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Application of Climate-Related Risk Scenarios to Asset Portfolios

Climate Risk Task Force

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IAA Paper

Application of Climate-Related Risk Scenarios to Asset Portfolios

This paper 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 by the IAA's Council on 7 May 2020.

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This paper has been approved for IAA publication by the Climate Risk Task Force in accordance with the IAA's Communications Policy.

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Executive Summary

This paper on the application of climate-related risk scenarios to asset portfolios is the fourth in a series of IAA papers on the integration of physical, transition, legal and reputational climate risks into the work of actuaries.

This paper's focus on assets is relevant to actuaries because:

- The assessment of assets is an integral part of actuarial work.
- Climate-related risks may affect the amount, likelihood and/or timing of expected future cash flows from individual investments and portfolios of assets. Asset prices and market values may also be affected by climate-related shifts in investor preferences, global climate policies and regulations.
- Where a business, such as an oil supplier, may lose a significant share of its market as a result of government actions or consumer views, the timing of the potential change in its market value is important. Risk assessment may include consideration of whether markets are already recognizing any parts of the business as stranded assets.
- Recent court cases,[1] legal opinions[2] and regulators' guidance[3] have strengthened the case for pension fund fiduciaries, insurers and other financial institutions to take into account the risks climate change poses to their investments.
- Actuaries need to:
    - Understand the potential impact of various climate scenarios on assets and the current frameworks to measure and report it; and
    - Consider, where applicable, the impact of climate-related risks on long-term actuarial liability discount rate and on the appropriateness of assets backing liabilities (asset/liability matching).

The key points of this paper are:

- Scenarios and pathways available to actuaries to understand and integrate climate-related risks into the measurement and management of asset portfolios include the Representative Concentration Pathways (RCPs) from the Intergovernmental Panel on Climate Change (IPCC) and the energy emissions scenarios of the International Energy Agency (IEA). An analysis of the climate-forcing (physical risk) and emissions-reduction (transition risk) requirements is included in the Network for Greening the Financial System (NGFS) scenarios.
- Depending on the purpose of a climate-related risk assessment, actuaries advising asset owners could start with a bottom-up approach considering the exposure of individual investments to climate-related risks or a top-down approach modelling the impact of climate scenarios on macro-economic parameters. However, using both would provide a more complete picture.
- There are additional considerations by asset class, the main classes being bonds, equities, real estate and infrastructure. Difficulties in defining what is meant by "green" are highlighted. Efforts are made around the world to establish "green taxonomies" and to limit "greenwashing", where unjustified claims are made.
- Various risk measures and metrics have been developed in recent years, such as portfolio alignment, Climate Value-at-Risk and Implied Temperature Rise, but these need to be treated with caution at present as there can be a lack of transparency and comparability.

Case studies are provided to illustrate how climate-related risk scenarios are applied to asset portfolios, particularly in the context of life insurers, pension funds, general insurers and lending banks.

1 Introduction

Climate-related risks to asset portfolios arise directly from:

- The risk of physical damage to assets due to extreme weather events and longer-term changes (e.g., sea-level changes);
- The transition to a lower-carbon economy, which will entail extensive policy, technology and market changes to address mitigation and adaptation requirements related to climate change; or
- Legal and reputational risks.

Transition risks apply particularly to assets and sectors with high emissions of greenhouse gases (GHGs) (or who facilitate such emissions, such as the oil supply sector). Energy generation, transportation, heavy industry (e.g., steel and cement) and agriculture face major transition risks. Transition risks are likely to increase rapidly, as political promises are implemented to try to achieve a net zero economy by 2050.

Corporations are exposed to reputational damage, especially those selling consumer goods, if they are perceived to be laggards in climate action. Similarly, insurers and banks are also coming under increasing scrutiny regarding their financing of fossil-fuel investments. While pension funds do not have a comparable commercial purpose, their members are being encouraged to take a greater interest in their investment funds with a view to reducing climate risks. The actuarial profession is not immune to damages if actuaries collectively fail to advise appropriately. In 2017 the Institute and Faculty of Actuaries (IFoA) issued non-mandatory guidance[4] alerting actuaries to consider how climate-related risks affect the advice they are providing, and much additional advice has been provided subsequently.

This paper follows three earlier publications from the IAA and focuses on the impact of physical and transition risks to the asset side of the balance sheet. The previous papers gave an overview of climate-related risk and how to assess the potential impact, focusing mainly on the liability side. Readers are advised to look at these papers (listed below), especially the second as it provides basic notions that are the foundations on which this paper is built.

