uncertainties, especially for industries related to fossil fuels. The degree to which countries can adapt to climatic changes is a major source of uncertainty for climate economics. As governments respond to climate change, they may introduce new regulations, taxes, or incentives. These policy shifts can influence the competitiveness of industries and markets. They could introduce financial risks in the form of stranded assets and market disruptions.

Finally, it is important to note the inherent uncertainties around climate science and climate modelling to assess the future physical impacts from climate change. Notwithstanding the large research effort devoted to climate studies, there is still a large degree of uncertainty regarding the exact nature of future climate scenarios. It is also extremely difficult to model with any degree of accuracy the impact of climate change on society and the economy, such as how society will adapt to climate change and future technological advancement on future GHG emissions, since individuals and communities affected directly and/or indirectly by climatic shocks behave in a rather complex and heterogeneous way.

Opportunities

While climate change presents significant challenges and risks, some potential opportunities may arise. The transition to a low-carbon emission economy can create green jobs and green investments, which are all critical components of the transition.

The term “green jobs” refers to employment opportunities in sectors that prioritize the preservation or restoration of the environment. They facilitate environmental sustainability, reduce carbon emissions, and promote resource efficiency. Examples of such sectors include renewable energy, energy efficiency, sustainable agriculture, green manufacturing, green transportation, and waste management. As transitioning to a green economy may change the labour markets, social security plans could be adapted to provide support and retraining programs for those whose livelihoods are impacted by the transition.

Green investments involve allocating capital to projects, companies or initiatives that have positive impacts on the environment. These investments can take various forms. They can involve capital allocated to fund renewable energy projects (such as solar farms, wind or hydroelectric power-generation facilities), to purchase green bonds issued by government or corporations to fund environmentally sustainable projects (such as public transportation or green infrastructure), or to support startups or companies that develop innovative solutions for climate change to address water scarcity, pollution, and waste reduction. They not only have the potential for financial returns but also contribute to addressing climate change and environmental degradation. Similarly, social security plans may also redirect investments towards more sustainable sectors. They could also support research and development in new technologies that promote sustainability, which could lead to improved living standards and new job opportunities.

As a result, climate-related investments may also represent new business opportunities. According to a 2019 Carbon Disclosure Project report about 80% of the world’s biggest companies believe climate change could generate over $2.1 trillion in new business prospects. There will be more opportunities in sectors related to clean renewable energy and green buildings. The production of hybrid and electric vehicles is expected to grow, and the construction of green infrastructure and more resilient coastal infrastructure could create many new career opportunities.

3.5. Potential Impacts on Actuarial Work for Social Security Programs

The previous sections underlined the ways climate change may affect social security programs. In this section, the non-exhaustive impacts on the work of social security actuaries and on social security institutions are examined, especially in connection with the model International

**Assumptions**

ISAP 2 specifies in Section 2.3 that the work for social security programs should be based on *neutral assumptions*; that is, the resulting projection of the social security program experience is not a material underestimate or overestimate. Further, the same section specifies that the projection period might be 75 years or more. Similar topics are addressed in Guideline 2 – Assumptions – of the Actuarial Guidelines.

In choosing neutral assumptions over such a long-term period, it is hard to ignore the potential impacts of climate change on demographic and economic assumptions. However, at this point in time, the lack of historical data and extreme uncertainty surrounding transitional pathways and residual physical risks make it difficult for actuaries to directly incorporate climate change impacts in neutral assumptions. In this case and according to ISAP 2, the actuary may be required to disclose the lack of data as well as the fact that the neutral assumptions do not incorporate the considerations related to climate change. Such disclosure will provide an important signal to social security institutions regarding the uncertainty surrounding the projections. Furthermore, the actuary may choose to develop reasonable scenarios incorporating the various ideas that have been presented earlier in this paper and use the pathways through these scenarios as they impact the assumptions and their consequences relevant to the social security program. In this case the actuary should be transparent on the choices of the scenarios in their report. The actuary may want to consider the Communication section of ISAP 1 (General Actuarial Practice)\textsuperscript{101} and ISAP 2.

