

## Research Paper

# Climate Change and Resource Sustainability An Overview for Actuaries

Climate Change and Sustainability Committee

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## Foreword

The topics of global warming and climate change are currently being discussed widely in all modes of media. Not a day passes when there is no coverage of these topics. Associated with them are the topics of increasing concentration of greenhouse gases, carbon dioxide emissions caused by fossil fuels, reduction of emissions, renewable energy generation, sustainability of the earth’s limited resources, and so on. The issues involved are complex. Even though a very large majority of the climate science community agrees on the causes of climate change, differing views do exist on ways to mitigate its adverse effects.

Climate change is expected to influence the work done by actuaries. The purpose of this paper is to provide some background on the science of climate change, its impacts, key ways to minimize the damage and the roles that the actuarial profession can play in dealing with the risks.

The following members of the CIA’s Climate Change and Sustainability Committee have prepared this paper for circulation to the members of the CIA.

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It is hoped that the paper will prompt discussions on the topics of climate change, resource sustainability and risk management and will encourage members of the CIA to present more papers on these issues.

We would like to express our sincere thanks to Kenneth Donaldson, Chair of the Resource and Environment Working Group (REWG) of the International Actuarial Association (IAA), and Alain Bourque, Chief Executive Officer of Ouranos – Climate Change Consortium for their detailed reviews of the paper. Their comments were very helpful.

The authors take full responsibility for the material contained and views expressed in the paper.

## **Abstract**

Actuaries are becoming more aware of the combined impact of climate change and limitations of resources—two separate and very significant issues—putting at risk the sustainability of the current socio-economic systems that support our way of life. Although actuaries do not claim professional expertise in environmental issues, they can be guided by the growing body of knowledge publicly available from reliable scientific sources. Being particularly qualified to deal with modelling financial consequences of risks and uncertainties, the actuarial profession has a duty to provide training and education on climate change and sustainability so that its members are qualified to contribute to the well-being of the society as a whole. In undertaking this exercise, the actuarial profession needs to be cognizant of the fact that even within the climate change science community there are differing views on the nature and amplitude of the risks and the profession should be aware of these differing views

Climate change is more than global warming. The rise in average temperature is only one indicator of broader changes also translating into extreme temperatures, drought, flooding, storms, rising sea levels, impacts on food production, and infectious diseases. Although the scientific community has been aware of the link between greenhouse gases (GHGs) and climate change for many years, world leaders have been slow to react and implement measures to mitigate the risks.

Key sources of information on climate change are synthesised by the successive reports of the Intergovernmental Panel on Climate Change (IPCC) created by the United Nations and the World Meteorological Organization in 1988. The prevalent view is that there is a significant anthropogenic contribution to the increase in atmospheric CO<sub>2</sub> and other GHGs resulting from fossil fuels emissions and deforestation. Unless new policies are implemented, global warming will exceed the threshold of 2°C agreed to by the parties to the UN Framework Convention on Climate Change for which Canada is a signatory.

In 1970, a paper by the Club of Rome pointed out that limited planet resources cannot support unlimited exponential growth. Even renewable resources will be depleted if they cannot be renewed fast enough. By some estimates, we are now using 50% more resources than the sustainable level. The 8 billion population projected by 2030 is twice the 4 billion the earth had to feed as recently as 1974. The pursuit of economic growth is compounding the growth in demand. Global warming is exacerbating the sustainability challenge as it may

reduce agricultural production and will result in physical damage resulting from extreme weather events, sea-level rise, etc.

Mitigating resource scarcity entails adopting new approaches such as a “circular economy”. This refers to an industrial economy that is restorative by definition. It aims to rely on renewable energy; favors recycling; minimizes, tracks, and hopefully eliminates the use of toxic chemicals; and eradicates wastes through careful design. The mitigation strategy can be guided by a new paradigm defining a planetary boundary framework providing a science-based analysis of the risk that human overuse of resources will destabilize the earth system at the planetary scale.

The potential impact on actuarial methods and assumptions, especially future growth expectations, is pervasive in the work of actuaries and affects traditional life and non-life, health and pensions areas, investment practices, and newer areas like enterprise risk management. The actuarial profession has created interest groups at the national and international levels to help deepen the understanding of the quantitative aspects of sustainability. It can collect feedback and provide critical reviews of actuarial risk models, establish standards of practice, and promote the adoption of best practices. The North American actuarial associations are jointly creating actuarial climate and risk indexes that will monitor future changes and provide comparisons of benchmarks with the data published by climate scientists.

Actuaries can examine the different scenarios for climate change and use of resources to quantify the risks and provide guidance through cost/benefit analyses. Given the multidisciplinary nature of these issues, actuaries can benefit from inputs by non-actuarial entities and work in cooperation with other professionals to serve the public interest through optimizing policy options.

## **Part 1 – Introduction**

### **1.1 Objective**

Extensive discussions are taking place throughout the world in all forms of media on the subjects of global warming and climate change. These discussions point to the global dangers posed by the earth’s warming. Discussions are also taking place on the related question of resource limitations, given the manner in which humans are using the planet’s limited resources.

The purpose of this paper is to provide some education to the members of the CIA. This will consist of providing some background to these issues, identifying some of the current and future risks involved, the possible financial and other impacts posed by these risks, and the worldwide efforts that are being made to minimize these risks. Empowered by a wider access to this knowledge, actuaries can employ their expertise in quantifying these risks and provide guidance to the different publics served by the CIA and thus enhance the well-being of society as a whole. A failure by the actuarial profession to provide advice on these risks could damage its credibility.

The different sectors of the economy have been examining these risks. A timely input by the actuarial profession would increase the visibility of the profession and create new opportunities.

## 1.2 Recognition of Risks

Due to the nature of the subject, the international discussions on climate change are driven by worldwide climate scientists. There would be a few members of the CIA who would have a good understanding of the issues involved. But the majority of actuaries may not have such understanding. As a result, actuaries have to be guided by the work done by the climate science community. No doubt, even within the climate change science community there are differing views on the nature and amplitude of the risks and actuaries should be aware of these differing views. However, considering the fact that a very large majority of that community is of the view that the risks posed by climate change are serious and could cause disastrous consequences if immediate action is not taken, actuaries have to consider these as distinct possibilities. The fact that climate science is still evolving or there are opposing views would not be a valid reason for the profession to choose to do nothing.

As understood from the work done by climate scientists, impacts of climate change will be very wide ranging—extreme climate, increased losses due to floods and storms, rising sea levels, food scarcity, clean water shortage, increased mortality and illness, devaluation of assets, constraints on energy use, and so on. The actuarial community has to obtain a good understanding of the issues involved. Just sitting there without doing anything will severely damage the profession's reputation.

The issue of climate change has been recognized by many professions. The actuarial community can benefit from finding out the perceptions of the different professions of how climate change will affect the work done by them.

A classic example of proactive action taken by the actuarial profession would be how it handled the risk of AIDS in the early 1980s. As soon as the world became aware of the AIDS risk, different actuarial bodies designed a variety of infection scenarios that enabled the life insurance industry to set up adequate reserves for the additional mortality. A similar proactive approach can be taken to address the risks posed by climate change. The methods and solutions would be different, but the first steps would be risk recognition and quantification for different scenarios.

## Part 2 – Climate Change, Process, Reasons, and Future Impacts

### 2.1 What is Climate Change?

Climate change is the subject of how weather patterns change over decades or longer. Climate change takes place due to natural and human influences. Since the Industrial Revolution (i.e., 1750), humans have contributed to climate change through the emissions of GHGs and aerosols, and through changes in land use, resulting in a rise in global temperatures.<sup>1</sup> Increases in global temperatures may have different impacts, such as an

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<sup>1</sup> [http://www.wmo.int/pages/themes/climate/causes\\_of\\_climate\\_change.php](http://www.wmo.int/pages/themes/climate/causes_of_climate_change.php)

increase in storms, floods, droughts, and sea levels, and the decline of ice sheets, sea ice, and glaciers.

## 2.2 Process of Global Warming

The earth receives energy through radiation from the sun. GHGs play an important role of trapping heat, maintaining the earth's temperature at a level that can sustain life. This phenomenon is called the greenhouse effect and is natural and necessary to support life on earth. Without the greenhouse effect, the earth would be approximately 33°C cooler than it is today.<sup>2</sup> In recent centuries, humans have contributed to an increase in atmospheric GHGs as a result of increased fossil fuel burning and deforestation. The rise in GHGs is the primary cause of global warming over the last century.

There are three main datasets that are referenced to measure global surface temperatures since 1850.<sup>3</sup> These datasets show warming of between +0.8°C and +1.0°C since 1900.<sup>4</sup> Since 1950, land-only measurements indicate warming trends of between +1.1°C and +1.3°C, as land temperatures tend to respond more quickly than oceans to the earth's changing climate. Figure 2.1 shows the global surface temperature trend (1880–2014).

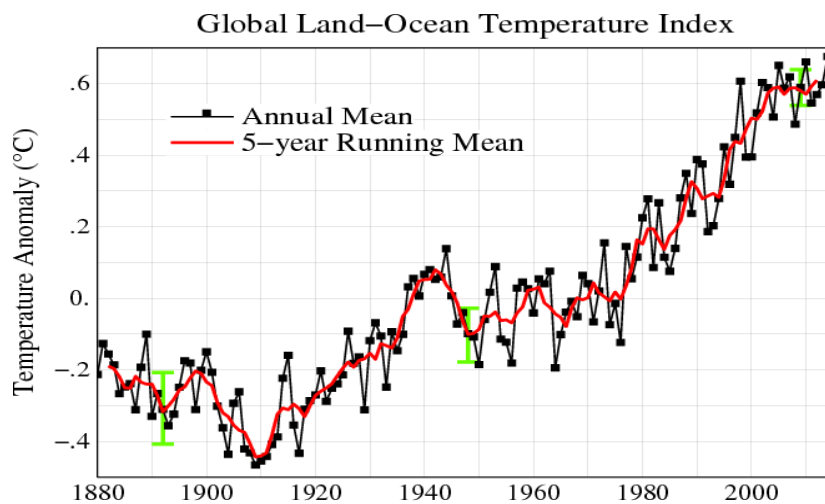


Figure 2.1: Instrumental temperature data 1880–2014. Source: NASA Goddard Institute for Space Studies (GISS)<sup>5</sup>

While global warming is typically measured on multi-decadal time scales (30+ years), attributing trends over time periods of less than 30 years can be tricky, due to the influence of natural variability. Natural variability is defined as variations in climate that are due to internal interactions between the atmosphere, ocean, land surface and sea ice. Those variations occur with or without climate change and are often described as “noise” or

<sup>2</sup> [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr\\_appendix.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_appendix.pdf)

<sup>3</sup> i) [The Hadley Centre for Climate Prediction and Research](#), ii) [Goddard Institute for Space Studies](#), and iii) [National Climate Data Center](#).

<sup>4</sup> Least-squares trend lines are calculated with the following tool: <http://www.skepticalscience.com/trend.php>

<sup>5</sup> [http://data.giss.nasa.gov/gistemp/graphs\\_v3/](http://data.giss.nasa.gov/gistemp/graphs_v3/)



normal variations around a “normal” value. The El Niño Southern Oscillation (ENSO) cycle is considered to be the strongest source of internal natural variability due to the exchange of heat between the oceans and the surface along the equatorial Pacific. Because of this internal and natural variability, global warming does not necessarily occur linearly in response to the increase in GHG concentrations, and various periods of accelerated warming and warming slowdowns are a natural source of variability. Figure 2.2 shows two such periods in the context of longer-term global warming and also illustrates natural variability occurring on a yearly basis.

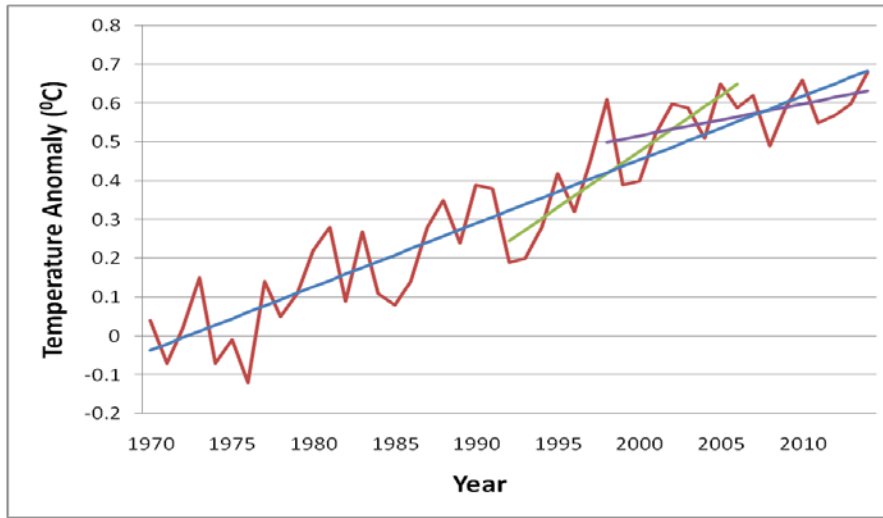


Figure 2.2: NASA GISS Global average temperatures. Forty-five-year trend is shown in blue. The “warming slowdown” (purple trend line: 1998–2014) was preceded by a period of accelerated warming (green trend line: 1992–2006).<sup>6</sup>

### 2.3 What is Causing Global Warming?

The climate of the earth is affected by a number of factors. These factors include output of energy from the sun (warming effect), volcanic eruptions (cooling effect), concentration of GHGs in the atmosphere (warming effect), and aerosols (cooling effect).

Since the Industrial Revolution (i.e., 1750), the largest contributor to the increase in global warming is **carbon dioxide** (CO<sub>2</sub>), followed by **methane** (CH<sub>4</sub>). CO<sub>2</sub> concentrations have increased from 278 parts per million (ppm) in 1960 to 401 ppm in 2015—a 44% increase (Figure 2.3).

<sup>6</sup> Derived from NASA GISS: [http://data.giss.nasa.gov/gistemp/tabledata\\_v3/GLB.Ts+dSST.txt](http://data.giss.nasa.gov/gistemp/tabledata_v3/GLB.Ts+dSST.txt)

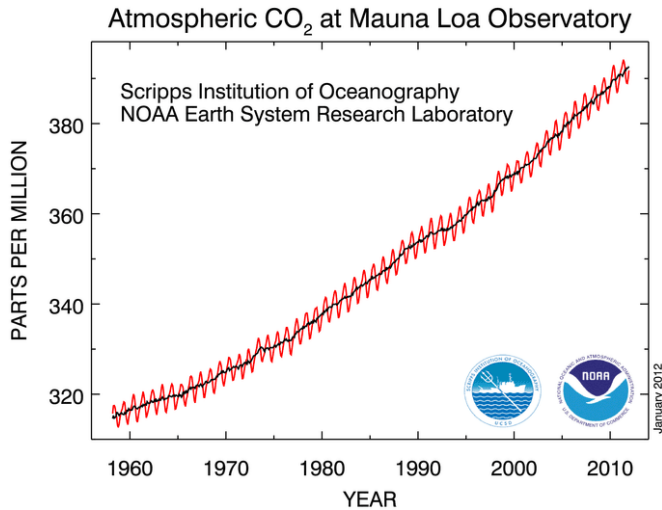


Figure 2.3: Growth of CO<sub>2</sub> concentrations at Mauna Loa Observatory since 1960<sup>7</sup>

Since 1951, approximately 100% of warming is attributed to anthropogenic forcings, while more than 100% is due to greenhouse gases due to offsets in anthropogenic aerosols (see Figure 2.4). Natural forcings and internal variability are considered to be negligible during this time period.