- Paper 1: *Importance of Climate-Related Risks for Actuaries*;[5]
- Paper 2: *Introduction to Climate-Related Scenarios*;[6] and
- Paper 3: *Climate-Related Scenarios Applied to Insurers and Other Financial Institutions*.[7]

The focus of this fourth paper is the assessment and projection of asset cash flows and values taking into account climate-related risks to be incorporated in the different analyses and reports provided by actuaries.

This paper is intended to allow readers to:

- Understand how institutional asset portfolios may be affected by climate-related risks (a bottom-up approach), at both the asset-class and security levels (personal portfolios can be affected as well) (Section 2);
- Appreciate how climate-related risk scenarios could impact macro-economic variables (a top-down approach) (Section 3);
- Understand how different asset classes are impacted by climate-related risks (Section 4);
- Distinguish between commonly used portfolio-level risk measures and metrics (Section 5); and

- Learn about the specific considerations for a portfolio of assets through case studies involving pension plans, insurers and banks, and understand the importance of ensuring consistency between assets and liabilities climate-related risk modelling assumptions (Section 6).

Theoretically, the "market" captures changes in the value of assets due to perceived future risks (e.g., climate change). However, a climate-related risk assessment may help determine the risk to market values under various scenarios regarding both climate change and transitional impacts on the economy.

Risk measurement starts with the various scenarios and pathways developed by the Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA) and Network for Greening the Financial System (NGFS). Corporate disclosures, such as those recommended by the Task Force on Climate-related Financial Disclosure (TCFD), help to provide the data for portfolio analysis. These scenarios explore possible outcomes and are not intended as predictions.

The Organisation for Economic Co-operation and Development (OECD) provides extensive global information on the assets and liabilities of the main types of financial institutions. Table1 summarizes the overall position and describes the various sources used by the OECD for these data.

Table 1: Mapping of Financial Assets

	USD trillions
Institutional investors (pension funds, insurers)	68.5
Banks	147.9
Other financial intermediaries	115.3
Public institutions (central banks, sovereign wealth funds, public financial institutions)	54.9

Source: *www.oecd-ilibrary.org/sites/095705eb-en/index.html?itemId=/content/component/095705eb-en*

Note: Within the category "Institutional investors", global pension fund assets represent USD 35.6 trillion, with insurers alone managing USD 32.9 trillion.

Similar figures were produced by the Thinking Ahead Institute, which surveyed total assets under management of the top 500 global asset managers. Its 2021 report[8] included total assets of USD 154 trillion, including pension funds (57), mutual funds (55), insurance funds (33), sovereign wealth funds (8) and endowments & foundations (1).

Accompanying this paper is a separate glossary[9] of terms used, which the IAA will update as further papers on climate-related risks are developed.

2 Individual Asset Selection: Building a Portfolio from "Bottom-Up"

A portfolio may be examined as the collection of individual assets (bottom-up approach) or from its overall composition (top-down). As of the time of writing, the methods used to assess climate-related risk at the individual security level are still developing, and practice may vary from one geographical region to another. Portfolio managers who use discounted cash flow (DCF) models to analyze companies can stress-test cash flows for future carbon

pricing, especially in the energy and utilities sectors. The energy asset class is hard to assess, particularly fossil-fuel companies and other heavy emitters. There is a vicious circle in that the future of energy production, transmission and consumption is sensitive to future clean-energy expansion and international cooperation. But the demand, supply and inventory of oil will impact its price and, by extension, future investments in renewable energies.