**Scenario Analysis and Models**

Guideline 9 – Uncertainty of Results of the Actuarial Guidelines – recommends inclusion of analysis of future uncertainties and quantification of risks stemming from these uncertainties. Further, this guideline recommends that social security institutions consider this analysis as a part of their risk management processes. Guideline 34 – Actuarial Input into the Understanding of Catastrophic Risk – explicitly refers to climate-change-related risks and highlights the importance of social security institutions considering actuarial input in understanding these risks and in modelling them.

To respond to these guidelines, social security actuaries need to develop expertise in climate-change-related risks, modelling of such risks and, in particular, scenario analysis. The reader is referred to the IAA papers Importance of Climate-Related Risks for Actuaries\textsuperscript{102} and Introduction to Climate-Related Scenarios\textsuperscript{103} for in-depth discussion of these issues.

**Involvement of Actuaries in Policy and Strategy Issues in Respect to Climate-Change-Related Risks**

As stated in Section G – Policy and Strategy Issues – of the Actuarial Guidelines, actuaries play a key role in the design, implementation, and operation of social security schemes. Their expertise is an important contribution to the decision-making process in this respect.

As climate change impacts evolve and in view of changing demographic and economic environments, several actions may be required to adapt social security schemes to new realities. These may include:

- Amending existing schemes to strengthen protection to the covered population;
- Introduction of new schemes covering the climate-related risks where no current protection is offered;
- Analysis of risks to financing and sustainability – for example, from potential erosion of sources of revenues or increased demand for benefits;
• Analysis of risks to adequacy of benefits – for example, fragmented careers due to climate transition;
• Analysis of risks to coverage – for example, coverage of migrants; and
• Changes in funding, to move to a funded model.

Section G of the Actuarial Guidelines provides in-depth discussion on how actuaries need to be involved and how they can assist social security institutions.

4. Conclusions

Although this paper is written for the benefit of actuaries involved in social security areas, many of the concepts are in wide use among insurance and pensions actuaries; for example, they have significant expertise amassed over many years in calamity- and disaster-related claims, mortality development in different countries and investment-related risks. Due to this expertise in identifying and managing risk, actuaries are expected to make a relevant contribution in climate risk management.

In this paper we showed that the effects of climate-related risk could be significant on demographic, socioeconomic and investment-related indicators that are being impacted by climate-related physical and transition risk. Unfortunately, the literature also indicated that there is enormous uncertainty about the trajectory that our current socioeconomic model will take to become more ecologically sustainable. Thus, the consideration of practical scenarios is increasingly important for medium- and long-term projections.

The uncertainty in magnitude of the effects of climate-related risks (regarding both direction and scope) should not discourage actuaries in considering those risks and their effects in projections and valuations.

The studies conducted when writing this paper showed, for example, that research exploring the stochastic effects of technological advances, carbon emission reduction, economic growth and policymaker reaction is limited. Among experts there is a clear demand for more studies and stochastic modelling to understand the consequences of different actions. In this context, actuaries are well positioned to enhance modelling work by applying probability scenarios and introducing stochastic modelling techniques.

It is time for actuaries to actively contribute to incorporating probabilistic and statistical bases into existing analytical streams. Moreover, actuaries should be aware of the latest research and trends in order to evaluate their possible effects on assumptions and valuations.

It is important to keep in mind that the ultimate goal is for actuaries to work with other social security professionals to help ensure the design of climate-resilient and sustainable social security programs. Given the broad scope of climate risk management, actuaries will need to collaborate with other professionals such as economists, demographers, and climate change scientists. Effective collaboration between these groups of professionals is essential to leverage a wide range of skills and expertise and improve overall climate risk management.

In doing so, we can help policymakers gain greater theoretical and practical support for their risk projections.
Appendix: Scenario Analysis for Climate-Related Risks in Social Security

A.1 Quantitative Frameworks for Scenario Analysis

**Integrated Assessment Models**

To comprehend the impact of climate change, a comprehensive understanding of both socioeconomic and natural systems is necessary. Integrated assessment models (IAMs) have been developed to bridge these different fields and offer cohesive frameworks for policymakers to create effective climate policies and determine the social cost of carbon emissions. This collection of models consists of mathematical representations of the world from various disciplines, including climate science, biology, and economics. They work together within a unified framework to evaluate the effects and outcomes of environmental shifts and potential policy solutions. In general, for climate change analysis, IAMs aim to represent the industrial and natural production of GHG emissions, the carbon cycle, and their effects on temperature increases and climate change.