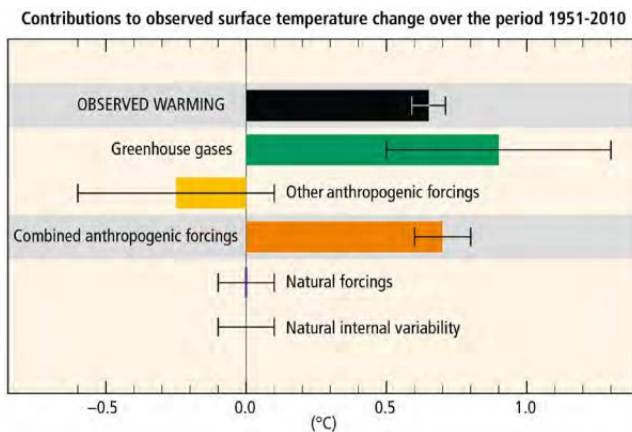


Figure 2.4: Growth of CO<sub>2</sub> concentrations at Mauna Loa Observatory since 1960.<sup>8</sup>

Water vapour has an important indirect effect on temperature increases resulting from increasing GHG concentrations. Increased global temperature resulting from GHGs increases the capacity of the atmosphere to hold water vapour, thus acting as a positive feedback, as water vapour also produces a greenhouse effect. An increase in global temperature by 1°C results in approximately a 7% increase in atmospheric water vapour. “Therefore, although CO<sub>2</sub> is the main anthropogenic control knob on climate, water vapour is a strong and fast feedback that amplifies any initial forcing by a typical factor of between

<sup>7</sup> <http://www.esrl.noaa.gov/gmd/ccgg/trends/>

<sup>8</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5\\_SYR\\_FINAL\\_SPM.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf) (p.6)

two and three. Water vapour is not a significant initial forcing, but is nevertheless a fundamental agent of climate change”.<sup>9</sup>

Not all industrial emissions result in a warming bias. **Aerosols** resulting from industrial emissions have worked to offset about 26% of greenhouse warming due to blocking solar radiation from reaching the earth’s surface. There is, however, large uncertainty regarding the extent of influence that aerosols have on climate, mainly due to aerosol interactions with clouds.<sup>10</sup>

GHGs (particularly CO<sub>2</sub>) have a longer **residence time** in the atmosphere (~100 years) compared to aerosols (only 10 days). As a result, the short-term effect of industrial pollution can be cooling followed by long-term warming. Aerosols are expected to offset a lower percentage of greenhouse warming in most future scenarios due to residence time, which allows for the possibility of an acceleration of future warming even without an acceleration of GHG concentrations.<sup>11</sup>

The **greenhouse effect** occurs when solar energy making contact with the earth’s surface is retransmitted to the atmosphere in the form of **infrared thermal radiation**. This radiation has a lower wave frequency than solar energy itself. GHG molecules absorb this thermal radiation at low frequencies, causing these molecules to vibrate. These greenhouse molecules then emit energy in the form of infrared photons, many of which return to the earth’s surface. Non-GHGs such as oxygen and nitrogen do not absorb thermal radiation.<sup>12</sup>

The greenhouse effect is measured in terms of **Radiative Forcing** (RF) in units of watts per square meter (W/m<sup>2</sup>). Since the Industrial Revolution, the total RF is estimated to have increased by approximately 2.3 W/m<sup>2</sup> (1.1 W/m<sup>2</sup> – 3.3 W/m<sup>2</sup>; 90% confidence interval) mainly due to the net effect of increased GHG and aerosol concentrations in the atmosphere.<sup>13</sup>

The response of climate to the change in the earth’s energy is referred to as **climate sensitivity**. **Equilibrium Climate Sensitivity** (ECS) is used to gauge the long-term response (i.e., 100+ years) to a doubling of CO<sub>2</sub> concentrations in the atmosphere, and estimates range from 1.5°C to 4.5°C according to the IPCC. This corresponds with an increase in RF of +3.7 W/m<sup>2</sup> (+3.0W/m<sup>2</sup> to +4.4 W/m<sup>2</sup>). Alternatively, a **Transient Climate Response** (TCR) estimate is used to gauge shorter-term impacts (i.e., over 20 years) to a doubling of CO<sub>2</sub> concentrations in the atmosphere, and estimates range from 1.0°C to 2.5°C. The shorter-term estimates are lower due to the time it takes to heat up the oceans.<sup>14</sup>

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<sup>9</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_Chapter08\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf) (pp. 666–667).

<sup>10</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_SPM\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf) (pp. 13–14)

<sup>11</sup> <http://www.realclimate.org/index.php/archives/2007/02/aerosols-the-last-frontier/>

<sup>12</sup> <http://scied.ucar.edu/carbon-dioxide-absorbs-and-re-emits-infrared-radiation>

<sup>13</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_SPM\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf) (p. 14; figure SPM-05)

<sup>14</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_TS\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_TS_FINAL.pdf) (pp. 67–68; 82–85)

## 2.4 Historical Emissions

Figure 2.5 shows historical anthropogenic GHG emissions by type of GHG (expressed as CO<sub>2</sub> equivalent/year). CO<sub>2</sub> emissions represented 76% of GHG emissions. “CO<sub>2</sub> FOLU” refers to net CO<sub>2</sub> emissions resulting for forestry and other land use.

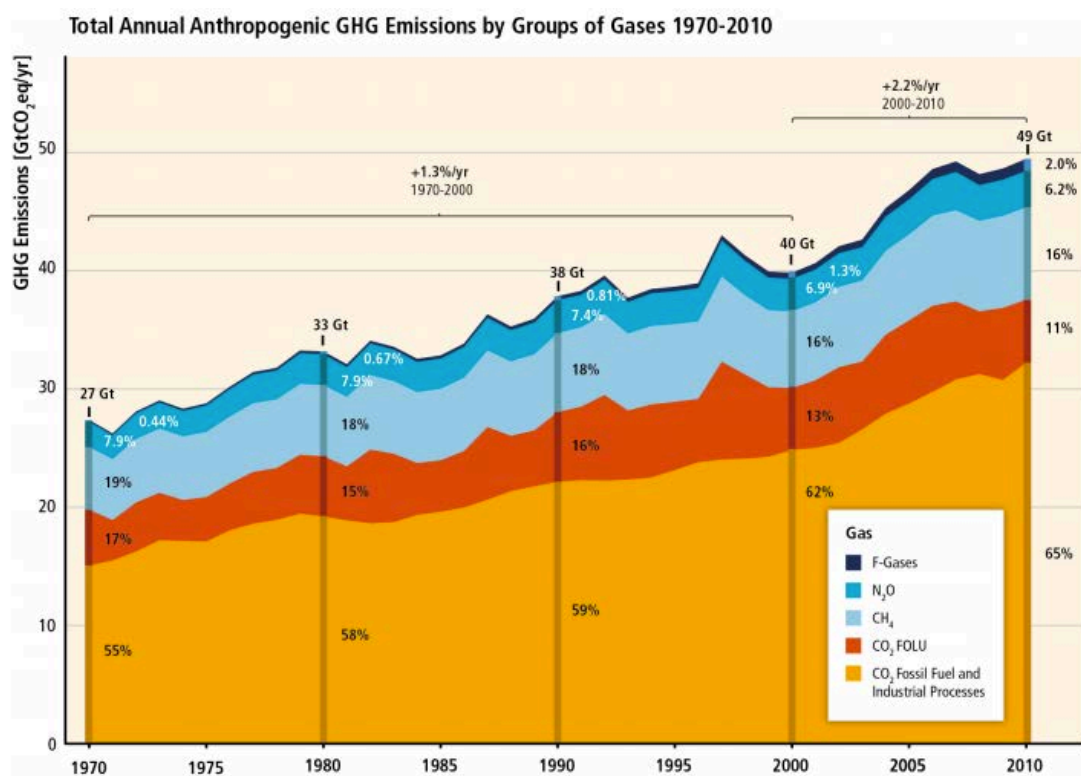


Figure 2.5: Historical Annual Anthropogenic GHG emissions, 1970–2010 (Gt CO<sub>2</sub>e/yr)<sup>15</sup>

## 2.5 Future Emissions Pathways

There are many factors that can influence future GHG emissions. The 2013 IPCC report uses Representative Concentration Pathways (RCPs) to illustrate various plausible emission scenarios, ranging from an aggressive action plan to mitigate greenhouse warming (RCP 2.6) to a fossil fuel-intensive scenario (RCP 8.5), where annual carbon emissions continue to increase. Climate model projections using RCP 2.6 to RCP 8.5 range from a century scale (between 1995 and 2090) increase of between +1.0°C [0.3°C, +1.7°C] and +3.7°C [2.6°C, 4.8°C] (mean estimates of low- and high-carbon scenarios with 90% confidence intervals). Note these estimates exclude warming prior to 1995 (~+0.6°C). The IPCC does not offer an opinion as to the likelihood of these scenarios essentially because it is not a “science” question but rather a “societal” question – how much reduction do the societies are willing to reach during the next century.<sup>16</sup>

<sup>15</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc\\_wg3\\_ar5\\_summary-for-policymakers.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf) (p. 7)

<sup>16</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_TS\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_TS_FINAL.pdf) (p. 90)

Figure 2.6 illustrates future potential GHG emissions pathways under three of the IPCC RCP scenarios. Keeping warming to under 2°C worldwide (relative to 1750) is widely considered to be an important target in reducing the risk of dangerous warming, but is unlikely to be achieved without substantial reductions in GHG emissions.<sup>17</sup>

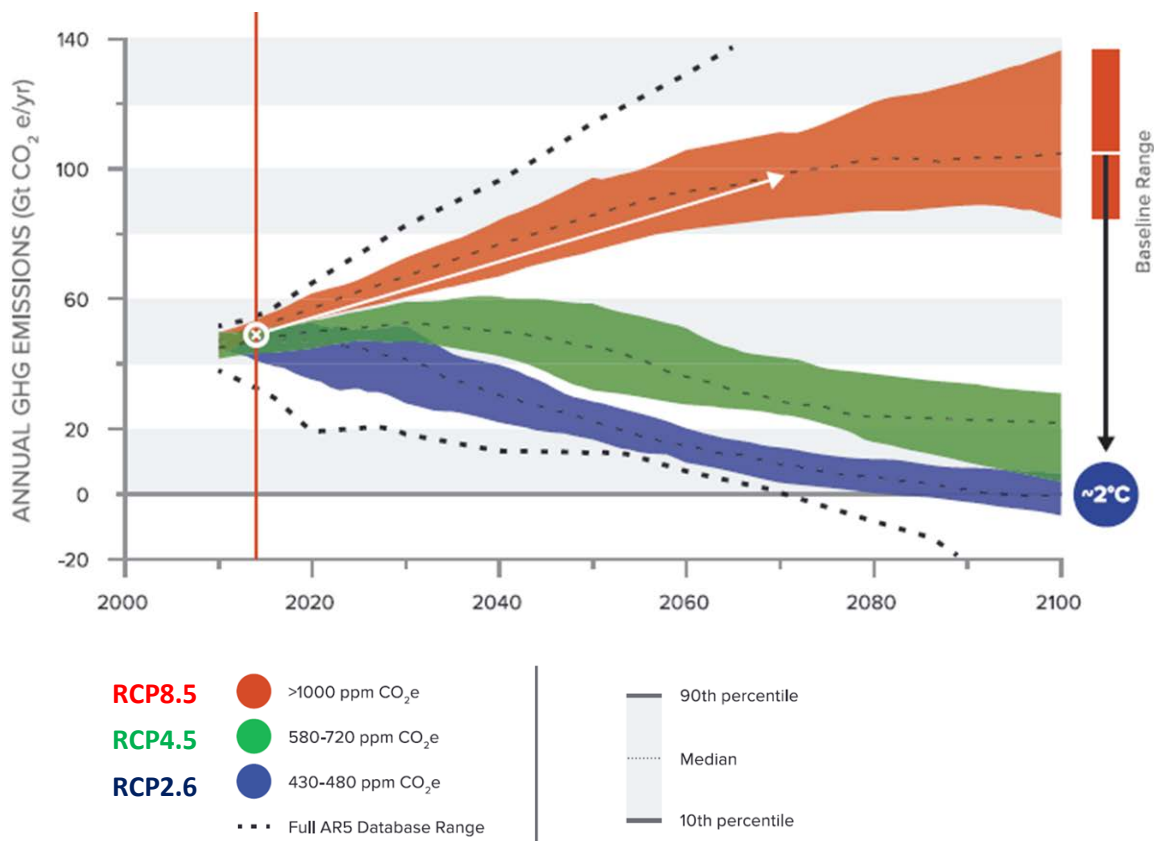


Figure 2.6 Future GHG Emissions Pathways, 2010–2100 (Gt CO<sub>2</sub>e/year)

## 2.6 Environmental and Social Impacts of Climate Change

Climate change involves a variety of potential environmental, social, and economic impacts. In most situations, these impacts will be adverse; in a few isolated situations, these could be more favorable (such as increased crop yield). The severity of the adverse impacts will increase with the rise in the average global temperature. Even if global warming is kept within 2°C relative to pre-industrial levels, adverse impacts will be experienced and the world will need to take appropriate measures to adapt to new climate conditions. If, in spite of the world efforts, the temperature increase goes beyond the 2°C threshold, it has been assessed that the consequences would become increasingly severe, widespread and irreversible.

<sup>17</sup> [http://newclimateeconomy.report/wp-content/uploads/2014/08/NCE\\_GlobalReport.pdf](http://newclimateeconomy.report/wp-content/uploads/2014/08/NCE_GlobalReport.pdf)

Canada has already become warmer by 1.5°C on average from 1950 to 2010.<sup>18</sup> Climate change is expected to make extreme weather events, such as heat waves, acute rainfall, floods, storms, droughts, and forest fires, more frequent and/or more severe in Canada. Worldwide, the areas in which adverse impacts will be experienced are described below.

#### *Floods and Droughts*<sup>19</sup>

Floods are expected to occur more frequently on more than half of the earth's surface. In some regions, they could decrease. During winter, snowfalls are expected to decrease in mid-latitudes, resulting in less significant snowmelt floods during the spring season. In Canada, increased rainfall is forecasted for the entire country.

On the other hand, meteorological droughts (less rainfall) and agricultural droughts (drier soil) are projected to become longer or more frequent in some regions and some seasons, especially under the RCP 8.5, because of reduced rainfall and increased evaporation, like in British Columbia and the Prairies. More severe droughts will put additional pressure on water supply systems of dry areas, but could be manageable in wetter areas, assuming adaption measures are implemented.

#### *Reduction in Water Resources*<sup>19</sup>

Renewable water supply is expected to decline in certain areas and expand in others. In regions where gains are expected, temporary deficits of water resources are still possible because of increased fluctuations of stream flow (caused by higher volatility of precipitation and increased evaporation during all seasons) and of seasonal cutbacks (because of lower accumulation of snow and ice). Clean water supply may also decrease due to a warmer environment inducing lower water quality. For example, algae-producing toxins could damage the quality of sources such as lakes. Such overall decline in renewable water supply will intensify competition for water among agriculture, ecosystems, settlements, industry, and energy production, affecting regional water, energy, and food security.

#### *Rising Sea Levels*

In some regions such as the U.S. Eastern Coast, tides are reaching up to three feet higher than they used to 50 years ago.<sup>20</sup> Rising sea levels will have more and more negative consequences near the coasts—such as flooding, erosion of the coasts, and submergence of low-lying regions—putting at risk populations, infrastructure, animals, and vegetation near the coasts. Low-lying regions (like Bangladesh) and whole islands (like the Maldives and Kiribati) are at risk of destruction in the short term from rising ocean levels, floods, and more intense storm urges.

Around the world, 15 of the 20 biggest urban regions are located near the coast (14 in Asia) and around 200 million people reside fewer than 30 miles from the ocean. Based on a Reuter's analysis, more than \$1.4 trillion worth of real estate would be at risk on the coast

<sup>18</sup> [http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report\\_Eng.pdf](http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf)

<sup>19</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap3\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap3_FINAL.pdf)

<sup>20</sup> <http://reut.rs/1MbnkBi>

of the U.S. alone. “An increasing percentage of the U.S. population and economic assets—including major U.S. cities and financial hubs such as Miami, Lower Manhattan, New Orleans, and Washington DC—are located on or near coasts, and they are threatened by sea-level rise.”<sup>21</sup>

### *Changes in Ecosystems*<sup>22</sup>

In the past millions of years, climate changes have naturally occurred at slower paces, permitting the ecosystems to adapt. However, in the 20<sup>th</sup> century many argue that we have entered the Anthropocene.<sup>23</sup> Species extinction rate has exceeded by up to 100 times the “normal” pace (i.e., without anthropogenic impact). We are facing a major biodiversity crisis and we might even be entering a sixth “mass extinction”.<sup>24</sup> In the 21<sup>st</sup> century and beyond, the risk of extinction that land and aquatic species are exposed to is higher under all RCP scenarios. As early as 2050, the rapid changes that are currently taking place are expected to jeopardize both land and ocean ecosystems, particularly under RCP 6.0 and RCP 8.5. It may be noted that the changes in ecosystems involve much more than climate change. Massive extinctions are caused by many factors including urbanization, increased world population, etc. Of course, climate change has made its contribution which will amplify with time.

Even under RCPs projecting modest global warming levels (RCP 2.6 to RCP 6.0), the majority of ecosystems will remain vulnerable to climate change. The increase in average temperatures will cause a lot of terrestrial and aquatic species to migrate towards more adequate climates, but many of them will not be able to do so quickly enough during the 21<sup>st</sup> century under RCP 4.5 to RCP 8.5, thus jeopardizing biodiversity. This migration trend is already being observed for vegetal and animal species in Canada.<sup>25</sup>

### *Food Production and Security*

Obvious climate change impacts on terrestrial food production can already be observed in some sectors around the globe. In the past few years, climate extremes such as droughts have occurred in major producing areas, resulting in many episodes of price hikes for food and cereals. Although these effects are beneficial in certain areas, adverse consequences are more frequent than favourable ones, especially, because key production areas (e.g. California) are located in historically favourable areas which will become unfavourable. Many climate change impacts will increasingly affect food security—particularly in low-latitude regions—and will be exacerbated by escalating food demand.<sup>26</sup> Forecasted ocean-level rise will threaten crucial food-producing areas along the coasts, such as India and Bangladesh, which are major rice producers.

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<sup>21</sup> [http://biospherology.com/PDF/MAB\\_2014.pdf](http://biospherology.com/PDF/MAB_2014.pdf) (p. 27)

<sup>22</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-FrontMatterA\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-FrontMatterA_FINAL.pdf) (chapters 4–6)

<sup>23</sup> Crutzen, P. J., and E. F. Stoermer (2000). "The 'Anthropocene'". *Global Change Newsletter* 41: 17–18.