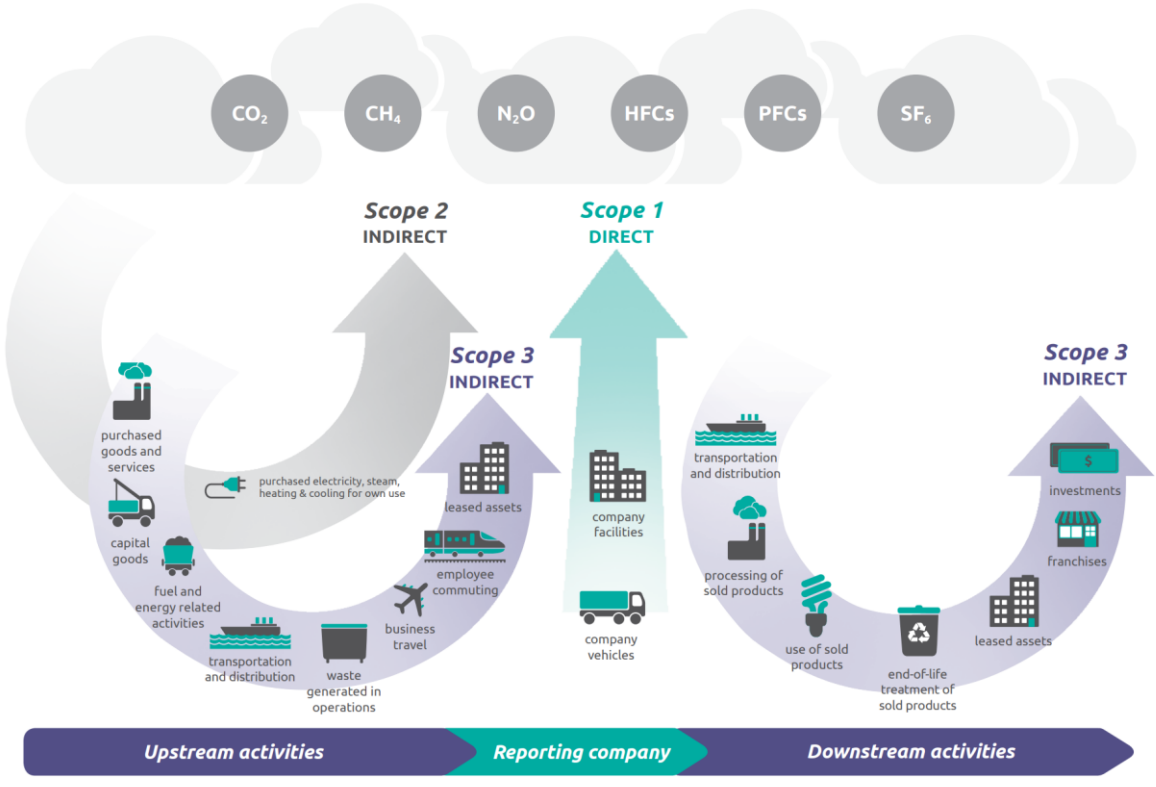
A key metric used to integrate transition risk in security analysis is GHG emissions data at the company and portfolio levels. The GHG Protocol[10] has defined three scopes of emissions:

Scope 1 emissions are direct emissions from company-owned and controlled resources. In other words, emissions released to the atmosphere as a direct result of a set of activities, at a firm level.

Scope 2 emissions are indirect emissions from the generation of purchased energy from a utility provider. In other words, all GHG emissions released in the atmosphere, from the consumption of purchased electricity, steam, heat, and cooling.

Scope 3 emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the company. Some examples of Scope 3 activities are extraction and production of purchased materials, transportation of purchased fuels and use of sold products and services, financing, investments, and insurance of emission intensive activity.

Figure 1: Overview of GHG Protocol Scopes and Emissions Across the Value Chain



Source: Greenhouse Gas Protocol (2011), Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p.5, https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf

Portfolio managers will typically track Scope 1 and Scope 2 emissions and consider Scope 3 emissions where possible. Double counting is inherent in Scope 3, as it includes emissions from a company's own products. So, an oil company would include in Scope 3 emissions

from when fuel is used in cars, while the same emissions would also be part of the Scope 3 emissions for the car manufacturer. However, both companies have an influence on the extent of Scope 3 emissions in their product design and strategy. For oil companies, most of their emissions would be under Scope 3.

An intensity metric such as units of absolute emissions per unit of output (either production or economic units like revenue) is preferred over an absolute measure. Portfolio managers typically prefer to follow annual trends for the same company as opposed to comparing emission metrics against peer companies or benchmarks, because the data may not be comparable across companies and some companies do not even issue emissions data. Also, the absence of disclosure requirements in some countries makes portfolio analysis on a global scale difficult to implement in terms of environmental, social and governance (ESG) considerations or similar factors.

One way some portfolio managers are approaching this, especially in transformational businesses like oil and gas, is looking at CapEx (capital expenditure) growth in different business areas. Portfolio managers also use emissions metrics to guide their engagement activities with heavy emitters. The speed of the transition and availability of alternative technology are crucial drivers of the intensity of the potential shock to asset values.

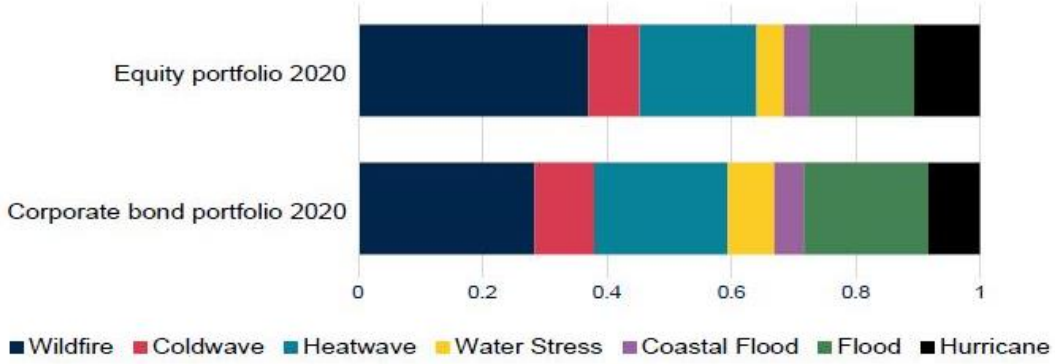
Physical risks include damage to real estate and other physical assets from events such as sea-level rise, hailstorms and flooding. The assessment of physical risk is highly complex, depending on superimposing climate projections and geographical analysis to historical claims data. For banks in the Netherlands, for example, the safety standards of various flood-protection barriers are combined with outstanding values on bank mortgages and the physical location of the mortgaged property. However, incidence of events is dependent on weather models which provide poor predictive accuracy at a local level. The 2021 floods in Germany, for instance, followed unprecedented rainfall intensity in that location, which also reduced warning times for evacuations and temporary flood defences.