All IAMs begin by establishing a set of assumptions and inputs regarding the functioning of socioeconomic and demographic systems. These assumptions are then used in a series of equations that describe the economy, energy systems, land use and climate changes. By connecting these equations, IAMs can create different projections that are relevant for analyzing climate risk. These projections include GDP, carbon costs, carbon emissions, energy pathways and land-use changes (see Figure 2).

![Figure 2. Example of input/output variables and integrated modules of IAMs](source)

The models under the IAMs label vary in complexity, methodology and assumptions. Nevertheless, they can be grouped into two categories: detailed process (DP) IAMs and benefit–cost (BC) IAMs. DP IAMs provide detailed projections of climate change impacts, including economic valuations or physical impact descriptions, such as crop growth and sea-level rise. These models use more complex equations than BC IAMs to describe the global functioning of the economy, energy, land use and climate. Due to their comprehensive representations, DP IAMs are used primarily to analyze climate impacts and assess the effectiveness of mitigation policies. Combining mitigation policies and climate effects is the most critical application of this type of model. They
allow for the creation of hypothetical scenarios that help analyze the impact of mitigation policies on climate change and how climate change, in turn, affects the effectiveness of these policies. These scenarios could provide insights into the possible effects on land and water of intensive use of renewable energy sources like biofuels, as well as how extreme weather conditions can trigger competition for natural resources.

On the other hand, BC IAMs generate aggregated representations of mitigation costs and climate impacts through a single economic metric, for instance, economic growth. This simplicity is quite convenient for finding optimal mitigation policies, evaluating suboptimal alternatives, and calculating estimations of the social cost of carbon (SCC). Three of the most used BC IAMs are the Dynamic Integrated Climate-Economy (DICE); the Framework for Uncertainty, Negotiation, and Distribution (FUND); and the Policy Analysis of the Greenhouse Effect (PAGE).

**Shared Socioeconomic Pathways**

One of the main purposes of IAMs is to generate accurate world representations that can help answer hypothetical questions. These questions encompass concerns about future plausible events, such as: what if there is a stagnation in economic growth, or what if carbon dioxide removal (CDR) is not possible on a large scale? Such questions constitute the core of scenario analysis. The Shared Socioeconomic Pathways (SSPs) are examples of such scenario representations. Five different SSP narratives have been suggested, each presenting unique challenges when it comes to mitigation and adaptation. These scenarios can be briefly described as follows:

- **SSP1: Sustainability (low socioeconomic challenges for mitigation and adaptation)**: The world is becoming more sustainable through increased international cooperation. Human welfare is prioritized over economic growth. A higher education and healthcare investment accompanies the demographic transition. Population and consumption grow at a lower rate. Commitment to achieving development goals leads to greater equality within and between countries.

- **SSP2: Middle of the Road (medium socioeconomic challenges for mitigation and adaptation)**: The world continues its current socioeconomic path, and only minimal efforts are being made to reduce GHG emissions. Population grows moderately and stabilizes during the second half of the century. There is no considerable enhancement in income equality.

- **SSP3: Regional Rivalry – A Rocky Road (high socioeconomic challenges to mitigation and adaptation)**: Policies are focused on domestic security, which in turn limits international trade. Investment in education and technological innovation is reduced. Economic growth declines and, as a result, social inequality rises. Developing countries experience a higher rate of population growth compared to other countries.

- **SSP4: Inequality – A Road Divided (low socioeconomic challenges to mitigation, high socioeconomic challenges to adaptation)**: The current state of social inequalities is being amplified due to significant disparities in investments made in human capital, as well as economic and political opportunities. This gap in inequality is expanding both within and between countries, leading to the degradation of social cohesion and an increase in conflict and unrest.

