Introduction to Climate-Related Scenarios

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IAA Paper

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This paper on the Introduction to Climate-Related Scenarios was prepared by the Climate Risk Task Force of the International Actuarial Association (IAA).

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

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

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Executive Summary

This paper discusses the potential sources of information on climate changes. It describes the various scenarios available and the criteria for selecting between them. Since the impact of global warming varies by geographic location and sector, a more granular view must be derived by applying a number of factors relating to local conditions, country specific legal environment, the purpose of the undertaking, and others.

This paper highlights considerations to be taken into account when selecting or modifying a global scenario to reflect local circumstances. It also examines difficulties generated by the combination of multiple options that could be used to adapt to or mitigate the effects of climate changes, and the many factors impacting balance sheets as economic agents anticipate the potential effect of climate changes.

This paper is not taking a position on any climate change scenario per se, it is portraying information which is articulated by the geophysical scientific community and supported by the international community and as such is a good common basis for risk disclosure.

Climate change refers to a statistically-defined change in the average and/or the variability of the climate system, which includes the atmosphere, the water cycle, the land surface, the cryosphere, the biosphere, and their interactions.

Climate-related risks arise when various climate effects interact with socio-economic systems which may disrupt the mechanisms traditionally used to maintain financial stability. Actuaries are increasingly involved in considering the potential business and financial impacts of climate scenarios on their organization, customers and the society, contributing to well-informed decisions through developing mitigation and adaptation strategies and building resilience.

This paper builds on and should be read in conjunction with the IAA paper “The Importance of Climate-Related Risks for Actuaries”1. It will also be followed by a series of complementary papers covering climate issues related to specific financial sectors or providing further insights.

1 Global Scenarios

1.1 Sources of Information on Climate Change

A widely-held view is that climate change is caused mainly2 by an increase in atmospheric carbon dioxide (CO₂) produced by humans burning fossil fuels to meet increasing energy demand or support industrial processes. There is also a significant contribution from human activities to the increase in other Greenhouse Gas emissions (GHG) through changes in land use, in particular. Agriculture, Forestry and Other Land Use (AFOLU) which includes livestock generating methane (CH₄) and nitrous oxide (N₂O), a more potent GHG than CO₂. This is commonly referred to as the anthropogenic contribution to climate changes in the literature.

The GHG emissions effect is a consequence of the Laws of Thermodynamics and was identified in 1824 by Joseph Fourier, but its impacts became more visible as the concentration rose significantly above pre-industrial levels of about 280 parts per million (ppm).

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1 Importance of Climate-Related Risks for Actuaries - September 2020
2 Not all the effect is due to human impact as there are also long-term cyclical climate changes. It is the rate of increase in global warming correlated with increased human activity that is the basis of the concern regarding the impact of the human activities.
The Intergovernmental Panel on Climate Change (IPCC)\(^3\) is the most common source of information about climate-related risks. The IPCC does not conduct its own research. Instead, scientists from all over the world contribute to the work of the IPCC. IPCC scientists assess thousands of scientific papers published each year to provide a comprehensive summary of what is known about the drivers of climate change, their impacts and future risks, and how adaptation and mitigation can reduce those risks. Through its assessments, the IPCC identifies the strength of scientific agreement in different areas and indicates where further research is needed. The IPCC assessment reports are supported by a wide consensus and are a key input into international climate change negotiations. Given the multiple levels of uncertainty, these reports do not attempt to predict future outcomes but rely instead on scenarios for a selection of pathways.

The Fifth Assessment Report (AR5), published by the IPCC in 2014, provides an overview of the state of knowledge concerning the science of climate change. It comprises a synthesis report and a summary for policymakers, as well as reports from three working groups. The Global Warming of 1.5-degree Celsius (°C) report, published in October 2018, indicates the need to take dramatic actions now to keep warming below 1.5°C and the potential severe consequences if this is not achieved. A Summary for Policymakers of the Special Report on the Ocean and Cryosphere in a Changing Climate was published in September 2019. The UNEP also publishes Emissions Gap reports, the last one was issued in 2019.

The Sixth Assessment Reports (AR6) are planned for 2021 and the Synthesis Report is scheduled for June 2022.

### 1.2 Identification of Scenarios

Climate change scenarios are often based on projections of future GHG emissions used by experts to assess future vulnerability to climate change. The goal of climate change scenarios is not to predict the future. Rather, they help to better understand uncertainties and the wide range of possible outcomes in order to make the best decisions possible. Although for simplicity’s sake, scenarios are represented by a curve, called “pathway” or “trajectory” that traces the evolution of a metric over time, often complemented by a confidence interval, each scenario comprises a narrative summarizing the associated impacts and relevant factors that describe the future states of the world. Producing scenarios

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\(^3\) The United Nations (UN) body for assessing the science related to climate change. The IPCC created by the UN in 1988 is an organization of governments that are members of the United Nations or the World Meteorological Organization (WMO), comprising 195 members.
requires estimates of future population levels, economic activity, structure of governance, social values, patterns of technological change and possibly many more factors.

The driving metric could be the additional warming in °C, the gigatons of GHG emitted expressed in eCO₂, or the atmospheric concentration of eCO₂ in ppm. These metrics are estimates based on reports collected globally. Daily measurements of CO₂ concentration in the Earth's atmosphere in ppm, taken at the Mauna Loa Observatory, Hawaii, are available continuously from the Scripps Institution of Oceanography, starting from 1958 to the present day. The graph of the daily values is known as the Keeling curve (see Figure 2 below).

The “ppm” is one of the preferred metrics because it facilitates continuous monitoring and can be seen as a leading indicator since an increase in ppm precedes an increase in warming. Metrics based on emissions are estimates subject to errors in reporting and need to be converted in atmospheric concentration using factors for the proportion absorbed by oceans and by forests whereas the Keeling values measure directly the net result. The Keeling curve is useful for determining the starting point of a projection and to compare past projections with actual observations.

Whatever the metric, it should be noted that the impacts as estimated by the IPCC or other models are based on probabilities. It is likely that keeping the concentration below 450 ppm will keep the global warming below 2°C, which in IPCC vocabulary means a probability of 66.7% that the temperature increase will not exceed 2°C.

**Figure 2- The Keeling Curve, source:** [https://sioweb.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/co2_800k_zoom.png](https://sioweb.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/co2_800k_zoom.png)

### 1.3 IPCC Scenarios and the Paris Agreement

The IPCC scenarios describe the effect on the energy balance of the global climate system due to changes in the composition of the atmosphere from sources like GHG emissions, other air pollutants and changes in land use.