<sup>24</sup> <http://advances.sciencemag.org/content/1/5/e1400253>

<sup>25</sup> [http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report\\_Eng.pdf](http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf)

<sup>26</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap7\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap7_FINAL.pdf)

Climate change is also a key political issue, and its consequences, such as food insecurity, are already generating conflict in vulnerable regions around the globe. For example in northern Africa, there is increasing evidence that even though climate change impacts such as food insecurity are not the “cause” of the 2011 Arab spring, they may have precipitated the uprisings. The expected impacts of climate change—such as extreme temperatures, flooding, droughts, rising ocean levels, and ocean acidification—will not only exacerbate existing tensions but will also be a major challenge for homeland security.<sup>27</sup>

### *Human Health*<sup>28</sup>

If climate change keeps occurring as forecasted under RCP scenarios, it will influence human health in three different ways:

- Extreme weather events have direct impacts such as increased risks of death and disability.
- Alterations of the environment and ecosystems indirectly affect human health, such as a higher prevalence of waterborne illnesses caused by higher temperatures or increased death and disability rates during extreme heat episodes. Climate change will exacerbate current illness loads, especially in regions with fragile healthcare systems and lesser ability to adapt. Poor regions—especially poor children—are expected to be the most vulnerable to climate-related health risks.
- Other indirect consequences pertaining to societal systems will arise, such as under-nutrition and mental disorders caused by stressed food production systems, increased food insecurity and relocation resulting from climate extremes.

## **2.7 Economic Impacts of Climate Change**<sup>29</sup>

In all likelihood, environmental and social impacts of climate change discussed above will have financial consequences on many sectors across the economy. Based on the Stern Review on the Economics of Climate Change, the price of doing nothing about climate change will be equivalent to an annual loss of 5% or more in global GDP, *ad infinitum*. If a broader spectrum of effects and contingencies is included in the analysis, the estimated costs could reach 20% of GDP or more. In comparison, the price of managing to stabilize atmospheric GHG levels within a range of 500–550 ppm of CO<sub>2</sub> equivalent is estimated to be 1% of global GDP annually, assuming that we begin implementing sharp mitigation measures now. Therefore, this cost/benefit analysis is a clear economic incentive to take significant actions sooner than later.<sup>30</sup>

A fundamental transformation away from fossil fuels and towards renewable energy at a global level such as envisaged under RCP 2.6 will have very large local and global consequences for all economic sectors, and presents both opportunities and downside risks. For example, the growth in energy demand has historically been highly correlated to gross

<sup>27</sup> [http://biospherology.com/PDF/MAB\\_2014.pdf](http://biospherology.com/PDF/MAB_2014.pdf)

<sup>28</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap11\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap11_FINAL.pdf)

<sup>29</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap10\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap10_FINAL.pdf)

<sup>30</sup> [http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview\\_report\\_complete.pdf](http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf)



domestic product (GDP) growth per capita, especially in low- and middle-income economies.<sup>31</sup> Moving away from fossil fuels involves a risk of “stranded assets”, but taking action to mitigate climate change will generate substantial commercial opportunities, with the development of new markets such as energy technologies and other goods and services that are low-carbon. “These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly. The world does not need to choose between averting climate change and promoting growth and development.”<sup>32</sup>

Thus, both physical impacts of climate change and adaptation measures will have consequences on basically all sectors across the economy. Here are some of them.

- The increased frequency and magnitude of extreme weather events will affect the insurance industry, causing greater damage and higher loss volatility to property/casualty, life, and health insurance. It may make it more difficult for insurance systems to provide coverage at a reasonable cost and to increase the risk-based capital.
- Impacts on human health will expand the need for healthcare and add stress to existing healthcare systems.
- The financial services industry may also be impacted at different levels, based on their asset/loan portfolios’ vulnerability to climate change.
- Weather-sensitive sectors such as agriculture, forestry, fisheries, tourism, hydroelectricity, transportation, and mining will inevitably be impacted.
- Economic development and productivity may decline.
- Extreme climate and weather events may threaten the proper functioning of pipelines, electricity grids, and transport infrastructure.
- The need for heating may lessen, and the need for cooling intensify, in properties of both individuals and businesses.

Estimations and projections of economic costs are complex and rely upon a multitude of assumptions that are difficult to determine. They vary widely among different countries. “Further research, collection, and access to more detailed economic data and the advancement of analytic methods and tools will be required to assess further the potential impacts of climate on key economic systems and sectors.”<sup>33</sup>

## 2.8 Global Perspective on Climate Change Impacts

The climate change impacts discussed above will cause rising risk exposure as the average global temperatures rise. Figure 2.7 below illustrates the observed and predicted global warming trends based on two RCPs alongside the degree of additional risk associated with different levels of potential global warming.

<sup>31</sup> <https://www.imf.org/external/pubs/ft/weo/2011/01/pdf/text.pdf>

<sup>32</sup> [http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview\\_report\\_complete.pdf](http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf) (p. viii)

<sup>33</sup> [https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap10\\_FINAL.pdf](https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap10_FINAL.pdf)

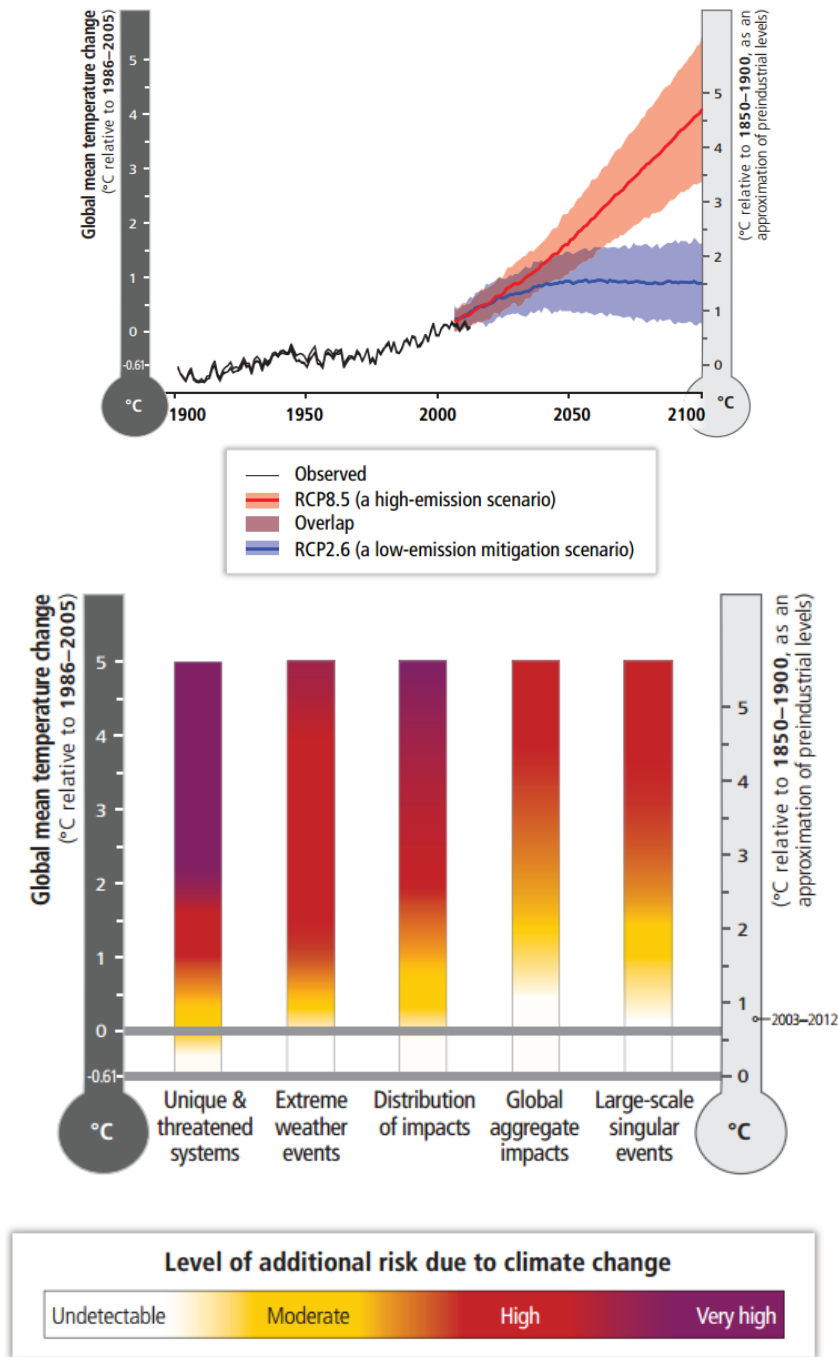


Figure 2.7: A global perspective on climate-related risks<sup>34</sup>

<sup>34</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5\\_wgII\\_spm\\_en.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf) (p. 13)

Global warming projections suggest that climate change impacts will vary greatly among regions, and happen on different time scales. However, it is important to keep in mind that a myriad of interrelations exist among communities worldwide. Effects of climate change occurring in a particular region may trigger ripple effects around the globe via internationally connected systems like the economy. For example, extreme climates interfering with agricultural harvests or warming sea temperatures leading to reduced fishing yields in a given region may affect both prices and food supply throughout the world. Moreover, climate change may modify migration patterns of human beings, other living organisms and physical materials, thus triggering collateral consequences elsewhere, even in remote areas. “Migration can affect many aspects of the regions people leave, as well as many aspects of their destination points, including income levels, land use, and the availability of natural resources, and the health and security of the affected populations—these effects can be positive or negative.”<sup>35</sup>

Also, as early as 2030, the population is projected to grow to 8 billion people. The U.S. National Intelligence Council’s “Global Trends 2030: Alternative Worlds” found that because of increases in the global population and the consumption patterns of an expanding global middle class, in less than two decades demand for food would increase by 35 percent, freshwater by 40 percent, and energy by 50 percent.<sup>36</sup> There is growing evidence that water, food, and energy are closely interrelated. Therefore, sustainable solutions to address reduction in water resources, food security issues, or energy challenges should consider this relationship to avoid having unintended collateral consequences in other areas.

For these reasons, in order to serve the public interest and provide best advice to our clients, we need to keep global well-being in mind, rather than focusing on a region- or sector-specific outlook.

### **Part 3 – Intergovernmental Work on Climate Change**

#### **3.1 Historical Perspective**

Climate science dates back almost 200 years, when Joseph Fourier described in 1824 what we know as the greenhouse effect. The Swedish physical chemist Svante Arrhenius deserves a mention for his 1896 pioneering study of how changes in the amount of CO<sub>2</sub> in the atmosphere may affect climate. By the second half of the 20<sup>th</sup> century, on the basis of numerous studies and more comprehensive modelling made possible by the exponential growth of modern computers’ capacity, many scientists concluded that increased CO<sub>2</sub> concentrations result in global warming as temperatures around the northern hemisphere reached early-20<sup>th</sup> century peaks. Concerns were expressed about rising sea levels, loss of habitat, and shifting agricultural zones.<sup>37</sup>

The 1979 World Climate Conference, a scientific gathering, said climate change was a problem and endorsed plans to establish a world climate programme under the joint

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<sup>35</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap19\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap19_FINAL.pdf) (p. 1062)

<sup>36</sup> [http://biospherology.com/PDF/MAB\\_2014.pdf](http://biospherology.com/PDF/MAB_2014.pdf) (p. 16)

<sup>37</sup> <http://www.colby.edu/sts/controversy/pages/9historical.pdf>

responsibility of the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions.<sup>38</sup>

In 1988, the WMO and the UNEP established the IPCC. In 1990, the IPCC released the first assessment report, saying “emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases”, which led to calls for a global climate treaty. The IPCC is discussed further in section 3.3.

### 3.2 United Nations Framework Convention on Climate Change

In 1992, the text of the United Nations Framework Convention on Climate Change was adopted by 196 parties/countries. The convention states its ultimate objective, which is to stabilize the concentration of GHGs in the atmosphere “at a level that would prevent dangerous anthropogenic (i.e., human) interference with the climate system.”<sup>39</sup>

Parties meet annually at the Conference of the Parties (COP) to negotiate multilateral responses to climate change. In 1997, the Kyoto Protocol was adopted at COP3, being the world’s first GHG emissions reduction treaty based on the principle of ‘Common but Differentiated Responsibilities’. The Kyoto Protocol came into force in late 2004 and expired in 2012. Canada was the first party to withdraw from the protocol in 2007. In 2009 (COP15), the Copenhagen Accord<sup>40</sup> represented the first time that the parties formally recognized that the increase in global temperature should be kept below 2°C.

### 3.3 Intergovernmental Panel on Climate Change

The IPCC is a scientific body which oversees the reviews and assesses the most recent scientific, technical, and socio-economic information produced worldwide relevant to the understanding of climate change. Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis as authors, contributors, and reviewers. The IPCC aims to reflect a range of views and expertise to provide rigorous and balanced scientific information to decision makers. The work of the organization is relevant, neutral, and non-prescriptive.

The IPCC is currently organized in three working groups and a task force that deal with different aspects of climate change:

- Working Group I—the physical science basis of climate change;
- Working Group II—climate change impacts, adaptation, and vulnerability;
- Working Group III—mitigation of climate change; and
- Task Force—refine a methodology for the calculation and reporting of national GHG emissions and removals.

The IPCC provides different reports (assessment reports (AR), special reports, and methodology reports). The most recent assessment report (AR5) was finalized in November 2014 with the following highlights:

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<sup>38</sup> [http://www.wmo.int/pages/themes/climate/international\\_wcc.php](http://www.wmo.int/pages/themes/climate/international_wcc.php)

<sup>39</sup> <http://unfccc.int/resource/docs/convkp/conveng.pdf>

<sup>40</sup> <http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf>

- Evidence that the climate is warming is unequivocal (Synthesis Report SPM<sup>41</sup>—page 1);
- The oceans have absorbed some of the CO<sub>2</sub>, causing acidification (WG1 SPM—page 11);
- Sea levels have risen and the rate of rise is accelerating (WG1 SPM—pages 11 and 26);
- The economic costs of mitigation would reduce consumption growth by about 0.04 to 0.14 percentage points per year (Synthesis Report SPM—page 24), depending on the level of warming; and
- Limiting total human-induced warming to less than 2°C with a probability of greater than 66% would require cumulative CO<sub>2</sub> emissions to remain below 2,900 Gt CO<sub>2</sub> (Synthesis Report SPM—page 10). (RCP 2.6)

### 3.4 Adaptation and Mitigation

The IPCC reports describe the consequences of uncontrolled global warming. “Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.”<sup>42</sup>

Technology development along with reduced energy use, decarbonized energy supply, reduced net emissions, and enhanced carbon sinks in land-based sectors are needed. This is discussed in greater detail in part 5 below.

### 3.5 Disagreements with the IPCC Report Conclusions<sup>43</sup>

A small segment of the climate scientist community has expressed disagreement with some of the conclusions drawn in the IPCC reports. Some non-climate scientists and socio-economic actors have also expressed doubts on conclusions from the IPCC. Some of the disagreeing scientists believe that the IPCC consensus overestimates climate sensitivity to CO<sub>2</sub> and underestimates the effect of natural variability. At the same time, some scientists believe that the IPCC underestimates the severity of climate change.<sup>44</sup> Generally speaking, the opposing views are more likely to be found in the newspaper articles and in other media rather than in the scientific literature.

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<sup>41</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5\\_SYR\\_FINAL\\_SPM.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf)

<sup>42</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5\\_SYR\\_FINAL\\_SPM.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf) Ibid

<sup>43</sup> <http://www.commdiginews.com/health-science/climate-change-where-theorists-and-skeptics-agree-and-disagree-18567/>

<sup>44</sup> <http://www.washingtonpost.com/blogs/wonkblog/wp/2014/10/30/climate-scientists-arent-too-alarmist-theyre-too-conservative/>

## Part 4 – Sustainability of Finite World Resources

### 4.1 Historical Perspective on Resource Scarcity

Although it may seem self-evident that the resources of our planet are limited and thus could not support indefinite exponential growth in the consumption of resources, the challenge has failed to generate enough attention. Even the report published in 1972 entitled *Limits to Growth*, sponsored by the Club of Rome, met with resistance and did not succeed in mobilizing public opinion at the time. The report estimated that constraints to growth would start to impact more visibly in the 21<sup>st</sup> century. It also indicated that changes in policies could yield an orderly end to growth and long periods of relatively high human welfare. The report generated controversy and its conclusions were generally rejected—especially the need for policy changes to ensure the sustainability of our way of life.

Unfortunately, the scenarios that were developed in the report seem to agree “worryingly well” with current projections as noted in a recently updated report sponsored by the UK actuarial profession and published in January 2013.<sup>45</sup> As population and economic growth accelerated and became exponential, a greater sense of urgency triggered calls for a response to this challenge to our way of life. The need for action has been compounded by the realization that the growth in the utilization of resources was exacerbating the effects of climate change. Reciprocally, climate change also impacts the availability of resources—in many cases negatively.

Despite growing concerns about sustainability, there is not yet a consensus about its definition and it is often confused with financial sustainability. An early definition used in the 1987 Brundtland report defines sustainable development as “meeting the needs of the current generation without compromising the ability of future generations to meet their own needs”. More recently, the emphasis has been on a more comprehensive view where sustainability refers to environmental, social, and economic sustainability. This has led to a proposal to assess sustainability on the basis of a “Triple Bottom Line” (TBL) framework, but the methodology to do it is still under development.

Since we all share the resources of the same planet, the pursuit of sustainability requires international coordination. As is the case for climate change, response to the challenge posed by the scarcity of resources has been delayed by controversy, differences of opinion as to the extent or the urgency, and by the difficulty of reconciling conflicting local interests that are impacted in different ways or degrees.