- **SSP5: Fossil-fuelled Development – Taking the Highway (high socioeconomic challenges to mitigation, low socioeconomic challenges to adaptation)**: Policies aim to promote sustainable development through competitive markets, technological innovation, and investment in human capital. However, this path of high economic growth leads to high energy consumption and intensive fossil-fuel exploitation. The population experiences a decline in growth over the century.

A more detailed description of these scenarios can be found in O’Neill et al.107
The SSPs consider relevant “what if” questions related to population, economic growth, education, health care and social equity, which are essential in assessing how adaptable social security systems are in light of the energy transition. Specifically, the two most critical factors that impact carbon emissions throughout the century are population growth and GDP growth. These two factors are also closely associated with the sustainability of social security. Figure 3 presents the assumed path of these factors for each SSP.

**Figure 3. Global GDP and population for each of the SSP scenarios**

Source: OECD/IIASA projections

According to SSP projections, all scenarios, except for SSP3, show a decrease in population after the first half of the century. If the world follows the current socioeconomic pathway (SSP2), economic growth is expected to be higher than in scenarios with regional competition (SSP3) and socioeconomic inequality (SSP4). However, a sustainable socioeconomic pathway (SSP1) is predicted to result in better GDP growth than all scenarios except SSP5.

Researchers can use socioeconomic assumptions like SSPs and IAMs to analyze climate risk and create scenarios for changes in land use, emissions, and energy consumption. The sections below illustrate two well-known examples of how SSP narratives have been applied to produce different families of climate risk scenarios, namely the Representative Concentration Pathways (RCPs) and the NGFS scenarios.

**Representative Concentration Pathways**

The socioeconomic assumptions given by SSPs can be integrated with scenarios depicting GHG emissions, concentrations, and alterations in land use. Researchers frequently study these scenarios using the so-called RCPs. These pathways encompass the spectrum of emission trajectories derived from previous analyses and aim to be consistent with all of them. According to the IPCC Fifth Assessment Report (AR5), there are four potential paths for the future, each with a different radiative force achieved by the year 2100. “Radiative forcing” refers to the extra heat retained in the lower atmosphere due to GHG emissions. The proposed radiative forces for high, intermediate, and low mitigation efforts were 2.6, 4.5, 6 and 8.5 W/m², respectively. These four RCPs can be briefly described as:

- **RCP 8.5**: Minimal efforts are made to reduce emissions, resulting in a radiative forcing increase of 8.5 W/m² by 2100.
- **RCP 6.0**: Emissions peak in 2080 and then level off at 6.0 W/m² by 2100 due to the implementation of new technologies and strategies for reducing emissions. Global temperatures will rise between 3 °C and 4 °C by 2100.
This scenario outlines how ambitious climate goals can be achieved early by actively involving major emitters and using carbon-removal techniques, such as reforestation. As a result, global temperatures will be reduced to below 2 °C by 2100.

However, since the RCPs were created using non-standardized socioeconomics values, they have been improved by connecting radiative forcing to the SSPs. This results in a new set of scenarios that take into account SSPs assumptions and climate policies needed to achieve a particular RCP radiative forcing level by 2100. Each SSP pathway can have several radiative forcing levels, depending on the mitigation actions outlined by a given RCP. These scenarios are usually named in the format “SSP narrative – radiative forcing.” For example, the scenario “SSP1-1.9” is based on the socioeconomic assumptions framed by the SSP1 and depicts the mitigation policies required to achieve a radiative forcing of 1.9 by 2100.

**Network for Greening the Financial System Scenarios**

The NGFS reference scenarios are a standardized set of pathways for socioeconomic factors, carbon emissions and climate variables. They provide a common framework for financial institutions to analyze climate financial risks, making it easier to compare and disclose data. There are six NGFS scenarios, commonly referred to as: “Net Zero 2050,” “Divergent Net Zero,” “Below 2 °C,” “Delayed Transition,” nationally determined contributions (NDCs), and “Current Policies.” These scenarios are grouped globally based on their transition paths, whether orderly or disorderly, and their effectiveness in meeting climate targets. Each NGFS category has a specific set of assumptions related to long-term climate targets, policy reaction, technological availability, and regional policy variation (see Figure 4). To project the transition pathways for each scenario, three IAMs are used: GCAM, MESSAGE-GLOBIUM and REMIND-MAgPIE. This results in 18 output trajectories that allow for comparison and provide insights into the uncertainties surrounding upcoming climate and financial events.