The AR5 IPCC report includes four scenarios identified by their forcing power (forcing is the difference between sunlight absorbed by the Earth and energy radiated back to space) to illustrate different compositions of the atmosphere at the end of the 21st century. The IPCC scenarios and associated

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[^4]: eCO₂ or equivalent CO₂ is a unit that allows emissions of greenhouse gases of different warming potential to be added together to simplify analysis and comparisons. However, the conversion does not fully reflect the differences in persistency and other impacts such as on agriculture.
Representative Concentration Pathway (RCP) scenarios are illustrated in Figure 3 and summarized as follows:

- **RCP 2.6** is consistent with an ambitious reduction of GHG emissions, which would peak around 2020, deemed a turning point, then decline on a linear path that aims to limit global warming to below 2°C above pre-industrial temperatures, the goal of the Paris Agreement. It is also known as a +2°C scenario.

- **RCP 4.5** is an intermediate-emissions scenario, consistent with a future with relatively ambitious emissions reductions and GHG emissions increasing slightly before starting to decline circa 2040. Despite such relatively ambitious emissions reduction actions, RCP4.5 falls short of the 2°C limit/1.5°C aim agreed on in the Paris Agreement. It is aligned broadly with the GHG emissions profile that would result from the implementation of the 2015 National Determined Commitments (NDC) up to 2030 followed rapidly by a 50% reduction of global emissions by 2080. It is considered likely to produce a warming of about 2.4°C.

- **RCP 6.0** is a high-to-intermediate emissions scenario, where GHG emissions peak at around 2060 and then decline through the rest of the century which is considered likely to produce a warming of about 2.8°C.

- **RCP 8.5** is aligned broadly with current policies. A high-emissions scenario, consistent with a future with no policy changes to reduce emissions and characterized by increasing GHG emissions that lead to high atmospheric GHG concentrations. It is considered likely to produce a warming of 4.3°C. It has been deemed to represent a Business-As-Usual (BAU) scenario, but it is not necessarily the worst-case scenario.

The RCP scenarios were produced before the conclusion of the Paris Agreement that created new expectations since a large majority of governments recognized the need to shift towards a low-carbon economy. In some of these scenarios the ultimate outcome remains dependent on negative emissions, adding to the risks by presuming the availability of efficient scalable Carbon Capture and Storage (CCS) technologies that do not exist yet.

*Figure 3- IPCC Scenarios, source: https://www.ipcc.ch/report/ar5/syr/synthesis-report*

The Nationally Determined Commitments (NDC) are at the heart of the Paris Agreement and the achievement of these long-term goals. The signatories agreed to strengthen the global response to the threat of climate change through three main actions:

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5 https://en.wikipedia.org/wiki/Climate_change

6 The Paris Agreement was adopted in December 2015 and ratified by 189 governments in 2016 https://en.wikipedia.org/wiki/Paris_Agreement
• Mitigation: holding the increase in average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C.

• Adaptation: increasing the ability of countries to adapt to the adverse impacts of climate change.

• Finance: making financial flows more consistent with a pathway to low GHG emissions and climate resilient development.

The NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each party to prepare, communicate and maintain the successive NDCs that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such commitments. NDCs made by the parties are voluntary. Each government is autonomous in setting policy objectives and responsible for implementing mandatory measures or initiatives to achieve them. The initial NDC scenario is the aggregate of the commitments submitted in 2016 by the 185 signatories based on the presumption that the commitments will continue to apply after the pledge period, ending typically in 2025 or 2030. The initial NDC scenario would entail warming estimated at around 3.2°C by 2100.

As per the Paris Agreement, the commitments are to be increased at 5-year intervals if they are not sufficient to achieve the agreed objective. The first revision was due to take place on the occasion of COP26 meeting in Glasgow in November 2020. Due to the COVID-19 pandemic it has been postponed to November 2021. Global warming has already reached 1.1°C, more than half-way to the target, while there has been no reduction yet in GHG emissions. The longer it takes to tackle GHG, the higher the transition risks and the potential costs.

These scenarios and many others created subsequently by various organizations, are further described in later sections covering a wider range of scenarios and criteria for selecting a set of scenarios with regards to the purpose and local conditions.

1.4 Adapting Scenarios to Changes

Changes in the climate are expected to give rise to both acute physical effects (e.g. increasing severity and frequency of extreme weather events like heat waves, landslides, floods, wildfires and storms) as well as chronic effects, (e.g. changes in precipitation, extreme weather variability, ocean acidification, rising sea levels and average temperatures).

A smooth transition to a low-carbon economy entails numerous adaptation and transformation initiatives that need to be synchronized and coordinated. Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives.

Scenario analysis consists of defining and specifying an event and then assessing its impact. The scenario would include all effects that are relevant for the analysis of the impact. The specification would be such that it is possible to obtain qualitative or quantitative estimates on the financial loss or other effect that are in scope. For climate change, this is challenging, since there are many effects, some obvious and some not, that will emerge over time. For actuaries, the problem is even more difficult, since it suffices not to merely consider the changes in the climate, but also the effects on other relevant domains that impact the balance sheet or business models of insurers.

A highly complex system like climate change together with the domains that it will impact, will have many drivers that will cause effects to spread and propagate. Actuaries who formulate climate change scenarios or adapt a scenario to their region or to the exposures of a specific insurer would consider such effects, quantitatively or qualitatively or both. There are a number of different effects, some of which are described below.
Drivers of climate change can cause cumulative effects. Incremental impacts of actions – e.g. the burning of fossil fuels – can add up over time. The cumulative effect can be close to linear or it can lead to tipping points and to a system entering a new state (see https://www.fs.usda.gov/ccrc/topics/cumulative-effects)

Some events can lead to a cascade of events, like dominoes that topple each other. The COVID-19 pandemic offers many examples of domino effects where an initial outbreak spreads, impacts supply chains, causes certain goods to be hoarded, impacts the free flood of goods, affects capital markets and much more (see https://www.scientificamerican.com/article/the-next-climate-frontier-predicting-a-complex-domino-effect/)

The ripple effects of climate change can propagate across different domains. CO₂ can lead to an acidification of the sea, which might cause coastal populations to be forced to migrate, which has impacts for both societies and economies. These effects are especially pronounced in long-duration events like climate change.

Tipping points are thresholds where a small change can qualitatively alter the state or development of a system. The climate itself has many such tipping points, ranging from the accelerated melting of glaciers to the change of oceanic circulation. The entire system has many more tipping points, where at least part of the system can enter new states with unknown consequences (see https://www.pnas.org/content/105/6/1786)

Feedback loops are effects which – possibly over several stages, dampen (negative feedback loop) or strengthen (positive feedback loop) the initial driver. The climate contains many feedback loops. A well-known positive feedback loop is that heating causes permafrost to melt, which then releases methane and carbon dioxide which are greenhouse gases that cause more heating. For many more examples see https://climate.nasa.gov/nasa_science/science/.