If resources constraints limit the potential for economic growth, they should be expected to have a pervasive effect on actuarial assumptions about financial, economic, and demographic outcomes. Thus, actuaries need to better understand the nature of these limitations and their impacts on a variety of actuarial assumptions.

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<sup>45</sup> <http://www.actuaries.org.uk/research-and-resources/documents/research-report-resource-constraints-sharing-finite-world-implicati>

## 4.2 Threat of Resource Scarcity

Limits and scarcity are relative concepts that apply differently to different categories of resources. Obviously there are finite quantities of gold, copper, iron, magnesium, rare earths, or other elements but they are not destroyed when used. However, their availability, cost, or ease of access can vary. Figure 4.1 illustrates for selected resources the 50-, 100-, and 150-year limits.

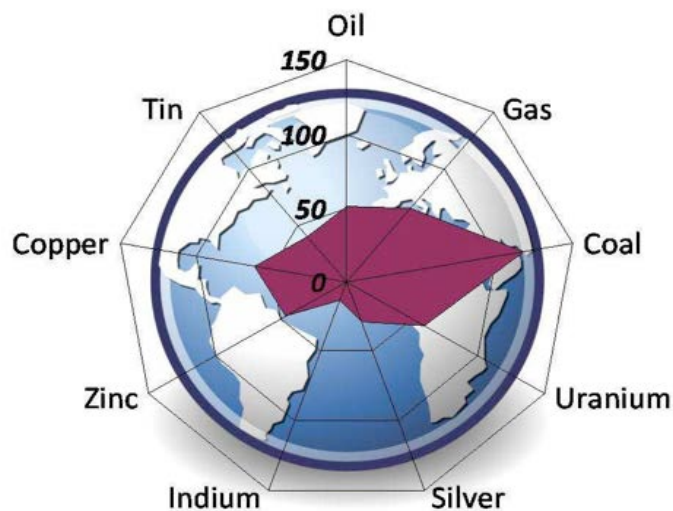


Figure 4.1: 50-, 100-, and 150-year limits for selected resources<sup>46</sup>

For example, at the current rate of consumption, oil will last about 50 years, gas somewhat more, but coal over 100 years. Thus, the way we use and recycle them may become an important policy option sooner or later depending on stock and ease of recycling. Some industries already apply methods allowing for easier recycling of metals like copper and aluminium. Other resources are consumed when used: for example, fossils fuels or nuclear fuels. Thus, their supply is finite and their effective availability can vary with the cost of accessing and processing them. In the short term, their scarcity may first affect their costs, but eventually availability may become the dominant issue.

Despite their name, renewable resources are in limited supply because the rate at which they can be renewed is limited. Food production relies on the availability of land and water. Methods of production may affect the quantity that can be produced or the rate at which it can be renewed. There is also competition between the various uses of land or water other than food production, so it is a complex challenge.

To add to the complexity, climate studies indicate that global warming may have a negative overall effect on food production and on sea level that would encroach on densely

<sup>46</sup> <http://www.actuaries.org.uk/research-and-resources/documents/research-report-resource-constraints-sharing-finite-world-implicati> (Page 12)

populated areas as well as on the availability of land for agriculture. It thus puts a premium value on initiatives that would enhance sustainability by optimizing the way humanity uses resources.

Since the earth receives each day more solar energy than it can use, the supply of energy could be deemed unlimited given the life expectancy of the sun. However, the accessibility and the costs of various sources of energy are important variables. For over 200 years, economic growth has been facilitated by fossil fuels that have been a massive store of energy available at a low apparent price relative to the income generated. They play a crucial role in the cost structure of agriculture, extractive industry, and transportation. In recent years, in a context of accelerating growth, despite the abundance of coal, concerns have been raised about the rate of discovery of new fossil fuels, oil in particular, falling behind the rate of extraction. That puts more pressure on substitution by other sources of energy, such as the wind or the sun, despite their higher cost using currently available technologies.

There is another dimension to the reliance on fossil fuels to meet growing energy demand: the impact of burning these fuels on climate change through the release of carbon in the atmosphere. Technologies to capture and store carbon are currently too expensive. Thus, despite their availability, humanity would need to agree to limit the burning of fossil fuels to avoid pushing global warming above the 2°C that has become the internationally agreed target. Implementing that limitation has given rise to the concept of “stranded assets”<sup>47</sup>. According to Mark Carney, a Canadian who became Governor of the Bank of England, the “vast majority of reserves are un-burnable” and thus have little or no economic value if the global warming is to be controlled.

Carbon is thus at the intersection of climate change and limits on resources. Shifting from a high-carbon economy to a low-carbon economy has gained more traction in recent years. That shift is necessary but not a sufficient condition to achieve sustainability, since it does not address the pressure of exponential growth on limited resources. A world that would no longer wish to pursue growth at all costs would need to overcome its addiction to growth and confront complex issues. The November 2014 report<sup>48</sup> of Canada’s Ecofiscal Commission suggests that better fiscal and pricing policies to correct market price signals would help ensure that “our grandchildren inherit Canada’s natural wealth, not its ecological debt”. Fiscal changes are to be seen as means to pursue a more ambitious objective stated in the conclusion of the report: “Future research by the Commission will focus on practical policy solutions that can drive the innovative economy we need to succeed in the 21<sup>st</sup> century”.

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<sup>47</sup> <http://www.smithschool.ox.ac.uk/research-programmes/stranded-assets/background.php>

<sup>48</sup> <http://ecofiscal.ca/reports/smart-practical-possible-canadian-options-for-greater-economic-and-environmental-prosperity/>



### 4.3 Overspending our Single Planet's Resources

An interesting way to look at renewable resources is illustrated in an article published by *Foreign Affairs* entitled "The Day the Earth Ran Out"<sup>49</sup>. It looks at the world ecological footprint that is the area of land and water required to meet human demand for resources and to absorb the waste, effluents, and pollutants it produces. Earth Overshoot Day marks the date when humanity's demand for ecological resources and services in a given year exceeds what the earth can regenerate in that year. The estimate for 2014 was August 19. By that calculation, humanity had consumed the resources of one planet in less than eight months. What is worse, each year that day has been coming a few days earlier. Even allowing for some uncertainty in the estimates, it seems obvious that we are consuming the resources of our planet in a non-sustainable way.

Only 14% of the world population lives in countries that do not overshoot their budget: Canada is one of the lucky few but it does not compensate for the fact that Canada ranks as the ninth country in terms of CO<sub>2</sub> contribution despite its low population. The margins of the few countries that show a positive balance are obviously insufficient to balance the deficit accumulated by the remaining 86% countries. Thus globally we are consuming about 1.5 earths each year. To survive, we need to learn how to live within our means.

### 4.4 Planetary Boundaries

In 2009, Johan Rockstrom et al published a paper entitled "Planetary Boundaries: Exploring the Safe Operating Space for Humanity". This paper was updated in 2015 and titled "Planetary boundaries: guiding human development on a changing planet".<sup>50</sup> Exceeding the planetary boundaries involves risks with associated costs that are difficult to quantify, since an earth system that functions within the typical parameters of the Holocene Period is foundational to our society's functioning. The Holocene Period is a geological epoch that began 10,000 years ago, when agriculture and human societies began to flourish. The world will need to take immediate steps to mitigate the risks of exceeding the boundaries. The mitigation efforts outlined in the different categories are interlinked.

According to the research, four planetary boundaries have been crossed:

#### *Phosphorus and Nitrogen*

Biogeochemical flows (phosphorus and nitrogen) are primarily from chemical fertilizers. Phosphorus use at approximately 22 million tonnes/year is double the boundary limit of 11 million tonnes/year. Nitrogen use at approximately 150 million tonnes/year is about 2.4 times the boundary limit of 62 million tonnes/year.

#### *Genetic Diversity*

The boundary for loss of genetic diversity is set at less than 10 extinctions per million species-years (E/MSY), while the actual rate is 100 to 1,000 E/MSY.

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<sup>49</sup> <https://www.foreignaffairs.com/articles/global-commons/2013-08-20/day-earth-ran-out>

<sup>50</sup> <http://www.stockholmresilience.org/21/research/research-news/1-15-2015-planetary-boundaries-2.0---new-and-improved.html>

### *Land Use*

The boundary for land use is set at having 75% of forested land compared to original forested cover. The current forestry cover is 62% of the original.

### *Climate Change*

The boundary for climate change is set at 350 ppm of CO<sub>2</sub> concentration in the atmosphere, while we had reached 395 ppm at the time of the research (and over 400ppm in 2015). This is discussed in detail in part 5.

The first two boundaries have been crossed beyond the zone of uncertainty, and represent a high risk. The latter two boundaries are within the zone of uncertainty, and represent an increasing risk. The estimated zone of uncertainty for land use is 54% to 75% of forested land compared to the original land cover.

## **4.5 Adoption of Circular Economy**

Adopting a new approach of “circular economy” can also mitigate resource scarcity. This refers to an industrial economy that is restorative by definition. It aims to rely on renewable energy; minimize, track, and hopefully eliminate the use of toxic chemicals; and eradicate waste through careful design.

Land use productivity will determine whether the world can feed a population projected to grow to 8 billion by 2030, while sustaining natural environments. This is twice the 4 billion the earth had to feed as recently as 1974. Food production can be increased and forest protected by raising crop and livestock productivity, using new technologies, and comprehensive approaches to soil and water management. Also, a given area of land can feed more people on a vegan diet than a vegetarian or an omnivorous diet. Studies as to the relative efficiency of vegan diets vary. The amount of usable protein for soy beans is 29 grams per m<sup>2</sup>, while for meat it is 4 grams per m<sup>2</sup>.<sup>51</sup> This means that one can have 7.25 times more usable protein per area of land if it is used to grow soybeans to feed people, rather than for meat production. At least 50% of all grain is used to feed animals<sup>52</sup>, so there is a large opportunity to feed more people, if we had less animal agriculture.

Another area that is ripe for innovation with respect to food is the reduction of food waste. According to the Natural Resources Defense Council, up to 40% of food is wasted, and the amount of food waste has increased by 50% from the 1970s.<sup>53</sup> This means that it is possible to decrease the amount of food wasted, which has the potential to save money, land, and energy.

## **4.6 Financial Implications of Resource Constraints**

Limits to resources imply constraints on growth or changes in the way of achieving it. How resource constraints impact the economy is complex and uncertain and depends on a number of factors. The outcomes for the global economy very much depend on societal and

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<sup>51</sup> [https://en.wikipedia.org/wiki/Edible\\_protein\\_per\\_unit\\_area\\_of\\_land#cite\\_note-NSRL-1](https://en.wikipedia.org/wiki/Edible_protein_per_unit_area_of_land#cite_note-NSRL-1)

<sup>52</sup> <http://www.fao.org/docrep/v8180t/v8180t07.htm>

<sup>53</sup> <http://www.nrdc.org/food/files/wasted-food-ip.pdf>

government response to the problems caused. Political and market responses will have far-reaching consequences, which need to be better understood and better modelled. To some degree, the impacts can be managed or at the very least influenced.

A world that would no longer wish to pursue growth at all costs would need to overcome its addiction to growth and confront complex issues. The evidence for resource constraints is strong but many actors in the global economy are not considering it in their decision-making processes. A pervasive difficulty is the “tragedy of horizon”, whereby the new challenges to long-term prosperity and economic resilience remain beyond the horizon defined by the conventional scope of risk analysis, the focus of equity markets, and the regulatory outlook. The impacts of future environmental shocks need to be considered and included in today’s asset values and capital allocation decisions to enable the financial system to see beyond that horizon.

Given their skills and experience in the modelling of the long-term outcomes of entities’ activities in the economic domain, actuaries are uniquely positioned in society relative to other professions to measure sustainability and model the effects of unsustainability on our assumptions and in the modelling and valuation of future or contingent liabilities.

Sustainability concerns could have a material effect on actuarial assumptions and future liabilities and on the advice provided to clients. Limits to growth are of importance to the actuarial profession. Implicit assumptions of indefinite exponential growth need to be revisited. If economic growth is limited by resource constraints, this could be reasonably expected to significantly affect future financial and demographic outcomes. If these future outcomes are indeed affected, then the assumptions that actuaries use should take into account these future developments.

Actuaries are well placed to advise governments and other economic agents because of their understanding of risk management and long-term modelling. To provide solutions that incorporate sustainability issues in investment decisions requires measuring the sustainability of the entities our clients invest in, the sustainability of our clients’ activities, and the effect of sustainability on economic returns. Developing appropriate methodologies will require a major investment in resources that can be shared on a global basis. We need to respect the eclectic nature of our discipline and recognize that to develop outcome-based measures to achieve sustainability, we will need to work with other disciplines and draw knowledge from them. Fortunately the pool of resources includes non-actuarial entities that are contributing in different ways to a better understanding of sustainability constraints.

## **Part 5 – Mitigation and Adaptation for Climate Change**

### **5.1 Keeping Global Warming under 2°C**

An international agreement had been reached at Copenhagen that global warming should be limited to 2°C. This is represented by RCP 2.6 (shown in figure 2.6 above). This RCP will be equivalent to CO<sub>2</sub> concentration of 450 ppm (with a range of 430–480 ppm). This scenario has emissions peaking by the year 2020, and reducing substantially after that, approaching zero carbon emissions by 2100. The IPCC Summary for Policymakers states:

“Delaying mitigation efforts beyond those in place today through 2030 is estimated to substantially increase the difficulty of the transition to low longer-term emissions levels and narrow the range of options consistent with maintaining temperature change below 2°C relative to pre-industrial levels (high confidence).”

The CO<sub>2</sub> equivalent emissions for 2010 were 49 Gt. It will be necessary to reduce these to 22 Gt by 2050. In order to reduce the emissions to zero by 2100, the total emissions up to 2050 will need to be limited to 825 Gt and those between 2050 and 2100 to 125 Gt. To stay within these “carbon budgets” for the rest of this century, the mitigation measures will need to focus on low-carbon electricity, reduced energy use, energy efficiency, and fuel switching. The implications for these measures are discussed below.

## 5.2 Mitigation Measures for Reducing Carbon Emissions

The need for reducing the CO<sub>2</sub> equivalent emissions will affect many sectors of the economy: energy creation, transport, buildings, industry, agriculture, human settlements, etc. These are discussed below.

### *Energy Creation*

Availability of adequate energy supply is fundamental to modern living. Currently, a major portion of the energy is generated using fossil fuels—coal, oil, and natural gas (in decreasing order of CO<sub>2</sub> emissions). These will need to be replaced by low- or zero-carbon fuels, such as wind, solar, and nuclear. It is true that nuclear power generation carries with it certain risks. But in order to increase the supply of low- or zero-carbon energy, attention will have to be paid to increasing safeguards. Increased emphasis will have to be placed on developing technologies for generating energy through renewable sources. In these efforts, the technology for carbon capture and storage (CCS) will play an important role. The CCS technology captures the CO<sub>2</sub> produced by fossil fuels and stores it permanently underground. Another area for technological advancement will be storage of the electricity generated from renewable sources as the energy supply is intermittent.

### *Transportation*

Advancements will need to take place in areas of energy efficiency, improved vehicle performance, use of electrical vehicles, integrated urban planning, development of high-speed rail systems, improvement in public transportation systems, etc.

### *Buildings*

Efforts will have to be made for adoption of low-energy building codes, use of energy-efficient appliances, reduced usage of non-renewable electricity, etc.

### *Industry*

Industry is a heavy user of energy. It will be necessary to undertake a wide-scale upgrading, replacement and deployment of new technologies, efficiency of material use, and recycling and re-using of materials and products.

### *Agriculture, Forestry, and Other Land Use*

The efforts in this area will be concentrated on crop land management, grazing land management, reforestation, restoration of organic soils, etc. A complimentary option for mitigation is the reduction in the amount of animal agriculture. The Food and Agriculture Organisation (FAO) of the UN estimates that 18% of the emissions are caused by animal agriculture. Livestock is responsible for 65% of emissions of nitrous oxide, a GHG that is 296 times more powerful than carbon dioxide.<sup>54</sup> Methane emissions are also a powerful GHG that is emitted by livestock.

### *Human Settlements, Infrastructure, and Spatial Planning*

Development of new concepts of urban planning (to minimize transportation needs of a growing population) will need to take place. Improving public transit systems will also play a big role.

## **5.3 Carbon Pricing**

Putting a price on carbon will be one widely discussed measure which could facilitate transition to the low/ zero carbon era.

At the present time, a very large proportion of the energy supply is provided by fossil fuels. In order to keep the global warming within the boundary of 2°C, the world has to move towards generating energy from renewable sources. While the fossil fuel industries are well established, the industries dealing with renewable energy are developing. This creates an imbalance in favour of the fossil fuel energy generation. On one hand, the fossil fuel energy is relatively less expensive but entails emissions that generate costs associated with global warming. On the other hand, the energy from renewable sources may be relatively more expensive but does not entail costs associated with global warming. A level playing field can be created by removing fossil fuel subsidies and putting a price on carbon. This would give an economic signal that will make fossil fuels' costs reflect the externalised costs for climate pollution, and make low-carbon energy more attractive. This will promote research in developing technologies in fields such as renewable energy generation and storage. It will also create an incentive for the fossil fuel industry to develop technologies for CCS—with reduced carbon emissions, the carbon cost will decrease.

The two major methods of carbon pricing are cap and trade and carbon taxes.