On the one hand, the “Net Zero 2050” and “Divergent Net Zero” scenarios assume early and ambitious policy reactions to meet emissions and climate goals. In both scenarios, the global average temperature target is set at 1.5 °C, and carbon emissions are reduced almost entirely. The “Divergent Net Zero” scenario includes a disorderly transition trajectory by diverging policy intensity across sectors. This condition is represented by assuming carbon prices three times higher than prices in the supply and industry sectors and assuming low availability of CDR across regions. The “Net Zero 2050” scenario, on the other hand, includes greater CDR availability with less sector variability. As a result, the “Net Zero 2050” and “Divergent Net Zero” scenarios differ in transition risk, with the latter having greater exposure.

The “Below 2 °C” and “Delayed Transition” scenarios met the climate targets with a lower level of ambition than the two previous scenarios. In fact, in the “Below 2 °C” scenario, the rate of increase in carbon prices is lower than in the two previous scenarios, while in the “Delayed Transition” scenario, the policy reaction is delayed until 2030, and then carbon prices are imposed abruptly to catch up with the orderly long-term price trajectory. These two forms of less intensive climate policies bring the global temperature to a less ambitious level (global mean temperature rise of 1.7 °C and 1.8 °C, respectively), but one that is still compatible with the objectives of the Paris Agreement. The additional disorder effects in the “Delayed Transition” scenario are explained by imposing more conservative restrictions on the availability and expansion of CDR and a more significant variation of the policy intensity between regions. Consequently, the “Delayed Transition” scenario implies a higher transition risk than in the “Below 2 °C.”

Finally, under the “Hot house world” category, two scenarios are presented that examine the impact of insufficient policies to achieve ambitious climate goals. In one scenario, policy
actions follow the NDCs defined at the beginning of 2021. Therefore, the moderate short-term policy targets set for 2025 to 2030 are extrapolated for 2030 to 2100. In the other scenario, current climate policies remain unchanged, thus representing a baseline scenario of the physical risk path of a world indifferent to climate goals. These scenarios imply low transition risk but considerably higher physical risk, with carbon emissions reduction below the level required to achieve a global average temperature below 2 °C. The weak intensity of climate policies in a “Hot house world” is reinforced by the low availability of CDR and homogeneous regional ambitions for soft climate targets.

Figure 4. The NGFS matrix: Categories and scenarios

The NGFS scenarios use two RCPs and rely on the socioeconomic assumptions given by SSP2. The categories “Target met orderly” and “Target met disorderly” follow the radiative forcing trajectory of RCP 2.6, resulting in a global temperature increase of 1.5 °C to 2 °C. However, temperatures in the “Hot house world” group are similar to those in RCP 6.112 All scenarios are based on SSP2, which assumes that the world will continue its current socioeconomic path. According to SSP2, the population will reach its peak around 2070 and stabilize, and GDP will continue to grow historically if climate change impacts are not taken into account.113

It is important to keep in mind that generic scenarios, such as those developed by the NGFS, may need regular updates due to changes in economic and climate data, new policy implementations and model updates. In November 2023, the NGFS launched Phase IV of its scenarios, which included new information and two new scenarios: the “Low Demand” scenario and the “Fragmented World” scenario. In the former, more rigorous measures are implemented to reduce energy demand and limit temperature increases to 1.5 °C. This scenario represents an additional pathway to an orderly transition. The “Fragmented World” scenario represents a new, “Too little too late” scenario where the implementation of climate policies is fragmented across different regions and time periods. This scenario is associated with the highest physical and transition risk pathways due to policy delays and divergences.114
This section presents a Canadian case study, outlining the approach used to illustrate and assess the future potential downside impact from climate change on the Canada Pension Plan (CPP). This assessment was included in the 31st Actuarial Report on the CPP as of 31 December 2021 (CPP31 AR), which was prepared by the Office of the Chief Actuary (OCA), Office of the Superintendent of Financial Institutions. Climate change can affect the CPP through various channels as the demographic, economic and investment environments can all be affected by climate change in the future. However, as discussed in earlier sections, there is significant uncertainty regarding the direction and magnitude of these potential impacts, and the risk is evolving constantly. In addition, research attempted, and data analyzed in an effort to quantify the full impact of climate change on the demographic, economic and investment environments are incomplete and, in certain cases, somewhat conflicting.