It is difficult, if not impossible, to predict how these effects will play out. Many of the effects are probabilistic, and data may be insufficient for certain prediction or modelling. These effects, which are certain or likely to arise, would nevertheless be included in the scenario. For example, a scenario that postulates a regional temperature increase of 3 degrees in Australia without considering effects on agriculture, the health system and society is not believable. Other effects are more speculative, especially in cases where a system might enter a new state after a tipping point. In these cases, the actuary would make an informed estimate. There are many techniques that allow the implications of climate change to be considered, including the analysis by experts from various professions, workshops, graphical methods or the building of models.

To develop climate change scenarios, a mix between intermediate approaches and a panel of experts might be most useful. To analyze the impact of climate change on clearly-delineated domains, the view of experts can be solicited. To assess the interactions between different domains, it is often more useful to ask for the help of a knowledgeable generalist.

It can be useful to employ graphical methods to think qualitatively through effects that can occur in a complex system like climate change. Many elements or sub-systems of the climate are coupled, and as the climate changes, propagate across different domains.

A graphical representation can help to think through implication and also see more clearly possible feedback loops.
1.5 Recognition of Climate-Related Stranded Assets

Reaching zero net emissions entails phasing out fossil fuels and obtaining energy from renewables (e.g. solar panels, or wind power). That means “decarbonisation”, a shifting away from a carbon-based economy to a low (or no) carbon economy. The IPCC reports state the maximum amount of CO₂ that can be emitted to keep the concentration below 450 ppm. That means fossil fuel reserves in excess of this budget cannot be extracted thus should become redundant and lose their economic value. They would then become what is called “stranded assets”, which it is thought to represent from 60% to 80% of known reserves⁷. The concept of stranded assets extends to the infrastructure that support the use of fossil fuels, from extraction, transportation, power plant and maintenance of internal combustion engines. A most visible shift is from cars, trucks, planes that in the future could become electrical but the shift is not a real improvement if the electricity is generated from coal power plants. This will impact the asset values as well as on the cash flows generated by the trading and consumption of fossil fuels.

To evaluate and monitor the impact, the actuary would establish relevant metrics (incl. the “carbon footprint”) to assess the dependency on fossil fuels related revenues.

Other types of assets can also become stranded assets as cities might have to be abandoned due to rising sea levels or infrastructure can become irrelevant because people migrate away. Industrial equipment dedicated to carbon-intensive processes such as cement and steel manufacture may need to be retired and/or replaced by less carbon-intensive technologies.

In all these cases, consideration would be given to the new investment opportunities presented by the mitigation activity.

2 Considerations in Applying Global Scenarios to Regional/Local

2.1 Considerations for Physical Risks and Opportunities

There are a number of physical phenomena that can be caused by climate change. Higher temperatures mean more energy that can lead to stronger windstorms and more frequent hurricanes and tornadoes. Rain patterns can change, leading to more rain in some regions and more pronounced droughts in others. Increased temperatures can lead to changes in agriculture and fishing as well as to longer and more extreme heatwaves in some areas. More speculative are the possibilities of increased Icelandic volcanic activity, the change of oceanic currents or the catastrophic collapse of Arctic or Antarctic ice shelves.

It is important to consider the effect that physical risks can have on the financial markets. These can range from direct impacts – positive or negative – on financial instruments, to indirect ones that can emerge from various causes related to climate change. A large catastrophe can lead to losses in equities

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or corporate bond exposures. Large catastrophes might also cause financial markets to freeze or at least to stop functioning properly for extended periods of time which might cause liquidity strains. Capital might flow out of jurisdictions that have been impacted severely by climate change, leading to further liquidity problems. Governments might react to the effects of climate change by lowering interest rates or nationalizing certain industries, which can also lead to market losses and decline in liquidity. Physical effects of climate change can lead to an increased demand of construction – dams, relocation of entire cities and populations, the building of new health facilities and more – which could lead to higher interest rates but also increased employment and investments.

Physical risks can directly or indirectly affect the exposure of an insurer or its operations. Hurricanes, windstorms, or heat waves can directly impact exposures and cause losses or impact the operations of insurers. Indirect impacts can occur e.g. from soil salinification or the acidification of the sea that impact agriculture and fishery or impacts on the financial markets. Exposures can also be affected by legal, regulatory and infrastructure measures that are being taken by governments to combat the impact of physical phenomena from climate change, e.g. building codes, risk pools or the construction of dams.

2.1.1 Characteristics of the Region

While climate change is a global phenomenon, its physical effects will differ across regions. The effects of climate change are not the same across all regions and can differ substantially. In one region, increased temperatures might lead to aridification, in another to more rain. While some regions might benefit from climate change by increased agricultural productivity, for others the rise of temperatures might be catastrophic. Regions that already now are hot might become uninhabitable without air-conditioning due to extended heatwaves. Other regions might be impacted by more energetic or more frequent tornadoes, hurricanes or windstorms.

Even within a region, climate change can lead to a variety of effects that might change over time. Coastal regions will likely be affected by rising sea levels, but also possibly by the death of marine diversity which would affect fishery. Further inland, glaciers might melt and destabilize mountain slopes which could destroy winter sport tourism and would require the construction of protective measures to keep villages in mountain valleys safe. Other areas of the region might be exposed to new wildlife and insects which might bring infectious diseases that had not been present there before.

Climate change will likely also affect financial markets in different ways. Actuaries might consider the reliance of a financial market on foreign investment and how these will change in situations of climate stress, the legal certainty of a jurisdiction, the expenditures needed to cope or adapt to climate change in a region, or the potential effects on exchange rates.

Differences across regions emerge from their location and energy mix, as well as from measures taken by each country to mitigate or adapt to the effects of climate change. Different countries will likely take different measures, ranging from legal and regulatory ones to the building of infrastructure. All this will impact the exposures and the potential losses of insurers, reinsurers and other assets holders. Actuaries would consider the location of exposures when analyzing the potential impact of climate change on the balance sheet of an insurer.

2.1.2 Infrastructure Building and other Legislated Measures

Costs and risks can also depend on physical measures taken by governments. These measures will depend on the specific exposures of the region to climate change. Coastal regions might build dams to reduce flooding, which lowers the risk to properties. Other regions might be affected by extreme heat waves and governments put infrastructure in place that allow people to work from home or strengthen electricity supply to ensure that cooling is always available.