### *Cap and Trade*

Cap and trade is a carbon pricing system where the government sets a cap on the amount of GHG emissions, and companies can meet the cap by reducing their emissions or paying another entity to do so. Trading of emission allowances enables emissions to be reduced at a lower cost than requiring each company to lower their own emissions. If Company A can reduce emissions at a lower cost than Company B, it will be profitable for Company A to reduce its emissions more than its needs and sell the excess emissions to Company B (at a charge lower than what it costs Company B to reduce emissions on its own). Company B will

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<sup>54</sup> <http://www.fao.org/docrep/010/a0701e/a0701e00.htm>

also find the arrangement profitable because it can achieve the reduction of emissions at a lower cost.

### *Carbon Tax*

This is a tax on carbon emissions, based on the carbon content of the fuel. This would, for example, add more to the price of coal than to the price of gasoline, due to the higher carbon content of coal. A carbon tax will increase the price of carbon-intensive fuels, which will make low-carbon fuels more attractive. This will spur innovation in clean technology, as businesses will see a way to profit by providing lower-cost alternatives to carbon-intensive products.

With a carbon tax, the government will need to decide what to do with the revenue. Some of the revenue might be invested in transit infrastructure and/or research into clean technology and/or compensating consumers for the resulting higher prices due to the carbon tax. A revenue-neutral carbon tax returns all the money to taxpayers through a dividend or through a tax shift, or a combination of targeted payments and reductions in taxes.

### **Making a Choice between the Two Systems**

Table 5.1 compares the pros and cons of the two systems.

	Pros	Cons
<b>Cap and Trade</b>	<ul style="list-style-type: none"> <li>• Focus on emission reductions set by government. Price will be determined by the market.</li> <li>• Emissions are reduced at a lower cost due to the trading mechanism.</li> </ul>	<ul style="list-style-type: none"> <li>• Takes more time to implement (took four years for Québec).</li> <li>• More difficult to administer.</li> <li>• Complex set of regulations.</li> <li>• Trading mechanism can be gamed and is subject to fraud and speculation.</li> <li>• Generally applied to large emitters.</li> <li>• Due to large sums involved, more temptation for avoidance.</li> <li>• Could result in ineffective industrial policies designed to support politically favoured industries.</li> </ul>
<b>Carbon Tax</b>	<ul style="list-style-type: none"> <li>• Quicker to implement (took four months for British Columbia).</li> <li>• Easier to administer.</li> <li>• Easier to apply to a wider segment of the economy.</li> <li>• Much less room for avoidance for the end users.</li> </ul>	<ul style="list-style-type: none"> <li>• Price is set by government. Resulting emission reductions will be determined by the market. There is no guarantee that the desired level of emission reductions can be achieved.</li> </ul>

Table 5.1 – Pros and cons of cap and trade and carbon tax systems

Both systems have the issue where companies avoid paying the carbon price by shifting production to a jurisdiction without a carbon price. This is referred to as leakage. One way to prevent this is to have the carbon pricing apply universally, or in many jurisdictions. Alternatively, the government could allocate free or lower-cost permits in the case of cap and trade, or apply tax exemptions in the case of a carbon tax. Another way to address leakage is through the use of border tax adjustments with carbon taxes. A border tax adjustment will impose a tariff on the carbon content of imported goods to level the playing field within the jurisdiction imposing the carbon tax. Border tax adjustments can be applied by nations, but not by sub-national jurisdictions.

Both systems can be subject to the political process, with companies asking for free or low-cost emission permits in the case of cap and trade, or exemptions in the case of a carbon tax.

The system that seems to work the best in practice is carbon taxes. Cap and trade did not work well in the European Union, where the reductions in emissions may have been due to recession, rather than the cap and trade system. The price of carbon allowances collapsed,

so the market did not work well. Figure 5.2 shows the countries and regions that have adopted or are planning to adopt either of the two systems. Since the creation of this map in 2014, Ontario has announced that it will be implementing an emissions trading system.

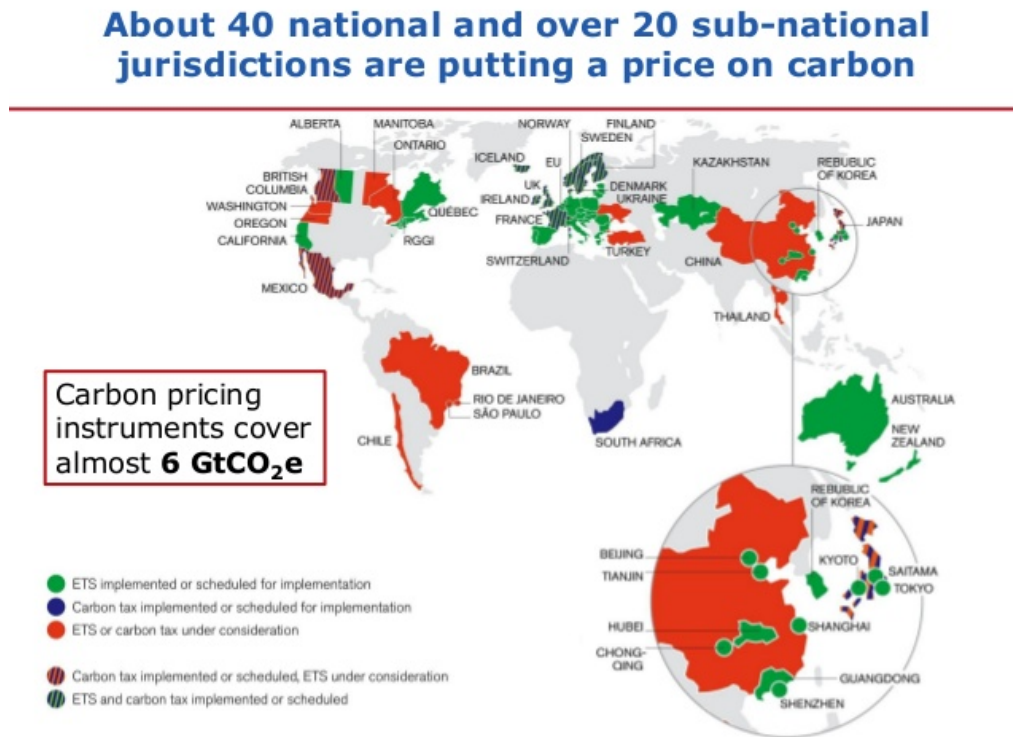


Figure 5.2 – Map showing the national and regional governments putting price on carbon<sup>55</sup>

#### 5.4 Impact of Low-Carbon Economy on Investments – Stranded Assets

In theory, CO<sub>2</sub> emissions can be reduced, even with the use of fossil fuels, via the use of CCS technology. However, due to the technological difficulties involved, widespread use of this technology does not seem likely. As a result, the reduced emissions have to be achieved with a drastic reduction in the use of fossil fuels. Current fossil fuel reserves are about 2,795 Gt of CO<sub>2</sub> equivalent. If the aim of zero carbon emissions is to be achieved by 2100, humanity will only be allowed to use 23% to 42% of the fossil fuel reserves. This means that the majority of fossil fuel assets will need to be left in the ground, and there is a risk of “stranded assets”. This will have implications on the valuation of such assets.

#### 5.5 Challenges in Implementing the Mitigation Measures

The increase in the concentration of GHGs (such as CO<sub>2</sub> or methane) due to increased emissions does not remain localized for very long; it gets uniformly distributed throughout the world in about 30 days. The world is getting smaller, interconnected, and interdependent. This means that no country can afford to remain isolated in the worldwide efforts to contain GHG emissions. Without full international cooperation from all countries,

<sup>55</sup> <http://www.slideshare.net/Ecofys/state-and-trends-of-carbon-pricing-2014-37901397>



it will be very difficult to make any meaningful progress. There are a number of challenges in being able to achieve the objective of a low- or zero-carbon world. Here are some of them:

#### *Political Ideology*

There are still a few countries with political ideologies that do not accept climate change as a reality and as a result they are making only lukewarm efforts. Perhaps there is an inherent fear that moving away from the relatively cheaper fossil fuels will have a serious effect on the GDP growth.

#### *Wide Variations in Emission Levels by Countries*

The GHG emissions of a country are the product of the country's population and the per-capita emissions. The current worldwide per-capita emissions are around 5 tonnes per year. The per-capita emissions by countries show a very wide variation. The highest is by Qatar with 40.3 tonnes; the U.S. is in 10<sup>th</sup> place with 17.6 tonnes, Canada in 15<sup>th</sup> with 14.7 tonnes. This can be compared with the per-capita emissions of China (6.2 tonnes), India (1.7 tonnes), and Zambia (0.2 tonnes)<sup>56</sup>. For countries at the low end of the scale, making emission reductions with current fuel sources for energy generation will be extremely difficult and may compromise their ability to achieve GDP growth.

#### *Economic Costs of Moving Away from Fossil Fuels*

Developing adequate low- or zero-carbon energy sources will require massive amounts of research and capital expenditure. There are widely differing views on how to share these costs.

The current situation has been caused by past emissions by regions with high per-capita emissions. The countries that will be most affected by the impacts of climate change will be those who had played no role in creating the problem. If the emerging economies are not to be held back in their GDP growth, ways have to be found to enable them to generate adequate low-carbon energy supplies.

#### *Uneven Impact of Climate Change*

It is estimated that the impact of climate change will vary by regions. While many will be severely affected, some may experience favourable effects (e.g., through increased crop yield)—at least initially. Such regions have to be persuaded to join the efforts to solve the worldwide problem. In the interconnected world, no country can remain unaffected for long.

### **5.6 Adaptation to Climate Change**

The global temperature records reveal that the earth has become warmer by about 1°C since 1900. International efforts are aiming to limit the increase to 2°C. Different regions are already experiencing the effects of global warming through increased floods, extreme temperatures, droughts, hurricanes, etc. As the temperature continues to rise, further

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<sup>56</sup> [http://en.wikipedia.org/wiki/List\\_of\\_countries\\_by\\_carbon\\_dioxide\\_emissions](http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions)

deterioration is to be expected. The world will need to take such deterioration into account in the years to come.

Public and private sectors and communities can adapt to the effects of global warming through disaster risk management, public health measures, livelihood diversification, coastal and water management, environmental protection, land planning, sea-level rise planning, etc. Adaptation will need to be embedded in the various planning processes. The following description from table SPM 3 contained in the 2014 IPCC Summary for Policymakers report<sup>57</sup> shows various approaches to adaptation and includes examples for each category.

#### ***Human Development***

- Improved access to education, nutrition, health facilities, energy, safe housing and settlement structures, and social support structures; reduced gender inequality and marginalization in other forms.

#### ***Poverty Alleviation***

- Improved access to and control of local resources; land tenure; disaster risk reduction; social safety nets and social protection; insurance schemes.

#### ***Livelihood Security***

- Income, asset, and livelihood diversification; improved infrastructure; access to technology and decision-making fora; increased decision-making power; changed cropping, livestock, and aquaculture practices; reliance on social networks.

#### ***Disaster Risk Management***

- Early warning systems; hazard and vulnerability mapping; diversifying water resources; improved drainage; flood and cyclone shelters; building codes and practices; storm and wastewater management; transport and road infrastructure improvements.

#### ***Ecosystem Management***

- Maintaining wetlands and urban green spaces; coastal afforestation; watershed and reservoir management; reduction of other stressors on ecosystems and of habitat fragmentation; maintenance of genetic diversity; manipulation of disturbance regimes; community-based natural resource management.

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<sup>57</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5\\_SYR\\_FINAL\\_SPM.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf)

***Spatial or Land-Use Planning***

- Provisioning of adequate housing, infrastructure, and services; managing development in flood-prone and other high-risk areas; urban planning and upgrading programs; land zoning laws; easements; protected areas.

***Structural/Physical***

- *Engineered and built-environment options*: sea walls and coastal protection structures; flood levees; water storage; improved drainage; flood and cyclone shelters; building codes and practices; storm and wastewater management; transport and road infrastructure improvements; floating houses; power plant and electricity grid adjustments.
- *Technological options*: new crop and animal varieties; indigenous, traditional, and local knowledge, technologies, and methods; efficient irrigation; water-saving technologies; desalinisation; conservation agriculture; food storage and preservation facilities; hazard and vulnerability mapping and monitoring; early-warning systems; building insulation; mechanical and passive cooling; technology development, transfer, and diffusion.
- *Ecosystem-based options*: ecological restoration; soil conservation; afforestation and reforestation; mangrove conservation and replanting; green infrastructure (e.g., shade trees, green roofs); controlling overfishing; fisheries co-management; assisted species migration and dispersal; ecological corridors; seed banks, gene banks, and other *ex situ* conservation; community-based natural resource management.
- *Services*: social safety nets and social protection; food banks and distribution of food surplus; municipal services including water and sanitation; vaccination programs; essential public health services; enhanced emergency medical services.

***Institutional***

- *Economic options*: financial incentives; insurance; catastrophe bonds; payments for ecosystem services; pricing water to encourage universal provision and careful use; microfinance; disaster contingency funds; cash transfers; public-private partnerships.
- *Laws and regulations*: land zoning laws; building standards and practices; easements; water regulations and agreements; laws to support disaster risk reduction; laws to encourage insurance purchasing; defined property rights and land tenure security; protected areas; fishing quotas; patent pools and technology transfer.
- *National and government policies and programs*: national and regional adaptation plans including mainstreaming; sub-national and local adaptation plans; economic diversification; urban upgrading programs; municipal water management programs; disaster planning and preparedness; integrated water resource management;

integrated coastal zone management; ecosystem-based management; community-based adaptation.

### **Social**

- *Educational options:* awareness raising and integrating into education; gender equity in education; extension services; sharing indigenous, traditional, and local knowledge; participatory action research and social learning; knowledge-sharing and learning platforms.
- *Informational options:* hazard and vulnerability mapping; early-warning and response systems; systematic monitoring and remote sensing; climate services; use of indigenous climate observations; participatory scenario development; integrated assessments.
- *Behavioural options:* household preparation and evacuation planning; migration; soil and water conservation; storm drain clearance; livelihood diversification; changed cropping, livestock, and aquaculture practices; reliance on social networks.

### **Spheres of change**

- *Practical:* social and technical innovations, behavioural shifts, or institutional and managerial changes that produce substantial shifts in outcomes.
- *Political:* political, social, cultural, and ecological decisions and actions consistent with reducing vulnerability and risk and supporting adaptation, mitigation, and sustainable development.
- *Personal:* individual and collective assumptions, beliefs, values, and worldviews influencing climate-change responses.

Responding to climate-related risks involves making decisions in a changing world with continuing uncertainty about the severity and timing for climate change impacts and limits to the effectiveness of adaptation. Those decisions can range from nature of strategies (location to a new long lasting infrastructure) to operational (managing water levels with dams).

## **Part 6 – The Role of the Actuarial Profession**

### **6.1 Contribution by the Actuarial Profession**

Actuaries are not climate scientists. As a result, they would not be in a position to provide an opinion on the science of climate change and its future impacts. For this purpose, they will have to be guided by the majority view held by the climate scientist community. The work done by the IPCC provides an indication of the likely future impacts under different scenarios. The actuarial profession should recognize climate change and its impact as a distinct possibility and use its expertise in quantifying these risks. The actuarial profession can make a valuable contribution to the current efforts to deal with climate change by setting up suitable indexes to monitor the future events that will permit them to increase the confidence level in their estimates of future costs.

The following sections describe the areas in which the actuarial profession can make its contribution.

## 6.2 Inputs on Climate Change Scenarios

The models used in the research for climate change are complex and use long-term projections. Actuaries are well versed in the use of models. The contribution by the profession could take the following forms:

- Examination of the different parameters used and their relevance to the projections;
- Examination of the data used as input to the models; and
- Examination of the analysis of results generated by the models.

An example of a contribution to climate change scenarios would be the work done by Mercer to model investment performance out to 2050 under alternate scenarios.<sup>58</sup>

## 6.3 Monitoring Climate Change

The actuarial profession can create indexes that will monitor the relationship between the primary variables of climate change such as concentration of GHGs in the atmosphere, average global temperature, and frequency and severity of extreme weather events. An example is the Actuaries Climate Index (ACI) being developed by the Climate Index Working Group and sponsored by the CIA, Casualty Actuarial Society (CAS), Society of Actuaries (SOA), and American Academy of Actuaries (AAA). This is discussed further in section 6.8 below.

## 6.4 Analysis of Climate Change Impact on Insurance

As discussed in section 2.6, climate change is expected to cause and/or exacerbate droughts, storms, and floods; extreme weather situations; scarcity of food supply and clean water; and impacts on human health caused by diseases such as malaria, etc. Actuaries can perform statistical analysis of trends and attribution of insurance events and climate change, building on the work of Francis Zwiers and other statisticians in the field of extreme weather events and climate change. Also, if the world is required to follow paths to keep the global temperature increase within the 2°C limit, many fossil fuel assets will be expected to be stranded. This will have an impact on asset values and the future yield on assets would be affected.

The above factors will increase exposure to loss and volatility for many lines of business such as property, flood, crop, automobile, liability, and life and health. “Green litigation” may impact product, environmental, directors’, and officers’ liability. These have been identified by actuaries for many years, e.g., the Australian Institute of Actuaries, 2003. Also the General Insurance Research Organising Committee has investigated the increased climate change risks on flood losses. The reinsurance community has been particularly active in the past. There can be impacts on costs as well as competitive implications.