In view of the high level of uncertainty, scenario analysis is used to illustrate climate-related risk in CPP31 AR as an alternative to incorporating future climate policy and the potential impact of technology into best-estimate assumptions. The analysis included in the CPP31 AR assessed the climate-related downside risks by looking at the potential changes in the minimum contribution rate (MCR) of the base CPP under different hypothetical climate scenarios. Given the complexity of climate models and the level of expertise required to develop them, it was decided to use information that was available to the OCA, from both publicly available or private sources, to develop these hypothetical climate scenarios, and to estimate the MCR under each of these scenarios.

It is important to note that this case study focuses on assessing downside risk only, and that the analysis is based on scenarios that are intentionally adverse. New technologies and business opportunities related to a transition to a lower-carbon economy may also create positive outcomes, which are outside the scope of this section. The case study is therefore not meant to represent forecasts or predictions.

The remainder of this section provides details on the approach that was taken, which was broadly based on the following steps:

- We conducted research on climate change and commonly accepted climate scenarios.
- We selected GDP as the broad macroeconomic variable to focus on when analyzing climate scenarios.
- Based on an overview of public research and private studies, we developed three hypothetical climate scenarios, illustrating impacts on GDP relative to a baseline scenario.
- We translated the GDP impacts by scenario into relevant variables in the CPP actuarial model in order to estimate the potential effect on the MCR, which is an important variable to assess the sustainability of the CPP.

For this purpose, a simplified approach was used in which the GDP impacts by scenario were reflected in the real wage and the investment return assumptions.

**Hypothetical Illustrative Climate Scenarios**

From available information, an important variable that is often analyzed in these climate scenarios 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. It was therefore decided to focus on GDP impacts in the selection of hypothetical climate scenarios in CPP31 AR.
An overview of the public research and private studies shows a wide range of climate scenarios with a correspondingly wide range of GDP impacts. The differences in scenarios can sometimes make it difficult to compare impacts and draw conclusions. One way of consolidating this information into a similar basis is by using some commonly accepted climate scenarios such as the RCP scenarios and the SSP scenarios:

- RCP scenarios are designed to provide plausible future scenarios of anthropogenic forcing spanning a range of scenarios with low to high emissions in 2100 (RCP 1.9, 2.6, 4.5, 6 and 8.5, respectively).
- SSP scenarios focus on modelling socioeconomic factors such as population, economic growth, education, urbanization, and the rate of technological development. They are designed to reflect the worlds in which mitigation and adaptation challenges vary from low to high (SSP 1, 2, 3, 4 and 5, respectively).

Using the narratives of the RCP scenarios and the SSP scenarios, the climate scenarios from the available sources that were reviewed when preparing CPP31 AR were categorized into groups. And, for each of these scenario groups, a range of potential cumulative GDP impact was obtained. These ranges of GDP impact for each scenario group were then used as a reference point for developing the hypothetical climate scenarios used in the CPP31 AR.

Table 2 shows the climate scenarios categorized by scenario groups and their corresponding estimated Canadian GDP impact in 2030, 2050 and 2100. The ranges of GDP impact for each group are determined using the minimum and maximum GDP impact estimated in the reviewed sources. The ranges of GDP impact can be wide even within similar scenario narratives. This highlights the level of uncertainty and wide range of views.