2.1.3 Impacts on the Insurance Industry

The cost to insurers of the effects of climate change can depend strongly on legislative requirements or measure taken in a jurisdiction. It is obvious that a building code that requires a hurricane-proof construction will lead to lower losses than a jurisdiction where buildings do not have to comply with such
requirements. Other legislative measures could be the requirement to participate in climate-related losses, e.g. via pools, tax incentives that promote local electricity generation or the requirement to reinsure climate-related risks with a domestic carrier.

While global climate change can affect regions differently, the effects of climate change on a regional level can also have global effects. Climate change is a highly complex system where seemingly small, localized events can percolate and spread to have global effects. Physical effects like the collapse of a large ice shelf can cause a tsunami and a quick rise in sea levels globally. People might be forced to relocate due to heat waves or water and food shortages and find new homes far away. Physical events like large hurricanes or severe flooding can interrupt global supply chains and cause local shortages. The financial market is another transmission channel that can cause the spread of effects of local events across the globe. This can make it necessary to not only consider the effects of climate change in the region of the exposures at risk, but possibly also in other regions where global effects might emanate from.

Insurers can affect the impact of climate change on a regional, if not global level. Pricing the risks and potential costs of climate change of exposures to be insured gives incentives for taking appropriate measures. By considering measures taken to adapt to or mitigate the effects of climate change, insurers can make it cheaper for clients to ensure their exposures if they take appropriate preventive measures. Pricing would usually also take into account governmental measures that mitigate effects of climate change, e.g. building codes, the building of dams, or the strengthening of essential infrastructure. In extreme cases, where no measures are being taken, insurers might even refuse to take on risks. By taking into account measures that reduce the risks to their exposures, insurers give positive incentives to tackle the effects of climate change.

2.2 Considerations for Transition Risks and Opportunities (Mitigation)

If emissions do not decrease fast enough in the first half of the 21st century, then they will need to decrease even more rapidly in the latter part of the century. Requirements for mitigation include making changes to the energy system, the land system, industry, transport, and agriculture as well as influencing consumer behavior (e.g. reducing food waste and consumption in general). These changes are designed to move human activity away from dependence on fossil fuels, to greater efficiency of energy usage, optimized land system usage and reduced emissions in agriculture and industry.

2.2.1 Local Incentives to Transition

The transition to a low-carbon economy is being driven by climate policies aiming at the decarbonisation of the economy adopted by the signatories to the Paris Agreement with the objective to reduce cumulative GHG emissions to a level compatible with keeping global warming below 2°C. Independently of the mitigation of climate change, a low-carbon economy presents multiple benefits to ecosystem resilience, trade, employment, health, energy security, and industrial competitiveness. Although the focus is generally on adverse consequences of global warming, the transition entails both downside and upside impacts.

However, the transition risks are dependent on the nature and intensity of the mitigation effort. Thus, a more stringent scenario, like the “below 1.5°C”, will entail higher transition risks than an NDC scenario, especially in terms of impacts on the value of assets, while a BAU scenario leads to lower transitional impacts. A more disorderly transition to a low-carbon economy resulting from switching to a “too little too late” scenario presents more significant risks.

The incentives to decarbonisation are likely to be defined at the country level as national governments implement policies driven by their commitments under the Paris Agreement. This would be the case for instance of the regulatory and compliance burden, carbon pricing, emissions reduction requirements such as standards for cars and industrial production, subsidies for solar panels or wind turbines or decommissioning of coal fired power plants.
2.2.2 Importance of Local Economic Drivers

Local economic drivers will depend on geographic location and composition of the market demand that depend on the local balance between energy production from fossil fuels and renewables, and investment opportunities in local infrastructure projects. Stranded assets can result from changing policies or regulations, reputational impacts, shifts in markets due to new technology, and physical risks. Asset stranding could affect a variety of infrastructure assets.

Entities need to evaluate their exposure to the impact of decarbonisation on their operation, assets and investments, independently of the exposure to physical risks. In a first phase investors could rely on carbon foot-print data, but these do not provide information on how prepared the entity is to adapt its business model and investment strategy to future risks, face supply chain disruptions and cope with changes in demand for products or services.

2.2.3 Local Disincentives to Transition

The transition to a low-carbon economy entails a major change in the sources of energy. According to a comprehensive report on The Geopolitics of Renewable Energy\(^8\) the global energy system is so vast-with trillions of dollars of legacy infrastructure - that even minor changes could have outsized impacts in some regions and sectors. In addition to the financial impact on fossil fuel producers, there is a major political impact on the international order since for many countries it is a significant source of revenues and power. This has led to the promotion of alternative solutions such as Carbone Capture and Storage (CCS) technologies to make the burning of fossil fuels compatible with the 2°C objective. As no such technology exists yet at the required scale, it entails a risky bet on the future: the largest CCS plant capturing 5 million tons of carbon is a very small fraction of the 36 billion tons emitted in one year\(^9\).

Many emerging economies see the reduction of GHG as a constraint on their economic development and make the political argument that the developed economies have achieved their development through building up the concentration of carbon dioxide that is now causing global warming, thus it would be unfair to deny them the same opportunity.

To put this in perspective, the per capita emission of CO\(_2\) is 16.6 tons per annum for the USA and 0.06 tons for the Democratic Republic of Congo in 2017. Some of these countries possess abundant reserves of coal from which they can produce energy that would become stranded assets in a low-carbon economy. To help resolve this conundrum, some developed countries have offered to contribute to a fund to subsidize the transition for developing economies. Nevertheless, the shift to a low-carbon economy is seen as destroying jobs, even though they could be replaced by different jobs of equivalent or better quality.

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\(^8\) [https://energypolicy.columbia.edu/sites/default/files/CGEPTheGeopoliticsOfRenewables.pdf](https://energypolicy.columbia.edu/sites/default/files/CGEPTheGeopoliticsOfRenewables.pdf)

More generally, the transition is a complex operation that require synchronization between many independent stakeholders to ensure continuity and orderly harmonization of supply chains. The uncertainty about the ultimate warming level and the timeline increases the transition risks and makes it more difficult to mobilize individuals to provide public support for difficult political choices. The resistance to the wearing of masks to combat the COVID-19 pandemic has demonstrated the challenge of modifying cultural habits of individuals and the risks of politicization.