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<sup>58</sup> <http://www.mercer.com/content/mercer/global/all/en/insights/focus/invest-in-climate-change-study-2015.html>

## 6.5 Evaluation of Mitigation and Adaptation Paths

Actuaries can evaluate the different options for mitigation and adaptation by performing risk-adjusted cost-benefit analysis. For this purpose, actuaries can adapt data from non-insurance sources. These could be stochastic models, or scenario testing. In using climate change models and other data in actuarial risk models, actuaries can establish practice standards and best practices. This could be beneficial in public policy development such as mitigation, resilience, and land-use planning (including over-building, over-population, and evacuation), e.g., the UN Office for Disaster Risk Reduction's 2015 Sendai resolution<sup>59</sup> on cat modelling for all investment decisions, to factor resilience into the global business thinking. This work would provide valuable input for determining public policy by different levels of government.

## 6.6 Developing New Lines of Business

Climate change can provide some insurance opportunities. For example, personal lines of business for property insurance offering rebuilding with more sustainable/green products, reimbursement for renewable energy use, discounts for loss mitigation devices, pay-as-you-drive or low-mileage discounts, and hybrid discounts. In commercial lines, products such as replacement "green" fleets, insurance for renewable energy projects and property, "green" building, energy savings insurance, carbon capture and storage, emission reduction projects, adverse publicity, perishable food, global weather insurance, and political risk for carbon trading. Special lines costing could include pollution and environmental insurance, directors' and officers' liability, architects' and engineers' professional liability for building commissioning, and professional liability insurance for home energy use survey professionals.

## 6.7 Analysis of Impacts on Investments and Society

Climate change may impact investments. New projects could be impacted. Also, changes such as carbon cap and trade or taxes can impact existing operations, e.g., power generation and liquid petroleum gas export.

Actuaries can incorporate limits to growth in the models used. Limits to growth models are of particular interest in pension and investments, including those of insurers.

Actuaries can also deepen the quantitative aspects of sustainability. There are many quantitative measures of sustainability; for example, sustainability reporting, TBL accounting, environmental performance indexes (for countries) and circles of sustainability (for cities).

Actuaries may also be involved in reporting and disclosure such as those that are compiled in Ceres' From Risk to Opportunity 2008: Insurer Responses to Climate Change<sup>60</sup> or the Carbon Disclosure Project.<sup>61</sup>

<sup>59</sup> [http://www.wcdrr.org/uploads/Sendai\\_Framework\\_for\\_Disaster\\_Risk\\_Reduction\\_2015-2030.pdf](http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf)

<sup>60</sup> <http://www.ceres.org/resources/reports/insurer-climate-risk-disclosure-survey-report-scorecard-2014-findings-recommendations/view>

<sup>61</sup> <https://www.cdp.net/en-US/Pages/HomePage.aspx>

## 6.8 Actuaries Climate Index

Four actuarial organizations of North America—the CIA, SOA, CAS, and AAA—have created the ACI.<sup>62</sup> The purpose of this index is to serve and educate the public about climate change by providing accessible and scientifically accurate information. The aim is to create an index, to be updated quarterly, that is statistically robust and easy to understand. The index will be launched for the U.S. and Canada combined on a website. The public will be able to follow changes in the seasonal ACI and its individual components, for both the entire Canada-U.S. region and also for a number of continental sub-regions.

### *Underlying Basis for ACI*

The ACI has six components, based on measurements from an extensive network of meteorological stations over the U.S. and Canada. Where possible, the components measure extremes, rather than averages. Extremes are of more interest in the current context, as they impact people and property the most. The ACI aims to measure the increase in the frequency of occurrence of such extreme conditions. It uses the 30-year period from 1961 to 1990 as the “reference” period. Each component variable entering the ACI is standardized relative to the reference period by computing the change in the variable since the reference period and dividing by the standard deviation of that quantity during the reference period. Unusual results can be defined as greater than one standard deviation from the mean, in either a positive or negative direction. The steps involved in the calculation of the ACI for high temperatures are shown below as an illustration of the general approach inherent in the process.

### *Steps in the Calculation of the ACI for High Temperatures*

Let us assume that the calculation of the index for the high temperature for June 2015 is to be made. The following steps will be involved:

1. Calculations will be made for each of the days in June 2015, viz. June 1 to June 30.
2. Two values will be calculated—one for the high daytime temperature (hot days) and the other for the high minimum temperature (warm nights). For each value, the value for the 90<sup>th</sup> percentile (based on the reference period) for the respective frequency distributions will be used. These two values are called TX90 (high maximum) and TN90 (high minimum). The value of the index T90 will be equal to the average of TX90 and TN90.
3. June 1. The highest temperature for the day will be established.
4. Records for the daytime high temperatures for June 1, 1961, to 1990 will be separated. In order to smooth the calculations, records for two days before and two days after June 1 for each year will also be separated. Using these 150 values, the value at the 90<sup>th</sup> percentile for the daytime high temperature will be established.
5. If the daytime high temperature for June 1, 2015, exceeded the boundary for the 90<sup>th</sup> percentile, the value for June 1, 2015, will be recorded accordingly.

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<sup>62</sup> <https://www.soa.org/Research/Research-Projects/Risk-Management/research-2012-climate-change-reports.aspx>

6. Similar calculations will be made for June 2–30, 2015.
7. The number of days in June 2015 when the high temperature fell beyond the 90<sup>th</sup> percentile boundary will be established. Let this be N.
8. With 30 days in June, the number of days in the 90<sup>th</sup> percentile should have been 3.
9. The value of the index is taken as  $(N-3)/\sigma$ , where  $\sigma$  is the standard deviation for the frequency distribution for the daytime maximum temperature records during the 30-year reference period. This is TX90.
10. Steps 3 through 9 are repeated for the 90<sup>th</sup> percentile of the night-time minimum temperature, yielding TN90.
11. T90 is computed as the average of TX90 and TN90.
12. As a final step, the value of the index T90 for June 2015 is taken to be equal to the average of the values for a period of five years going backwards from June 2015. This five-year average was carefully chosen as the most reasonable time period to reduce the noise of the time series data and allow users to see a clear climate signal.

The calculation is done using a gridded temperature data set (the grids are at 2.5° by 2.5° resolution) which is 275 km by 275 km at the Equator and averaged for a region(s). The calculation will be done on a quarterly basis for each meteorological season.

#### *Components of the ACI*

The ACI is the mean of the following six climate components, each calculated as a standardized anomaly:

1. Frequency of temperatures above the 90<sup>th</sup> percentile (warmer days and nights);
2. Frequency of temperatures below the 10<sup>th</sup> percentile (cooler days and nights);
3. Maximum five-day rainfall in the month (amount of rainfall);
4. Consecutive dry days (lack of rainfall);
5. Frequency of wind power, above the 90<sup>th</sup> percentile—wind power is equal to wind speed cubed, as damage has been found to be proportional to wind power; and
6. Sea level.

#### *ACI Components Graph*

Figure 6.1 shows the preliminary results of the six components of the ACI and the composite ACI for the period starting from 1961.



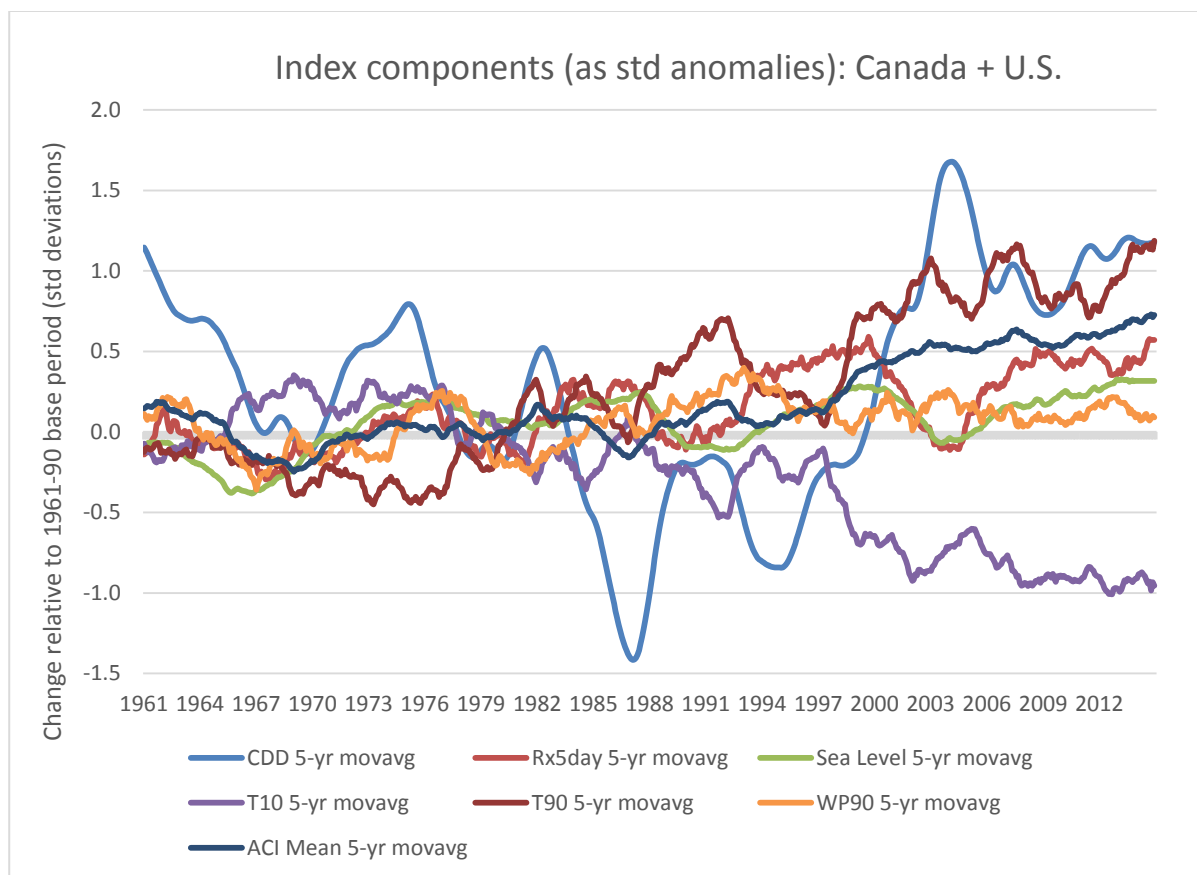


Figure 6.1 Time series of standardized anomalies used in the ACI (Actuaries Climate Index Working Group – preliminary results, unpublished as at the date of publication of the paper)

The most recent five-year moving average for the ACI (calculated using data up to the end of December, 2014) is at 0.7 standard deviations above the 1961–1990 mean. The three components that are showing or approaching unusual results overall of Canada and the U.S. are consecutive dry days (CDD; unusually large), incidence of high temperatures (T90; unusually large), and incidence of colder temperatures (T10; unusually small).

### 6.9 Actuaries Climate Risk Index

A further index that will be developed is the Actuaries Climate Risk Index (ACRI). This Index results from a regression analysis between the exposures (population data and the ACI values) and damages. A relationship is then determined, at the regional scale, by hazard, resulting in a measurement of risk, based on values from the ACI.

## Part 7 – Work Done Worldwide by Actuarial Organizations and Other Bodies

### 7.1 Roles Played by Actuarial Organizations and Other Worldwide Bodies

The risks posed by climate change have caught worldwide attention. The actuarial profession being the “risk experts”, it is no wonder that many actuarial organizations worldwide have shown interest in this issue. Other professional and industry bodies have

worked on analyzing these risks and their impacts on different areas of economic activity. The following sections are illustrative of these efforts.

## 7.2 Joint Project by North American Actuarial Organizations

Over the past few years, the CIA has partnered with three other North American actuarial organizations (the AAA, the CAS, and SOA) to provide actuarial insights on climate change issues. The research is being conducted in collaboration with Solterra Solutions, an environmental consulting firm in Victoria, BC. In 2012, the organizations released a phase one report, titled *Determining the Impact of Climate Change on Insurance Risk and the Global Community*.

For phase two, the organizations are releasing two separate indices—the ACI and ACRI. These were described in sections 6.8 and 6.9 above. The ACI is an educational tool designed to help inform the insurance industry and the general public on changes in the frequency of extreme weather over recent decades. It examines the frequency of unusually warm and cold temperatures, high winds, extreme precipitation, and consecutive dry days. Sea level is another component in the index, since rising sea levels have been a key measure of the effect of climate change.

The index is compiled from a number of public data sources, including the National Oceanic and Atmospheric Administration, Environment Canada, and the Permanent Service for Mean Sea Level. The ACI is expected to be released in the third quarter of 2015 and the ACRI is to be released later. The indices will be housed on a new website and updated on a quarterly basis.

## 7.3 International Actuarial Association<sup>63</sup>

The CIA, as a full member of the IAA, participates in the activities of the REWG created by the IAA in September 2011. The group meets regularly as a part of the biannual statutory meetings of the IAA Council and committees, as well as by teleconference when deemed necessary. The REWG reports on its activities on the IAA website and maintains a separate document library. The REWG has 70 members from 20 different local actuarial associations around the world out of the IAA's 67 full member associations.

## 7.4 Institute and Faculty of Actuaries (UK)<sup>64</sup>

In January 2014, the Institute and Faculty of Actuaries, which has been a pioneer in resources and environmental work, upgraded a committee as a separate board for resource and environmental affairs, providing input to the other boards to enhance recognition of environmental issues.

The Resource and Environment Board now has a research committee, which will build lines to academia. It has also formed a climate change working party, with a report intended to be developed prior to the Paris United Nations meeting, addressing its effect on liabilities and communication of uncertainty.

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<sup>63</sup> [http://www.actuaries.org/index.cfm?lang=EN&DSP=CTTEES\\_ENVIRO&ACT=INDEX](http://www.actuaries.org/index.cfm?lang=EN&DSP=CTTEES_ENVIRO&ACT=INDEX)

<sup>64</sup> <http://www.actuaries.org.uk/>

An updated literature review on sustainability and financial systems was published in May 2015.<sup>65</sup> The review found consistent pessimism on the role traditional economics plays in promoting behaviours that contribute to resource depletion and the inability of the current system to reform these behaviours. Three key themes were identified where further research is needed in order to understand the implications for anyone working with long-term financial institutions:

- The policy aim of pursuing growth without limit within a finite ecosystem.
- The potential replacement of GDP as the key metric of economic activity and success. GDP has received much criticism. In environmental terms, it does not capture the depletion of existing natural or human capital and so promotes capital erosion.
- The limitations of discount rates for making financial decisions needs to be better understood as they may have unintended consequences for sustainability. With the current approach, the far future may appear worthless (i.e., having negligible capital value).

### **7.5 Institute of Actuaries of Australia<sup>66</sup>**

The institute created an energy and environment committee many years ago and has been particularly active in the area of carbon footprints and carbon trading.

### **7.6 Actuarial Association of South Africa<sup>67</sup>**

The association has an environment e-mailing list, sharing environmental papers of possible interest. It may hold phone calls with interested parties.

### **7.7 Institut des Actuaire (France)<sup>68</sup>**

The French association reported at the last meeting of the IAA REWG in Zürich in April 2015 that it is concerned with the question of the financial hazards associated with resources and the environment.

### **7.8 International Social Security Association<sup>69</sup>**

The association's recent research paper on climate change is available on its website. In addition, the association is working on research on megatrends and how they affect social security programs. It is also interested in developing modelling on the topic of climate change. It is preparing a paper on long-term investment returns and the effect of the environment on interest rates, which it plans to present in its Budapest meeting in September 2015. It is also addressing public infrastructure and the inter-relationship between the environment and refugees.

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<sup>65</sup> <http://bit.ly/1BYfg6l>

<sup>66</sup> <http://www.actuaries.asn.au/>

<sup>67</sup> <http://www.actuarialsociety.org.za/>

<sup>68</sup> <http://www.institutdesactuaire.com>

<sup>69</sup> <https://www.issa.int/>

### 7.9 UN Environment Programme Finance Initiative's Principles of Sustainable Insurance<sup>70</sup>

The IAA REWG intends to support the programme's effort by applying to join as a supporting institution in addition to an inquiry into the design of a sustainable financial system. One of the programme's recent projects has been the study of disaster reduction, which the IAA may be interested in getting involved with, and a potential upcoming project on climate change.

### 7.10 Geneva Association<sup>71</sup>

Established in 1973, the Geneva Association, officially the International Association for the Study of Insurance Economics, is the leading international think-tank of the insurance industry. Based in Geneva, Switzerland, it is a non-profit organization funded by its members. Extreme events and climate risk are among its focus areas.

In May 2008, following a mandate from its General Assembly, the Geneva Association began its Climate Change and Insurance (CC+I) research project in response to one of the most multi-faceted challenges to the insurance industry since its inception. The association has held several international conferences on the subject and publishes research papers available on its website.

On the occasion of the 41<sup>st</sup> General Assembly in Toronto in May 2014, 67 chief executives of the world's leading insurers confirmed their commitment to the Geneva Association's Climate Risk Statement<sup>72</sup>—a set of guiding principles on the substantial role insurance can play in global efforts to tackle climate-related risks. The statement provides the foundations on which the direction of future climate-related initiatives by the Geneva Association will be based.