<table>
<thead>
<tr>
<th>Scenarios group</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios with very low GHG emissions and temperature rise of below 1.5 °C by 2100 (similar narratives as SSP1-1.9)</td>
<td>Range 0% to -18% -2% to -20% -3% to -23%</td>
<td>Average -5% -8% -11%</td>
<td></td>
</tr>
<tr>
<td>Scenarios with low GHG emissions and temperature rise of below 2 °C by 2100 (similar narratives as SSP1-2.6)</td>
<td>Range 0% to -18% -5% to -20% -3% to -23%</td>
<td>Average -6% -11% -12%</td>
<td></td>
</tr>
<tr>
<td>Scenarios with intermediate GHG emissions and temperature rise of around 2.5 °C by 2100 (similar narratives as SSP2-4.5)</td>
<td>Range -2% to -5% -5% to -18% -3% to -25%</td>
<td>Average -3% -9% -14%</td>
<td></td>
</tr>
<tr>
<td>Scenarios with high GHG emission and potential temperature rise of around 3 °C by 2100 (similar narratives as SSP3-7.0)</td>
<td>Range 0% to -3% -1% to -7% -17% to -40%</td>
<td>Average -1% -4% -27%</td>
<td></td>
</tr>
<tr>
<td>Scenarios with very high GHG emissions and potential temperature rise of around 4 °C by 2100 (similar narratives as SSP5-8.5)</td>
<td>Range -5% to -5% -3% to -9% -35% to -35%</td>
<td>Average -5% -6% -35%</td>
<td></td>
</tr>
</tbody>
</table>

Source: 31st Actuarial Report on the Canada Pension Plan as of 31 December 2021
Based on the information shown above, three scenarios with different pathways of Canadian GDP growth rates relative to a baseline scenario are selected, for the purpose of illustrating downside risk of the sustainability of CPP:

**Scenario 1** can be generally classified in the “orderly transition” category of scenarios, which has narratives that are closest to the scenarios listed in the first row of Table 2. It therefore assumes that successful climate policies are introduced early and gradually in order to limit global warming. Canadian GDP growth rates are lower relative to the baseline scenario over the whole projection period, 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, which share narratives close to the scenarios in the second and third group (the second and third rows of Table 2). It assumes that climate change policies only start in 2030. There is therefore no impact on GDP relative to the baseline scenario until 2030. However, late action 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, which share narratives close to those of scenarios in the last two groups (the fourth and fifth rows of Table 2). It assumes that no further climate change policies will be 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 create 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.

Figure 5 shows the difference in Canadian GDP growth rates relative to the baseline scenario for each of the hypothetical climate scenarios.

**Figure 5. Illustrative climate scenarios used in CPP31 AR – Cumulative Canadian GDP impact relative to baseline scenario**

![Graph showing cumulative Canadian GDP impact relative to baseline scenario for three scenarios: Scenario 1: Orderly Transition, Scenario 2: Disorderly/Delayed Transition, Scenario 3: Failed Transition.](image)

*Source: 31st Actuarial Report on the Canada Pension Plan as of 31 December 2021*

*Estimating the Impact of Hypothetical Climate Scenarios on Base CPP Sustainability*
As mentioned earlier, the sustainability of the base CPP is assessed through the MCR. The MCR is the measure prescribed by legislation to assess the sustainability of the base CPP, by comparing it to the legislative contribution rate, which is set at 9.9% for the base CPP. To assess climate-related risks in CPP31 AR, the hypothetical climate scenarios above are translated into potential impacts on the base CPP MCR, using the following simplified approach:

- Changes in Canadian GDP growth are translated one-for-one into changes in total employment earnings growth through the real wage assumption (lower GDP translates directly into lower productivity and real wages).
- Changes in global GDP growth are incorporated in the assumed investment returns through the growth-in-earnings component which is proxied by global GDP growth per capita. The growth in earnings is used to develop the assumption on rates of return on public equities, private equities, and real assets.

The real wage assumption and the investment returns are part of the assumptions underlying the determination of the MCR.