2.3 Considerations for Litigation and Reputational Risks

2.3.1 Expected Level of Care by the Corporations / Fiduciary Obligations

Care is expected at the various levels within a corporation: it is expected from its Board, from the Officers of the company, its managers and from its professionals. Whatever the actuary’s role, there is an implicit or explicit expectation of care. Climate-related risks are becoming part of the expected considerations. These considerations cover the entire business cycle: e.g. Business Plan, Product Design and Pricing, Risk Management, Investments, Human Resources, Governance, Financial Reporting. In addition, there are growing expectations that environmental risks are to be disclosed in a transparent manner.

More so than other environment risks, climate-related risks are rarely immediate risks but risks with consequences years in the future. What is potentially acceptable now may very well not be accepted in the future. Professional judgement and disclosure might be questioned in the future with the knowledge as of that point in time. In summary, even though the future is hard to predict, the future legal assessment of decisions taken today will be based on what could have plausibly been known today and whether it followed the prudential principle.

There will always be pressure for short-term results over long-term considerations but that will likely not be a good enough answer when a climate-related catastrophe materializes. If fiduciary obligations are not fulfilled satisfactorily to the stakeholders, there is both a legal risk as well as a reputational risk.

2.3.2 Legal Risk

There is a strong rise in climate-related litigation. As of January 2020, Norton Rose Fulbright estimates that 1,444 such cases had been filed so far in at least 33 countries.¹⁰ Most cases are based on

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constitutional and human rights laws attempting to hold governments or oil producers accountable for addressing climate change. References are made to government commitments under the Paris Agreement. Most lawsuits have not been successful so far, but a few have been. As an example, the UK Court of Appeal blocked plans to build a third runway at Heathrow Airport as its expansion violated the Paris Agreement. In the Netherlands, the case ‘Urgenda Foundation versus State of the Netherlands’ forced the Netherlands to make a 25% reduction in green-house gas emissions. In contrast, in a similar case in Germany, the courts found that the government had some discretion in how to achieve commitments.

The way to present cases is in evolution as claimants are looking for more effective approaches and an increasing number of lawsuits look at using scientific findings as their basis to prove causation. In the US, litigation is typically directed at the producers of emissions themselves rather than on the government. These lawsuits typically come from consumers, consumer advocates and regulators.

Litigation can be used to repair actual harm done or avoid potential harm from being done. The latter is harder to prove. Most often for climate-related risk, it is the failure to act as a reasonable and prudent person in the face of climate-related risks that triggers litigation.

Another major current cause is improper disclosure regarding emissions. In the case ‘Commonwealth of Massachusetts v Exxon’, it is alleged that “Exxon had deceived investors by not disclosing climate change-related risks to its business, and had deceived consumers through greenwashing campaigns and misleading advertisements that failed to disclose the impact of its fossil fuel products on climate change”11. In the future, sources of claims are likely to expand beyond use of fossil fuels.

Laws evolve and are influenced by developments in other countries. What is acceptable in court also evolves and the cultural evolution in the public minds about the acceptability of certain behaviors regarding climate-related risks is slowly percolating into the court system.

Legal risks can be mitigated through the use of insurance. When an insurer provides legal risk protection, this risk is reported as a Liability Risk in the insurer balance sheet to differentiate it from its own Legal Risk.

In the face of climate-related risks, insurers will adapt their coverage and pricing to offer up-dated products. New coverage is likely to respond to newer forms of risks with limitations to prevent undesired risks. Some systemic risks may not be hedgeable as the pooling of global risks fails to diversify them.

2.3.3 Reputation Risks

Climate change has been identified as a potential source of reputation risk tied to changing customer or community perceptions of an organization’s contribution to or detraction from the transition to a lower carbon economy. Reputation risk is similar to legal risk with the exception that the judgement is made by clients and the public in general rather than from courts. Reputation risk is harder to insure as the loss is very difficult to assess. It is nevertheless a real risk.

3 Criteria, Guidance and Tools for Selecting Scenarios

3.1 Considerations for Designing Scenarios

Climate change scenarios can be seen as pathways to achieve the transition from the current state of climate to an ultimate state where the climate has stabilized at some warming level and new GHG emissions have reached the Net Zero level12. Most of them assume that global warming will not continue

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11 See www.mass.gov/files/documents/2019/10/24/Complaint
12 The Net Zero level refers to an overall balance between greenhouse gas emissions produced and greenhouse gas emissions taken out of the atmosphere.
indefinitely. Multiple pathways are possible, that reflect the interaction of changes induced by the transition to a low-carbon economy.

In addition to their own needs, users should take into account the new context created by the recommendations issued by the Task Force on Climate-Related Financial Disclosures. The demand for climate-related disclosures has increased significantly since the release of the TCFD recommendations in 2017. These Recommendations\textsuperscript{13} promote the use of scenarios analysis in the disclosure of climate-related risks and opportunities. Any entity can freely use the recommended framework\textsuperscript{14} as an analytical tool to help manage risks even if there is no intent of reporting publicly.

Even though the recommendations are not mandatory, the trend is clearly for regulators and governments to require disclosures. It is in the user’s interest to avoid duplication, minimize the reporting burden and pre-empt reputational risks by including in the selection those scenarios that help meet the expectations of the market, of the investment community, and potentially the requirements of the financial regulators or credit rating agencies. Thus, an optimal selection should encompass the risks that are significant for the users and third parties, depending on the purpose of the analysis, which may include benchmarking and comparison with peers.

As shown in the Figure 5 below, despite national commitments to reduce emissions, the atmospheric concentrations of CO\textsubscript{2} since 1990 show an almost linear growth. Thus, using past data would not be a good predictor as it would imply indefinite growth at about 2 ppm/yr. Given that emissions have been higher than anticipated, an accelerated version of the +2\(^\circ\)C scenario, the “Net Zero by 2050” scenario, is currently promoted by UNEP FI\textsuperscript{15} to keep warming below 2\(^\circ\)C, have emissions peak in 2020 and reach net zero between 2050 and 2075.

\textbf{Figure 5 - Trend in CO\textsubscript{2} concentration, source:} \url{http://scrippsc02.ucsd.edu/data/atmospheric_co2/primary_mlo_co2_record}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{ Monthly CO2 ppm 1991-2019.png}
\end{figure}

Scenarios can be classified in accordance with the ultimate degree of warming and the year when emissions stabilize at the net zero level.

\textbf{Figure 6 – Illustrating a double alternative,}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{ Figure 6.png}
\end{figure}

\textsuperscript{15} https://www.unepfi.org/climate-change/united-nations-convened-net-zero-asset-owner-alliance/
The magnitude of future impacts will be determined, at least in part, by actions taken by governments, firms, individuals and a range of other actors. Their impact on the financial system may therefore be larger than other types of risks and is potentially non-linear, correlated and irreversible. In addition, the time horizons over which risks may be realized is uncertain and their full impact may crystallize outside many current business planning horizons. While there is a high degree of certainty that risks from some combination of physical and transition factors will occur, the exact outcome and the timing remain uncertain. There are many potential outcomes similar to the four illustrated in Figure 6 that may result from technological breakthroughs, political reversals, or feedbacks from emerging experience that will be at variance from expectations. Thus, the need to monitor progress against expectations and adjust dynamically for changes in the exposure.