### 7.11 Organisation for Economic Cooperation and Development<sup>73</sup>

The Organisation for Economic Cooperation and Development (OECD) environment directorate includes a Climate Change Expert Group (CCXG) to promote dialogue on and enhance understanding of technical issues in the international climate change negotiations. The group holds two seminars per year that bring together government representatives, the private sector, and civil society in order to share information on climate policies and issues. The CCXG also develops papers in consultation with a wide range of countries. It is working on technical issues under discussion in the international negotiations towards a 2015 climate change agreement.

The Environment Policy Committee (EPOC) implements the OECD's environment program. The EPOC, with support from seven working parties, oversees work on country reviews, indicators and outlooks, climate change, natural resource management, policy tools and evaluation, environment and development, resource efficiency, and waste.

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<sup>70</sup> <http://www.unepfi.org/psi/signatory-companies/>

<sup>71</sup> <https://www.genevaassociation.org/research/topics/climate-risk>

<sup>72</sup> <https://www.genevaassociation.org/media/878689/pr14-06-climate-risk-statement.pdf>

<sup>73</sup> <http://www.oecd.org/env/>

A recent publication, OECD Work on environment, 2015–16, has a special focus on the project Aligning Policy for the Transition to a Low-Carbon Economy. It provides an overview of work happening over the next two years and is *the* reference document for a glimpse into the key elements of OECD work on the environment.

### 7.12 International Labor Organization<sup>74</sup>

The organization focuses in particular on the optimization of the relationship with job creation: green jobs are central to sustainable development and respond to the global challenges of environmental protection, economic development, and social inclusion. By engaging governments, workers, and employers as active agents of change, the organization promotes the greening of enterprises, workplace practices, and the labour market as a whole. These efforts create decent employment opportunities, enhance resource efficiency, and build low-carbon sustainable societies.

A recent event Dialogue on Climate Change and Jobs: Shaping the COP21 Agenda of Solutions organized in collaboration with the Geneva Environment Network Secretariat provided a platform for sharing views and perspectives on ways in which the climate change and decent work agendas can be made mutually supportive, looking towards the COP21 in Paris.

The dialogue was expected to serve as a stepping stone in the approach to the 104<sup>th</sup> International Labour Conference at which the World of Work Summit (in June 2015)<sup>75</sup> was to be on climate change and the world of work.

### 7.13 World Bank<sup>76</sup>

The World Bank has dedicated a large amount of resources for research and programs in relation with climate change and environment. The Global Environment Facility (GEF) program launched in 1991 is one of the institution's largest and longest-standing trust-funded programs.

The GEF grants directly support actions to combat major environmental issues including climate change, and stimulate green growth.

World Bank Group engagement with the GEF has attracted the largest share of additional funding to global environment issues at \$33 billion, drawing on its capacity to bring multiple sources of financing together under a common investment framework.

The GEF grants managed by the group support low-carbon and carbon-resilient development in client countries that help them adapt to a changing climate by investing in climate-resilient approaches. They are used to support sustainable conservation and management of protected areas, integrate biodiversity conservation into production landscapes, and design sustainable financing to encourage long-term biodiversity conservation through, for example, conservation trust funds to ensure ongoing funding to

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<sup>74</sup> <http://www.ilo.org/global/topics/green-jobs/lang--en/index.htm>

<sup>75</sup> [http://www.ilo.org/global/about-the-ilo/multimedia/video/video-news-releases/WCMS\\_375212/lang--en/index.htm](http://www.ilo.org/global/about-the-ilo/multimedia/video/video-news-releases/WCMS_375212/lang--en/index.htm)

<sup>76</sup> <http://www.worldbank.org/en/topic/climatechange/brief/gef>

support management efforts or payment for ecosystem schemes.

Efforts also focus on prevention of carbon loss from forests, soil erosion and salinization, recovery of marginal lands, and the introduction of climate risk insurance through adaptation strategies to encourage sustainable land and water management, as well as to enhance trans-boundary cooperation and management of shared water resources in order to mitigate water pollution and build capacity and cooperation across river basins, aquifers, and seas.

#### **7.14 The Vatican**

The Vatican has been studying climate change, the economy, and poverty through the Pontifical Academy of Sciences and the Pontifical Academy of Social Sciences. In June 2015, Pope Francis released a much-anticipated encyclical, "On Care for our Common Home", which summarizes his teachings on the issues of climate change and the common good.<sup>77</sup>

### **Part 8 – Climate Change Science Skepticism**

#### **8.1 Scientific Skepticism**

Skepticism is the practice of raising doubts and questioning. For issues as complex and as scientific in nature as climate change, it is important to verify whether claims are supported by empirical research and have reproducibility. This is sound scientific skepticism.

Arguments that refute a scientific theory are not necessarily skeptical arguments, if they do not fulfill these qualities. Five areas of concern regarding the reliability of climate change science are addressed below.

#### **8.2 Earth's Climate Has Changed Before**

One argument is that the climate has changed before, and thus it would not be unreasonable to expect natural variation in the earth's climate. The earth has a long history, and has encountered many different climates. Over the past 2 million years, the earth has gone through ice age cycles lasting approximately 100,000 years due to changes in the eccentricity of the earth's orbit around the sun, and changes in the earth's axial tilt (also known as Milankovitch cycles). Milankovitch cycles are associated with increased CO<sub>2</sub> concentrations in the atmosphere that are increased due to warming ocean temperatures emitting more CO<sub>2</sub> as warmer waters are not able to hold as much CO<sub>2</sub> as colder waters. Water vapour concentrations also increase in response to warming atmospheric temperatures.

Many periods of past climate change occurred slowly over millions of years, but some changes were more abrupt, sometimes leading to mass extinction. The Paleocene-Eocene Thermal Maximum occurred about 55 million years ago, resulting in a 7°C increase in global temperature over a 20,000-year period. This warming period resulted in a sudden spike in paleo-climate temperature graphs and high extinction rates. Some speculate that the cause may be due to extremely high volcanic activity along the Indian plate, releasing abnormal

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<sup>77</sup> [http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco\\_20150524\\_enciclica-laudato-si.html](http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html)

levels of CO<sub>2</sub> into the atmosphere. Today, the possibility of rapid warming could take place over much shorter time scales (i.e., less than 100 years), compromising the ability of life on earth to adapt quickly enough. There are other examples of mass extinction, including the Permian extinction, which saw 90% of species go extinct 250 million years ago due to rapid climate change.<sup>78</sup>

While there were natural causes in play in past episodes of rapid climate change, such unusual circumstances are not present in today's natural climate, where the major catalyst of global climate change is in GHG concentration caused by human activity.

### 8.3 Sun Causes Global Warming

One of the most intuitive arguments is that the sun controls the ups and downs of the earth's climate, as the sun is the primary catalyst of the earth's energy content. There have been varying estimates of the sun's change in radiative forcing. The IPCC AR5 report estimated a range of 0.0 to +0.1 W/m<sup>2</sup> change between 1750 and 2011, whereas anthropogenic forcings contributed 2.3 W/m<sup>2</sup> over this time period. Since the satellite era began in 1979, solar radiation has experienced a downward trend. Solar forcing is considered to be somewhat larger in the first half of the 20<sup>th</sup> century, contributing between 0.1°C and 0.2°C of warming during that period, and roughly flat since 1950.<sup>79</sup> <sup>80</sup> Figure 8.1 shows that while there is some positive correlation between solar activity and the earth's temperature before 1940, the two diverge in years thereafter. Thus, the sun is not a good explanation for global warming since then.

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<sup>78</sup> <http://www.skepticalscience.com/climate-change-little-ice-age-medieval-warm-period-intermediate.htm>

<sup>79</sup> <http://www.skepticalscience.com/solar-activity-sunspots-global-warming-advanced.htm>

<sup>80</sup> [http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_SPM\\_FINAL.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf) (p. 14)

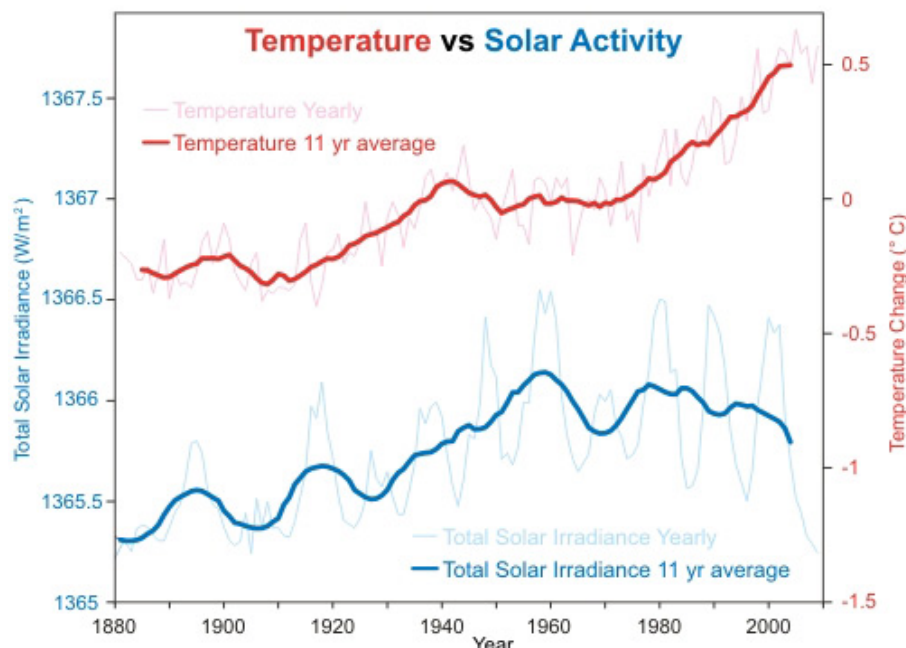


Figure 8.1. Divergence between solar activity (blue line) and global surface temperature (red line) is apparent after 1940<sup>81</sup>

#### 8.4 Warming Has Slowed Down

One subject that has been getting a lot more attention in recent years is the so-called “warming hiatus”, where there appears to be a slowdown in warming over the last 15–20 years.<sup>82</sup> Trends that begin with 1998, for example, are often lower than other starting points due to a very strong El Niño in 1997–1998. The Interdecadal Pacific Oscillation (IPO) also plays a role in the exchange of heat between the surface and the ocean, resulting in a larger net transport of heat to deeper ocean depths in recent years (see figure 8.2). A third source of natural variability is related to solar output, which recently went through a weak 11-year solar cycle.<sup>83</sup> While CO<sub>2</sub> concentrations continue to rise steadily, other GHGs such as methane and chlorofluorocarbons have levelled off in recent decades (though methane has started to increase again).<sup>84</sup> There is also uncertainty in Arctic warming due to limited weather station coverage. Attempts to adjust for poor Arctic coverage via satellite observations has been used (Cowtan and Way) and show that warming since 1998 has been understated due to the largest regional warming trends occurring in poorly covered areas.<sup>85</sup>

<sup>81</sup> <http://www.skepticalscience.com/solar-activity-sunspots-global-warming-advanced.htm>

<sup>82</sup> The IPCC Technical Summary has a more detailed summary regarding the attribution of the warming hiatus. See pp. 61–63: [http://www.climatechange2013.org/images/report/WG1AR5\\_TS\\_FINAL.pdf](http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf)

<sup>83</sup> <http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant>

<sup>84</sup> <http://data.giss.nasa.gov/modelforce/ghgases/>

<sup>85</sup> <http://onlinelibrary.wiley.com/doi/10.1002/qj.2297/abstract>



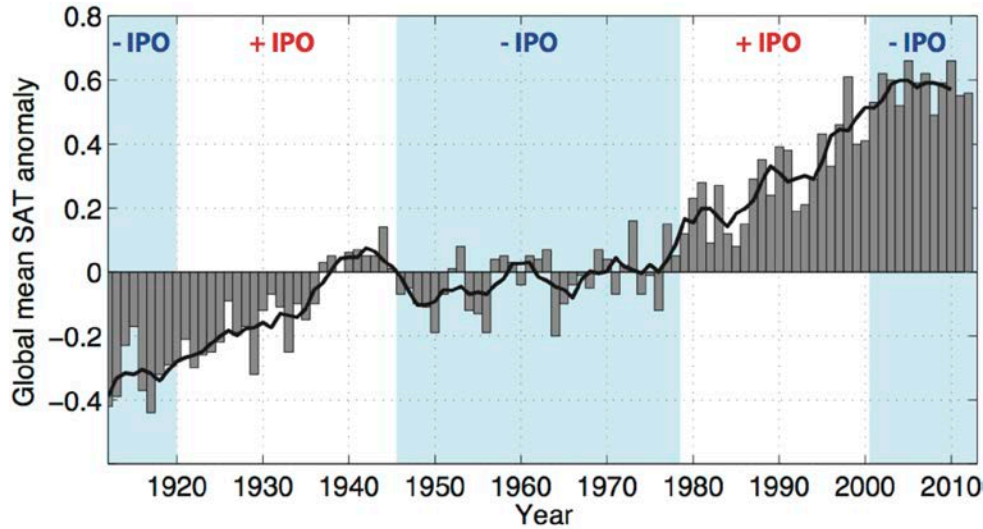


Figure 8.2: How the IPO may affect the rate of global warming over various time periods—the latest warming slowdown is during a negative IPO phase<sup>86</sup>

NOAA, which produces one of the four main surface temperature records, recently updated their global analysis, showing that the surface temperature trend has not slowed down (see Figure 8.3). This update contained an improvement in how ocean buoy and ship-based data are recorded over ocean surfaces. While these changes do not have a large impact on the long-term temperature trend, they do have some effect on the trend over the last couple of decades. Small changes in the start or end points can have a significant effect on trend calculations.

<sup>86</sup> <http://www.skepticalscience.com/climate-hiatus-doesnt-take-heat-off-global-warming.html>

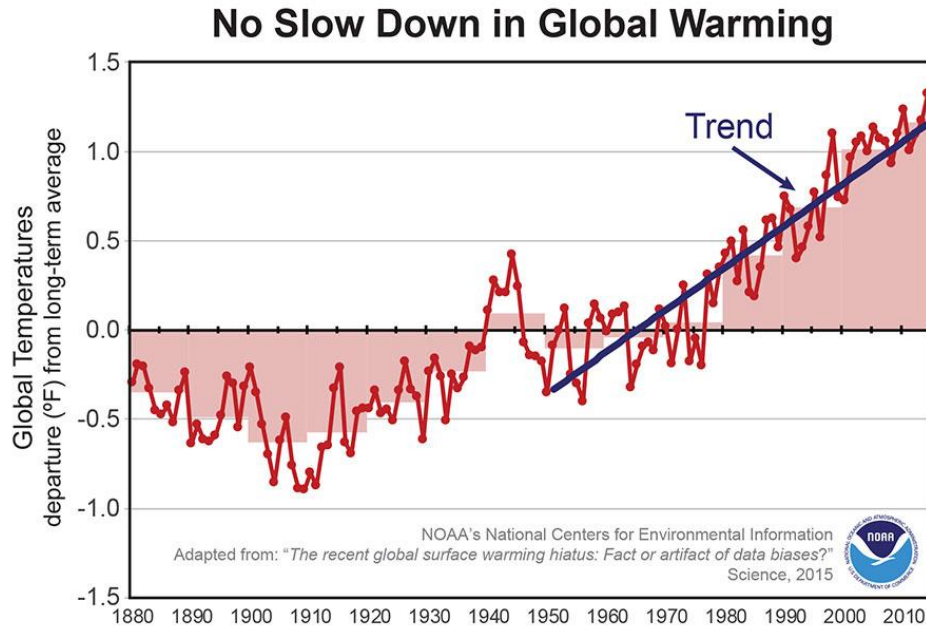


Figure 8.3: NOAA’s updated global surface temperature analysis, which does not show a slowdown in global warming over recent decades.<sup>87</sup>

It is important to consider short-term warming slowdowns in the context of long-term warming (see figure 8.4). Because of the large internal variability in the climate over decadal time periods, short-term trends (e.g., less than 30 years) are not considered robust. Trend calculations are very sensitive to natural variability biases over the early and later years over the specified time period.

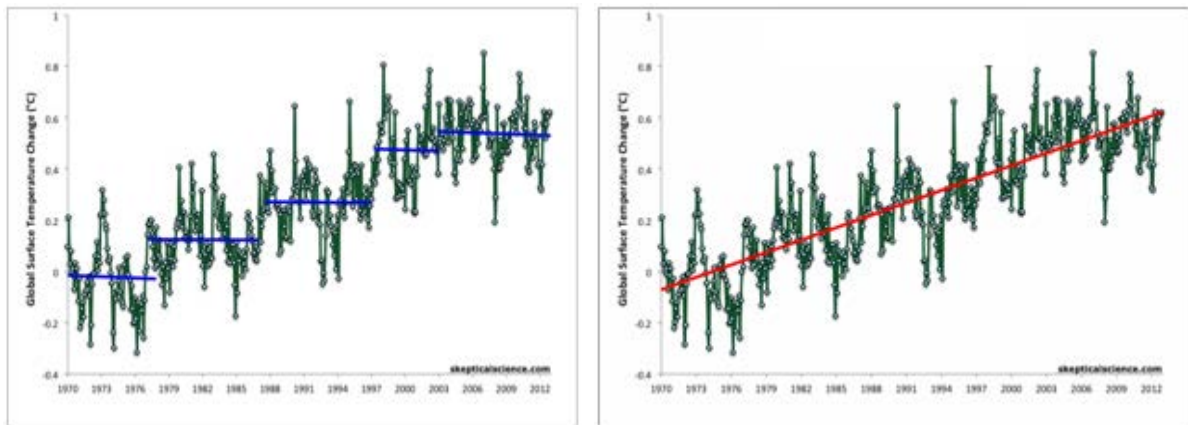


Figure 8.4. Blue trend lines in the first graph show there have been many instances of short-term cooling trends, but within the context of long-term warming (see red line in second graph)<sup>88</sup>

<sup>87</sup> <https://www.ncdc.noaa.gov/news/recent-global-surface-warming-hiatus>

It is also important to look at the larger context of the earth's overall heat content, which continues to grow while surface temperatures have slowed down (see figure 8.5).