**Results**

The resulting impact on the base CPP MCR for each scenario is shown below, as well as the comparison relative to the base CPP MCR under the best-estimate assumptions. It is important to note that these scenarios are intentionally adverse. They are meant to illustrate downside risk only and are not meant to be forecasts or predictions.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>MCR</th>
<th>Change relative to Best-Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best-Estimate</td>
<td>9.54%</td>
<td>Nil</td>
</tr>
<tr>
<td>Scenario 1 – Orderly Transition</td>
<td>9.75%</td>
<td>0.21%</td>
</tr>
<tr>
<td>Scenario 2 – Disorderly/Delayed Transition</td>
<td>9.94%</td>
<td>0.40%</td>
</tr>
<tr>
<td>Scenario 3 – Failed Transition</td>
<td>10.06%</td>
<td>0.52%</td>
</tr>
</tbody>
</table>

*Source: 31st Actuarial Report on the Canada Pension Plan as of 31 December 2021*

**A.3 Considerations for Climate Migration Scenarios**

For actuaries looking to understand the impact of climate on migration and social security, a number of scenarios have been explored in the literature. A study of population scenarios and forecasts published by *The Lancet* in 2020\(^\text{117}\) assumed migration as a function of each country’s socio-demographic index, death due to conflict and natural disasters, and the difference between birth and death rates, as well as a random walk with drift.\(^\text{118}\) The study concludes that global population is likely to peak before the end of the century, but countries which can sustain populations are likely to have larger overall GDP as a benefit of a stable working population. For social security projections, changes in migration and the trajectory of the working population will directly impact the sufficiency over time, and overall financing.

Another recent study explores the policy implications from migration driven by drought-related physical risks.\(^\text{119}\) This study explores the implications for migration based on projected drought scenarios, under a range of climate policies. Based on ensemble modelling, this paper concluded that drought-induced migration could increase by up to 200%, based on current climate policies. This article finds that international cooperation on climate risks can substantially reduce the global potential for climate migration, compared to unilateral policy approaches.
An early study in 2011 developed four scenarios around migration and global environmental change, with considerations around demographic, economic, social, political, and environmental factors. The narratives around the four scenarios were aimed at forecasting over the next 50 years. The scenarios are complex and inter-related and summarized in Table 4 to show at a high level the types of nuances that could be considered.

Additionally, studies have indicated that the populations impacted by climate-related factors are predicted to increase. According to a paper by Black et al., the number of people living in floodplains of urban areas in East Asia may rise from 18 million in 2000 to 45–67 million by 2060, and:

- from 4 million in 2000 to 35–59 million by 2060 in South-Central Asia;
- from 7 million in 2000 to 30–49 million by 2060 in South-Eastern Asia;
- from 2 million in 2000 to 26–36 million by 2060 in Africa (depending on various scenarios of the future).

The same paper also introduces a concept of the “trapped population”: those who are highly vulnerable to environmental change, with a low ability to move. Among more recent publications, the UN Network on Migration has called on states to integrate migration scenarios into climate change policies and plans. In 2022, it was reported that annually more than 20 million people are already forced to migrate due to climate reasons. Meanwhile, uncertainties and likely migration caused by climate-induced intra-group violence and geopolitical risks could also be a factor. Thus, actuaries may wish to incorporate migration outcomes when considering social security implications from climate changes, and the interactions with other macroeconomic and geopolitical scenarios.

Table 4. Headline and Climate Assumptions

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Headline assumptions</th>
<th>Climate assumptions</th>
</tr>
</thead>
</table>
| A        | High global growth, and **exclusive** local social, political, and economic governance | • Increase in global temperature of 2.4 °C by 2060  
• Substantial decrease in crop productivity in dry regions, but increase in high latitudes  
• Substantial increase in the frequency of river flooding in South and East Asia, and West Africa  
• Substantial increase in the frequency of flooding for coastal cities  
• Substantial increase in water resource stress in North Africa, Middle East, and Europe  
• Increase in changes in mountain ecosystems  
• Permanent inundation of coastal property and infrastructure |
| B        | High global growth, and **inclusive** local social, political, and economic governance | |
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Ibid.


Ibid.


The baseline scenarios in the reviewed sources can vary and are not defined; therefore, they cannot 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 this CPP31 AR.

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