The COVID-19 pandemic will likely cause a temporary blip in emissions that could be misinterpreted as a new trend or on the contrary the confinement may motivate individuals to act to avoid further risks of disruption in their lifestyle. The reverse is also possible and a worse case than RCP 8.5 cannot be excluded, which means that resilience needs to be tested also against severe outcomes like runaway emissions that would push global warming beyond the range of current expectations.

The choice of the scenarios should maximize the utility of the information for the user to:

- Assess its exposure to a complex combination of climate changes;
- Understand the impacts on its enterprise, supply chain, business model or program;
- Identify risks and opportunities associated with the future eco-system; and
- Test the resilience to more extreme scenarios.

A scenario better fulfills its function as part of a family of scenarios based on a distinct and clearly differentiated set of determinants. The choice of the scenarios should maximize the utility of the information for the user. The TCFD lists as follows the main desirable characteristics of scenarios:

- **Plausible**: the events described in the scenario should be possible and credible;
- **Distinctive**: each scenario should be based on a distinct and clearly-differentiated set of determinants;
• **Consistent**: interaction between the qualitative and quantitative elements described in the scenario should obey strong logic. If the reversal of past trends is predicted, a logical explanation of such a reversal should be provided;

• **Relevant** (to the issues examined): the specific issues at stake should be key to the scenario;

• **Challenging**: the scenarios should challenge the prevailing visions of the future and the status quo.

• **Transparent** as to the methods applied, the assumptions made, the reasons behind their choice, the results and the conclusions.

It is expected that global emissions will not change dramatically from year to year but will gradually reflect mitigation efforts, thus the pathways would become continuous curves differing mostly by the year emissions peaks, the speed at which they reduce and the ultimate stabilization level. History shows how difficult it has been to reach a consensus across nearly 200 countries and the Paris Agreement is imperfect like all compromises. The COVID-19 crisis illustrates the difficulty to coordinate actions and decisions to resolve global issues. The IPCC RCP and most other existing scenarios are mathematical projections based on physical laws or extrapolation, which therefore seem orderly and reach stabilization at some future date. However, one cannot rule out inflection points linked to political reactions or shifts in public opinion. In addition, the inherent volatility of impacts of climate-related risks is compounded by externalities such as earthquakes or pandemics but more importantly by unpredictable human factors, aggregating a large number of uncoordinated decisions.

### 3.2 Types of Scenarios

There are different ways risks can be analyzed. There are the existing risks on the balance sheet assuming the world is not going to change and there are the risks that are likely to arise as the environment changes. If the environment changes, there will be disruption and therefore, one needs to be prepared. The difficulty with climate-related risks and opportunities is that future changes are hard to predict both due to the slow development of climate change and its effects and the long-term nature and the multitude of interactions between variables. Depending on the purpose and depth of the desired analysis, there are different ways of approaching the question.

#### 3.2.1 Frozen Balance Sheet

A first type of analysis is to look at the current portfolio of business and assets and rank each of its components according to their sensitivity to tested changes in the environment, possibly splitting into short, medium and long-term with impacts associated with each bucket.

The advantage of such an approach is that it makes it easier to compare between different organizations. It is also easier to model and therefore a good introduction to the analysis of a risk as complex as climate change. The main disadvantages are a) that it assumes that no corrective actions will be undertaken to adjust the portfolio and b) that it is difficult to account for dynamic paths. It is an approach that is particularly useful when looking at the possible impact of stranded assets and making adjustments to the asset portfolio.

#### 3.2.2 Dynamic Paths

Not all risks can be captured by a ‘frozen balance sheet’ approach. Because of all the variables involved, it may be more useful to look at the impact of the interaction of a number of variables over time through a dynamic model. Such models attempt to provide a more realistic projection or look at predefined paths to facilitate the understanding of the interrelations. Dynamic paths allow to study the impact of changes in one variable at a time or the combined impact of changes in a set of circumstances. It also allows examination of the impact of delayed changes either in the risk itself or the response to the risk, since managers will not sit passively. The actuary could build his or her own scenario or use existing ones.

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The use of existing scenarios facilitates the disclosure of results to an external audience and even internally to non-specialists. Of course, this approach is much more complex than the 'frozen balance sheet' approach. It captures more information for the medium term, but not enough for the true long-term projections indicated below.

### 3.2.3 Impact of Limited Resources (Food, Water, Land)

A broader and longer-term analysis requires a holistic projection with all factors involved and their potential secondary effects. It requires projections of resources (land, water and food supply) both in term of quantity and usability and the need for resources (population size, inequality of distribution). It would project the impact of new means of adapting to the environment, both through technical advancement and the change in volume and type of consumption. The major downside of this type of analysis is the sheer size of assumptions and interactions needed, making it complex to handle, validate and explain. Whatever the type of analysis selected, it is important that the models be internally consistent and coherent. Often more than one model is being used and the combination of the results requires consistency and coherence.

### 3.3 Criteria, Guidance and Tools for Selecting Scenarios

There is no “silver bullet” for selecting a set of scenarios but there is an abundance of material, tools and data, some are available for a fee from commercial providers.


The end-to-end climate scenario analysis process, as Figure 7 illustrates, is iterative. The process will need to be applied to more than one major emission pathways to provide adequate coverage of the exposure to climate-related risk and updated in a dynamic way as the actual experience emerges. Some firms may want to start with various reference scenarios and alter them to be relevant to their own business models, rather than start from scratch. Another approach is to start by asking a set of ‘what if?’ questions, rather than launching into full blown scenario analysis: e.g. what if there was a carbon price of $100? The final stage is to assess the financial impacts of these scenarios and/or ‘what if?’ questions. Insights gained from that financial impact analysis should in turn feed back into the refinement and identification of new risks and potential exposures, which will then inform the development of
scenarios as well as supporting identification of potential new scenarios to be analyzed\(^{17}\). A climate scenario can typically be defined using a combination of four main components:

i. **Emission pathway and associated changes in the concentration of GHG in the atmosphere** comprising the timing and intensity of associated climate events such as temperature, precipitations, winds and sea rise. Basic information is available from IPCC reports\(^{18}\), think-tanks or academic research institutions. This component will set the timeline, the ultimate target of global warming and thus the balance between physical risks and transition risks.

ii. **Climate policy landscape**: assumptions about future climate policy ambition and economic policies, impacting emissions either directly (e.g. through imposing taxes or quantity restrictions on emissions) or indirectly (e.g. through regulations on technology, materials and efficiency).

iii. **Technological evolution**: Reducing emissions will require a shift to renewables driven by a combination of pricing and technological efficiency that need to be quantified. This component will cover the setting of parameters such as carbon taxes, sources of energy and costs and investments in renewables.

iv. **Socio-economic context**: Shared Socioeconomic Pathways’ (SSPs)\(^ {19}\) have been developed by internationally recognised teams of academics to support the analysis of the physical impacts of climate change by setting their socioeconomic narratives.