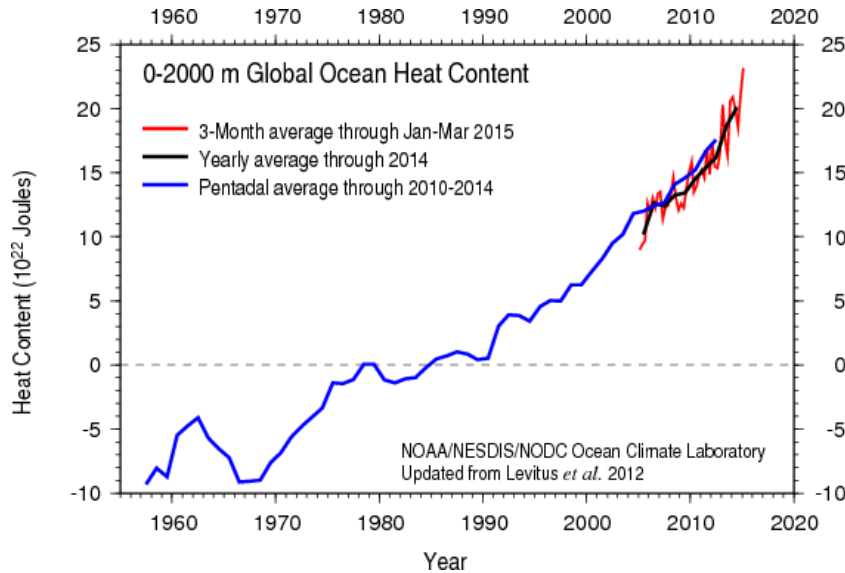


Figure 8.5. The earth's oceans (comprising 93% of the earth's additional heat content) have continued to warm during the warming slowdown<sup>89</sup>

### 8.5 There is No Consensus on Climate Change

One argument that is heard many times is that there is no consensus among climate scientists about the causes of climate change and its impacts in the future. Various surveys have shown that there is a gap between the public and scientific opinions regarding the realities of anthropogenic climate change. The studies that have been undertaken to assess the level of consensus can be grouped into two categories—*opinions* and *literature surveys*. Most surveys indicate strong consensus among scientists regarding the human attribution toward climate change. Many studies show that the extent of climate consensus increases with publication experience, and with specialized knowledge of climate science. Publication studies generally yield the highest support as scientists who agree with the scientific consensus average more publications than those who do not. The public generally has a lower opinion, and is largely unaware of a high scientific consensus.

A brief description of the different studies is given below:

*Oreskes (2004)*<sup>90</sup>

Surveyed studies done between 1994 and 2004 with the keyword “global climate change”:

- 928 abstracts surveyed in refereed scientific journals;
- 75% affirmed anthropogenic climate change;

<sup>88</sup> <http://www.skepticalscience.com/graphics.php?g=47>

<sup>89</sup> <http://www.realclimate.org/index.php/archives/2013/09/what-ocean-heating-reveals-about-global-warming/>

<sup>90</sup> <http://www.sciencemag.org/content/306/5702/1686.full>

- 25% were regarding methods or paleoclimate (out of scope); and
- No papers were found explicitly rejecting anthropogenic climate change.

*Doran (2009)*<sup>91</sup>

- Two-question interview of 3,146 earth scientists regarding their views on climate change.
- First question was “Whether mean global temperatures have risen as compared to the pre-industrial levels?” Seventy-six out of 79 scientists said yes (96.2%).
- Second question was “Do you think human activity is a significant contributing factor in changing mean global temperatures?”
  - Eighty-two percent of all earth scientists said yes (compared to 58% of public Gallop poll).
  - The level of consensus grows with climate expertise, and among active publishers.
  - Active publishing climatologists had 97.4% consensus (75/77).

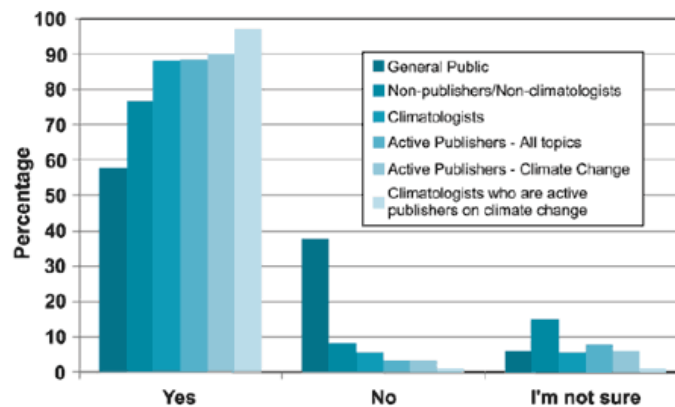


Figure 8.6. Scientific consensus on anthropogenic climate change grows higher when filtered by active publishers and climate scientists

*Anderegg (2010)*<sup>92</sup>

- Paper reviewed 1,372 climate researchers showing 97–98% support for the IPCC tenets of climate change.
- Researchers were drawn based on authorship of scientific assessment reports and membership of multi-signatory statements about anthropogenic climate change. Statements were sorted into UE (Unconvinced of Evidence) and CE (Convinced of Evidence) categories.
- Top 200 researchers were 97.5% in the CE group.

<sup>91</sup> [http://tigger.uic.edu/~pdoran/012009\\_Doran\\_final.pdf](http://tigger.uic.edu/~pdoran/012009_Doran_final.pdf)

<sup>92</sup> <http://www.pnas.org/content/107/27/12107.full>

- The UE group averaged 60 publications vs. 119 for the CE group (minimum 20 publications required to qualify for each group).
- Eighty percent of the UE group had fewer than 20 publications vs. 10% for the CE group.

Cook (2013)<sup>93</sup>

- In total, 11,944 abstracts between 1991 and 2011 were reviewed.
- Among abstracts expressing an opinion on anthropogenic global warming, 97.1% endorsed the consensus position that humans are causing global warming.
- Scientists self-rated their abstracts, of which 97.2% endorsed the consensus position.

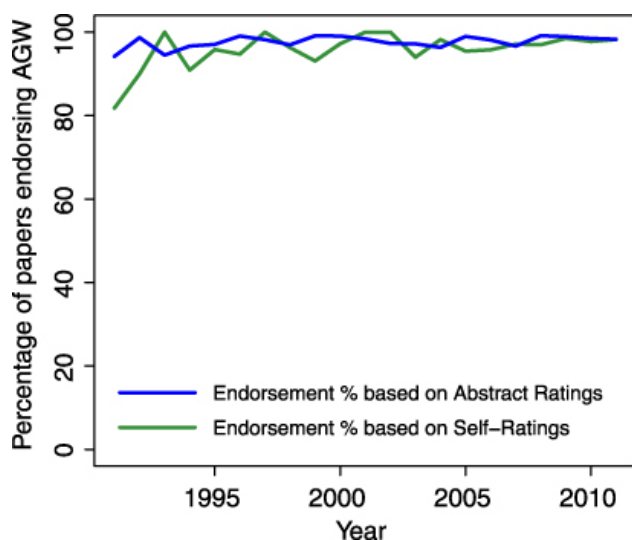


Figure 8.7. Scientific consensus supporting anthropogenic global warming between 1991 and 2011

Verheggen (2014)<sup>94 95</sup>

- Survey of 1,868 scientists on their opinions on climate change science. More than 6,000 were invited to participate in the survey from researchers who have written on topics of global climate change.
- Thirty-five questions were asked, making the survey unique in its level of detail.
- Ninety percent of scientists with a minimum of 10 publications affirmed that more than half of global warming since 1950 is man-made.
- Scientists who had the most publication experience were more likely to state that GHGs had a strong warming impact.

<sup>93</sup> <http://iopscience.iop.org/1748-9326/8/2/024024/article>

<sup>94</sup> <http://pubs.acs.org/doi/abs/10.1021/es501998e>

<sup>95</sup> [http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2015-climate-science-survey-questions-and-responses\\_01731.pdf](http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2015-climate-science-survey-questions-and-responses_01731.pdf)

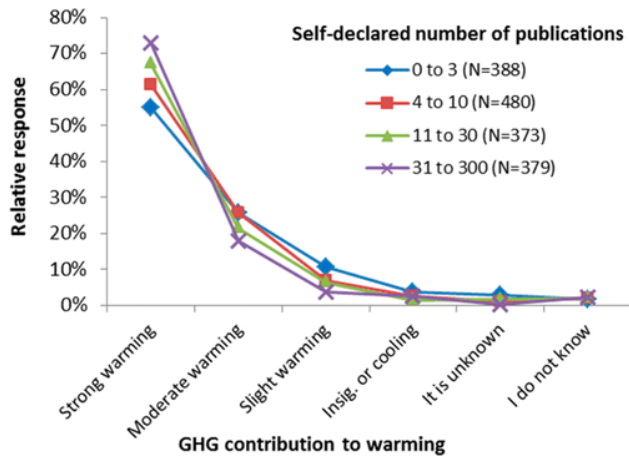


Figure 8.8. GHG contribution to warming (since 1750) is considered to be strongest among the most-active climate science publishers

#### *Consensus among National Academies of Science*

National academies of science of 80 countries have endorsed the consensus about climate change among their membership. These include the National Academy of Science (U.S.), the Royal Society (UK), and the Royal Society of Canada.

### **8.6 Historical Temperature Records are Not Reliable**

There are many questions surrounding the nature of the accuracy of warming metrics. Are there uncertainties with regard to the extent of warming? Why do satellites sometimes disagree with surface temperatures? Are the records contaminated by poor surface station siting or urban heat islands?

#### *Ocean Measurements*

Surface temperatures can refer to either “land alone” or “land plus ocean”, but typically refer to “land plus ocean”. About 93% of the earth’s additional energy content (i.e., the effect of greenhouse warming) occurs in the oceans, while the remaining 7% is a mix of land, atmosphere, and melting ice sheets (see figure 8.9). This is important in the context of the warming “hiatus”.

## Where is global warming going?

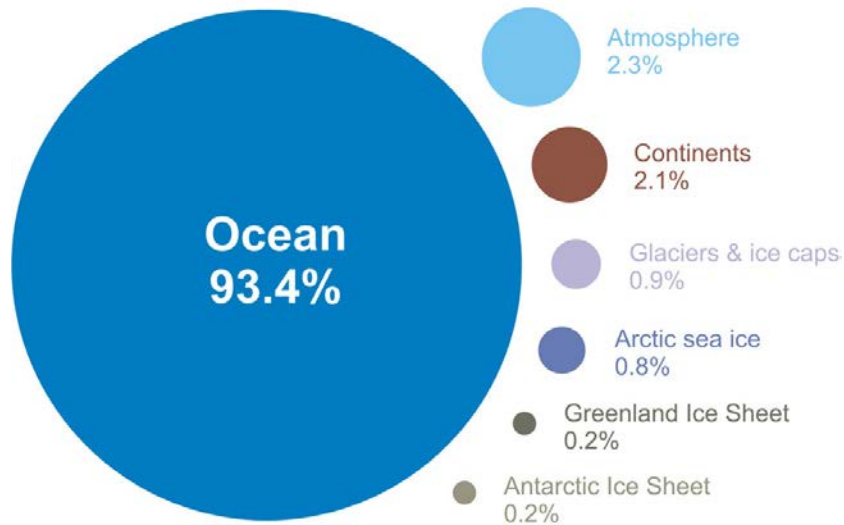


Figure 8.9. Ninety-three percent of the earth's additional heat content goes into the oceans<sup>96</sup>

The warming “hiatus” (or more accurately, warming slowdown) is observed for surface temperatures. It is not an accurate observation for the globe as a whole. The steady rise in ocean heat content shows the consistent impact of increased GHG emissions (see figure 8.5).

### *Instrumental Temperature Records*

Various questions have been asked concerning the reliability of the instrumental temperature records. Do poorly sited surface stations impact temperature records? In absolute terms, there is evidence they do, but in terms of measuring warming or cooling trends, they are neutral. Menne (2010)<sup>97</sup> shows that in the U.S., surface temperature stations that were poorly rated had similar overall trends to those that had high-quality siting ratings.

On the question of urban heat islands (i.e., weather stations in cities tend to be somewhat warmer than surrounding rural stations), surface station records can be divided into a rural and urban cohort to see if they yield similar trends (Jones 2008).<sup>98</sup> Urban trend adjustments are made to ensure that urban and rural trends are consistent (Hansen 2001).<sup>99</sup> Interestingly, the most significant warming trends have usually occurred over poleward regions, indicating that urbanisation could not have created a signal associated with currently observed climate change.

<sup>96</sup> <http://climatestate.com/2013/09/02/world-ocean-heat-content-and-thermosteric-sea-level-change-0-2000-m-1955-2010/>

<sup>97</sup> <http://onlinelibrary.wiley.com/doi/10.1029/2009JD013094/full>

<sup>98</sup> <http://onlinelibrary.wiley.com/doi/10.1002/wea.432/pdf>

<sup>99</sup> [http://pubs.giss.nasa.gov/docs/2001/2001\\_Hansen\\_etal\\_1.pdf](http://pubs.giss.nasa.gov/docs/2001/2001_Hansen_etal_1.pdf)

There are other types of observation biases that need to be corrected (most prevalent in the U.S.). When corrected for this bias, the warming trend in the U.S. increases. The issue has to do with how the timing of minimum and maximum observations may have changed over time. As a validation to the correction, a technique called pairwise homogenization can be used that eliminates the need to correct for time of observation bias directly. Both methods yield nearly identical results (Williams 2012).<sup>100</sup>

#### *Satellite Temperature Records*

Satellites have been measuring tropospheric temperatures since 1979. They do not measure temperature directly, but use a proxy method by measuring variances in varying wavelength bands. There have been various challenges over time with satellite measurements, resulting in some significant corrections to temperature trend calculations. One example is orbital decay, which resulted in a trend adjustment of +0.10°C/decade (Wentz 1998).<sup>101</sup>

Models have predicted that satellite temperatures should show greater warming trends in the lower troposphere relative to the surface, consistent with the hotspot theory, which suggests that increased water vapour in the lower troposphere should increase temperatures as it condenses and releases latent heat (Bengtsson 2009).<sup>102</sup> Currently, warming trends are seen to be similar between surface and satellite measurements.

### **Part 9 – Concluding Observations**

The objective of the paper was to present the views on climate change and resource sustainability that have been widely accepted in the world. On any contentious issue, it is impossible to have 100% acceptance. No doubt, there are differing views on these dual issues. Each differing view has to be evaluated on its own merits. On the other hand, many actuaries have to translate this information to assess past, current and future risks.

The earth has been showing a rapidly warming trend. This has been primarily caused by the increasing concentration of the GHGs—particularly carbon dioxide. There is worldwide acceptance for the fact that the largest contributor to the increase in CO<sub>2</sub> concentration is the burning of fossil fuels and deforestation. This is causing climate change that will have a very wide-ranging impact on life on earth. This will include increased frequency of extreme temperatures, floods, hurricanes, storms, droughts, and sea levels, to name a few. If no immediate action is taken and the concentration of GHGs is allowed to increase unchecked, the resulting consequences could be disastrous and humanity could reach a point of no return.

The world community has accepted the need to limit the increase in the earth's temperature to 2°C and initiate changes to achieve this objective. This will require the world to move away from burning fossil fuels and effectively reach a stage of zero carbon emissions. This will require a radical change in the way humanity lives as we move forward.

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<sup>100</sup> <ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/papers/williams-etal2012.pdf>

<sup>101</sup> <http://www.nature.com/nature/journal/v394/n6694/full/394661a0.html>

<sup>102</sup> <http://www.researchgate.net/publication/225724174> On the Evaluation of Temperature Trends in the Tropical Troposphere



Because of climate's momentum and the delays involved in transitioning to a new energy portfolio, the world community will also need to live under a climate regime that is significantly different than past centuries.

The earth has limited resources. Also, there are limits on the renewability of some of its renewable resources. Humanity is using substantially more resources than the earth can renew. We all need to change the way we live to achieve a proper balance.

In order to face the challenges posed by these dual issues, the world has to act in unison. This will require cooperation from all countries in the world. There are a number of disparities to be addressed. There is a very wide range of per-capita emissions—generally, the wealthy countries having higher per-capita emissions. There is a perception among the emerging economies that the world has reached the current situation due to the past emissions by high emitters and that they should be willing to share a higher cost of moving to low-carbon economy. Further, different regions will be affected differently—some may not feel the consequences; at least immediately. Such countries may not want to join the worldwide efforts in a meaningful way. Getting all countries to follow a common path will be the biggest challenge in the years to come.

The new risks have been recognized by worldwide professional bodies and other organizations—including actuarial organizations. The actuarial profession is well equipped to understand and analyze these risks. It should make its contribution in these efforts. Doing nothing will not be an option.