Further details on the interaction between the 4 components are illustrated in Figure 8 below.

**Figure 8 - Components interaction**, source: https://www.fca.org.uk/publication/corporate/climate-financial-risk-forum-guide-2020-scenario-analysis-chapter.pdf

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Figure 9 below illustrates a potential Technological evolution driving the shift to a low-carbon economy.

**Figure 9- Global Power Generation Mix, source:** [https://about.bnef.com/new-energy-outlook/](https://about.bnef.com/new-energy-outlook/)

![Global Power Generation Mix](https://about.bnef.com/new-energy-outlook/)

Embedded in Figure 10 are variables that will help estimate stranded assets and the impact on future cash flows and investments. Given the importance of these variables, they are the object of a separate paper to be published later.

**Figure 10- Variables to be defined, source:** [https://www.bankofengland.co.uk/-/media/boe/files/paper/2019/the-2021-biennial-exploratory-scenario-on-the-financial-risks-from-climate-change.pdf?la=en&hash=73D06B913C73472D0DF21F18DB71C2F454148C80](https://www.bankofengland.co.uk/-/media/boe/files/paper/2019/the-2021-biennial-exploratory-scenario-on-the-financial-risks-from-climate-change.pdf?la=en&hash=73D06B913C73472D0DF21F18DB71C2F454148C80)

<table>
<thead>
<tr>
<th>Climate risk variables</th>
<th>Macrofinancial variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical variables</strong></td>
<td><strong>Transition variables</strong></td>
</tr>
<tr>
<td>Frequency and severity of specific climate-related perils in regions with material exposure (including UK flood, subsidence and freeze).</td>
<td>Emissions pathways (aggregate, and decomposed into world regions and sectors).</td>
</tr>
<tr>
<td>Longevity.</td>
<td>Commodity and energy prices (including renewables), by fuel type.</td>
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The graph in Figure 11 explains how different types of risks combine to define a scenario adapted to the purpose, geographic location and circumstances of the user over different timelines.
Additional information about scenarios can be found in Appendix 1

4 Key Challenges

There are several challenges and barriers that need to be considered in the development or use of workable climate scenarios to support the assessment of the potential business- and financial impacts of climate change. As adaptation moves from theory to practice, there is growing recognition that barriers may make it difficult for individuals, businesses and governments to plan and implement adaptation actions and build resilience. These involve a variety of issues, especially for long-term decisions, and include economic, political and governance challenges. Addressing these barriers is critical to advancing climate compatible development, and actuaries working on scenario analyses will need to consider the degree to which they are likely to be successfully addressed.

Some of these challenges have been highlighted in the NGFS first comprehensive report and the Climate Financial Risk Forum 2020 Scenario Analysis guide.

- **Far-reaching impact in breadth and magnitude:** Climate change will affect all agents in the economy (households, businesses, governments), across all sectors and geographies. The risks will likely be correlated and potentially aggravated by tipping points, in a non-linear fashion. This means the impacts could be much larger, and more widespread and diverse than those of other structural changes.

- **Foreseeable nature:** While the exact outcomes, time horizon and future pathway are uncertain, there is a high degree of certainty that some combination of increasing physical and transition risks will materialise in the future. While using a shorter timeframe (up to a few years) may seem more relevant for decision-making now, the most significant impacts from physical risks will arise over decades. Conversely, transition risks can occur much sooner, if momentum builds towards a policy change and public opinion shifts (as happened with diesel emissions or plastic bag use).

The time horizons over which climate-related risks may be realized are uncertain, and their full impact may crystallize beyond most current business planning horizons. Conversely, social tipping-points are rarely modelled but may mean some transition elements affect certain sectors.

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abruptly, using past data may not be a good predictor of future risks and currently there is often little

- **Dependency on short-term actions**: The magnitude and nature of the future impacts will be determined by actions taken today which thus need to follow a credible and forward-looking policy path. This includes actions by governments, central banks and supervisors, financial market participants, firms and households.

- **Cognitive biases must also be recognised and accounted for when developing and using any type of scenario**: For example, people unconsciously assess the probability of a future event or outcome on the basis of how easily they can remember past examples or how easily they can imagine possible events. Many economic models of climate impacts are still developing, and data is not always available.

- **Data gaps and comparability of disclosures**: Firms may need to use additional metrics requiring new data and new modelling methods to capture climate impacts on the economy and their business. Such variables might include hazard factors for physical events or green-house gas emissions from specific economic activities. Firms are likely to find that their existing risk models will also need to be adapted to capture climate factors.

### 5 Next Steps

This paper is the second of a series of papers that the IAA Climate Risk Task Force has committed to develop over the coming years. The first paper was entitled “The Importance of Climate-related Risks for Actuaries” and was an introductory paper to the series of paper that the IAA committed to. In order to address the needs of the actuaries, the following papers are scheduled to be released over the following years, such as:

- A paper designed to further stimulate development of effective and globally applicable links between climate-related risk scenarios and insurance and pension risks and costs.

- A paper on the application of climate-related risk scenarios to asset portfolios with an important subsidiary goal of encouraging consistency between assets and liability modeling.

- Advice on climate-related risk management and addressing emerging third party regulatory/reporting/disclosure requirements.

- A paper on the potential effects of transition and adaptation steps.

- Review of existing IAA publications to identify and address any climate risk related gaps.

- A paper on the link between climate-related risk scenarios and social security.

The IAA Climate Risk Task Force welcomes and encourages input and involvement in these activities.
Appendix 1 – Additional Information Available about Scenarios

Summary of a Set of Illustrative Scenarios

The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes. The current status is used as the baseline for comparison purposes.

<table>
<thead>
<tr>
<th>Current</th>
<th>Transition milestones and commentary</th>
<th>Physical damage milestones and commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• 2017 emissions reached 37 GtCO₂.(^6)</td>
<td>• Temperature has increased 1.1°C relative to preindustrial levels.</td>
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<tr>
<td></td>
<td>• Fossil fuels are 80% of the energy mix.</td>
<td>• CO₂ concentration is over 400 ppm (last occurred three million years ago).(^4)</td>
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<td></td>
<td>• 80% of emissions are not covered by carbon pricing.</td>
<td>• Sea-level rise is at 22 cm.(^9)</td>
</tr>
<tr>
<td></td>
<td>• 59% of 2017 energy supply investment went to fossil fuels.</td>
<td>• Half of the Great Barrier Reef has bleached to death since 2016,(^7) which has significant biodiversity and flood protection implications.(^8)</td>
</tr>
<tr>
<td></td>
<td>• 3.3 million electric vehicles were on the road in 2017.(^7)</td>
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</tbody>
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2°C

Aggressive climate action:

• Emissions peak in 2020.
• Emissions fall to 16 GtCO₂ by 2050 (57% decrease versus 2017).
• Net-zero emissions are reached by 2080–2100.

By 2050 (relative to 2015):

• Total energy demand is down by 12%.
• Coal is aggressively phased out.
• The energy sector is electrified.
• Power generation increases by 60% (with 55% of generation from renewables and 8% nuclear).
• Oil and gas supply is down by 10% (oil demand down by 33%; gas supply up by 20%).
• New vehicle sales are 60% electric vehicles (EV) and 25% liquefied petroleum gas (LPG).

• There is a 50% chance of keeping temperature increase below 2°C.
• By 2050, temperature rises 1.7°C. Physical damage examples at 2°C of warming include:
  • Average sea level rises around 50 cm.
  • Annual maximum daily temperature is 2.6°C higher; the number of hot days increases by 25%.
  • Frequency of rainfall extremes over land increases by 36%.
  • Average drought length increases by four months.
  • Suitability of drylands for malaria transmission goes up 27%.
  • Average crop yields for maize and wheat decrease by 9% and 4%, respectively.

Some climate action but not transformative, and we fail to achieve a 2°C outcome:
- Global emissions are essentially flat to 2050 and rise slightly after.
- Emissions reach 41 GtCO₂ in 2050.
By 2050 (relative to 2015):
- Total energy demand is up 18%.
- Fossil fuels represent 80% of primary energy.
- Coal use is down but only by 7%.
- Power generation increases by 85% (with 27% of generation from renewables and 3% nuclear).
- New vehicle sales are 37% EV and 35% LPG.

In 2050: Temperature increases by 1.9°C.
By 2100: Temperature increases by 3.2°C.

By 2100, example physical damages are largely considered irreversible (permanent loss of arctic sea ice) and include:
- Sea levels rise approximately 58 cm on average.
- Average drought length increases by four months.
- There is 30% less water availability.
- Heat waves and forest fires are greater than recent years.
- Risk to marine fisheries and negative aggregate impact on agriculture and food production increases chance of famine.

Business as usual pathway:
- Global annual emissions increase by 49% by 2050 relative to 2015.
- Emissions reach 91 GtCO₂ by 2100.
By 2050 (relative to 2015):
- Total primary energy is up by 28%.
- Fossil fuels represent 84% of primary energy at 2050.
- Power generation is 25% renewable (plus 5% nuclear).

In 2050: Temperature increases by 2.0°C.
By 2100: Temperature increases by 3.9°C (heading higher).

By 2100, example physical damages are largely considered irreversible (permanent loss of arctic sea ice) and include:
- Sea level rise of approximately 70 cm on average.
- There is 50% less water availability.
- The strongest Northern Atlantic cyclones increase by 80%.
- Heat wave and forest fire risk is very high and compromises normal outdoor activities.
- Risk to marine fisheries and ecosystems and medium-to-high risk of decline in fish stocks, plus negative aggregate impact on agriculture and food production, increases chance of famine and reductions in food supplies and employment.
Additional sources of information

The Technical Supplement to TCFD recommendations\(^{22}\) offers information regarding “Key Considerations: Parameters, Assumptions, Analytical Choices, and Impacts” and includes a comparison of several publicly available scenarios.

Additional scenarios are listed below.

- 2019 CRO forum. Their report “The heat is on - Insurability and Resilience in a Changing Climate”\(^{23}\) compares physical and economic impacts for scenarios leading to global warming of 1.5°, 2°, 3° and 5°C.
- The Network for Greening the Financial System (NGFS)\(^ {24}\)
- Climate Interactive\(^ {25}\)
- The Bank of England\(^ {26}\)
- Climate Financial Risks Forum\(^ {27}\)
- BloombergNEF (BNEF)\(^ {28}\)
- Greenpeace\(^ {29}\)
- Institute for Sustainable Development\(^ {30}\)

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\(^{25}\) [https://www.climateinteractive.org/tools/c-roads/](https://www.climateinteractive.org/tools/c-roads/)
\(^{28}\) [https://about.bnef.com/new-energy-outlook/#toc-download](https://about.bnef.com/new-energy-outlook/#toc-download)
\(^{29}\) [https://www.greenpeace.org/usa/research/an-abrupt-climate-change-scenario/](https://www.greenpeace.org/usa/research/an-abrupt-climate-change-scenario/)
\(^{30}\) [https://www.iea.org/reports/world-energy-model/sustainable-development-scenario](https://www.iea.org/reports/world-energy-model/sustainable-development-scenario)
References

1. Importance of Climate-Related Risks for Actuaries - September 2020

2. Not all the effect is due to human impact as there are also long-term cyclical climate changes.
   It is the rate of increase in global warming correlated with increased human activity that is the basis of the concern regarding the impact of the human activities.

3. The United Nations (UN) body for assessing the science related to climate change. The IPCC created by the UN in 1988 is an organization of governments that are members of the United Nations or the World Meteorological Organization (WMO), comprising 195 members.

4. eCO₂ or equivalent CO₂ is a unit that allows emissions of greenhouse gases of different warming potential to be added together to simplify analysis and comparisons. However, the conversion does not fully reflect the differences in persistency and other impacts such as on agriculture.


6. The Paris Agreement was adopted in December 2015 and ratified by 189 governments in 2016 https://en.wikipedia.org/wiki/Paris_Agreement


11. See www.mass.gov/files/documents/2019/10/24/Complaint

12. The Net Zero level refers to an overall balance between greenhouse gas emissions produced and greenhouse gas emissions taken out of the atmosphere.


16. This article illustrates the complex interactions between science and politics https://www.nytimes.com/2018/08/31/podcasts/the-daily/climate-change-losing-earth.html