More risks also emerge where prolonged dry periods result in ground-level subsidence or “heave” damaging the foundations of buildings.

The risk to a property portfolio includes the cost of improving the energy label/efficiency, the risk of physical damage and the profile of tenants. Similar risks apply to mortgages secured on property. Important research is available from climate adaptation centres globally, an example being the Intact Centre on Climate Adaptation in Waterloo, Canada.[11]

Investment managers analyze corporate data to assess the physical risks associated with their equity and bond holdings. Such data include the extensive information in corporate accounts, in prospectuses for new issues, in other public records and perhaps from satellite imaging. Figure 2 shows the result of such a physical risk analysis.

Figure 2: Example of Physical Risk Exposure in Portfolios



Source: TCFD (2021), Guidance on Metrics, Targets, and Transition Plans,p. 20, https://assets.bbhub.io/company/sites/60/2021/07/2021-Metrics_Targets_Guidance-1.pdf

Such a chart provides a summary of physical climate-related risks and needs to be considered with other data to assess the overall potential impact on a company or portfolio. For example, what profits or assets are subject to these various risks, the timescale, the likely impact and the extent to which assets are subject to multiple risks, such as wildfires, heatwaves and water stress.

Apart from transition and physical risks, legal and reputational risks can cause sudden changes in assets' values if not priced in. Some legal risks are more uncertain than others and may lend themselves to a qualitative or stress-test type of analysis. Lawsuits against a particular company or industry for damage against the environment are examples. Legal risks should be distinguished from policy risks which would be included in various transition scenarios; for example, legislated carbon pricing. Reputational risk can obviously arise for a large polluter; however, it is also becoming a concern for companies (or investment managers) failing to adhere to their public climate commitment, or whose sustainability ratings are proving inconsistent with their actions.

Advantages and disadvantages of a bottom-up approach

A bottom-up approach is helpful for performing investment analysis and supporting investment decisions at a micro level. The approach reflects characteristics of the securities analyzed and offers a customized approach to risk analysis.

However, a potential limitation of this approach is revealed when risks need to be aggregated at the portfolio level. The failure to ensure that the valuation of individual securities is based on a consistent view of the overall climate and mitigation risks, and that all relevant impacts are included,[12]can lead to incomplete or inconsistent results. Also, it fails to identify high-level concentrations of risks.

2.1 Asset Climate-Related Risk Disclosure and the Legislative Landscape

Disclosure of climate-related risks to assets varies considerably between jurisdictions and companies but there is growing use of the TCFD disclosure recommendations. The TCFD was established by the international Financial Stability Board in response to concerns about the impact of climate change on financial institutions. The TCFD recommendations[13] were published in June 2017 as a voluntary disclosure standard and intended for use by any organization producing financial statements, including asset owners like pension funds,

asset managers and insurers. Although the TCFD recommendations are not legislation as such, they are being adopted as part of legislation requiring financial sector organizations to make climate disclosures, for example in the United Kingdom, with proposals being developed in Brazil, the European Union (EU), Hong Kong, Japan, New Zealand, Singapore and the United States. More generally, the TCFD recommendations regarding the use of scenario analysis have been instrumental in the widespread adoption of these techniques around the world in assessing climate impacts.

In regard to disclosed information, the extent and trends would be examined, including the approach to the calculation and disclosure of Scope 1, 2 and 3 emissions. Scope 3 emissions are frequently not addressed even though they are potentially the biggest source of emissions for many industries (especially oil and gas).

Beyond the TCFD, there are mandatory climate-related reporting requirements and standards which will provide useful information to assess the risks facing specific assets. Those being developed include the:

- EU taxonomy – a framework for establishing whether investments and economic activities can be considered sustainable.[14]

  EU Sustainable Finance Disclosure Regulation (SFDR)[15] –this introduces various disclosure-related requirements for financial market participants and financial advisors at entity, service and product level. It aims to provide more transparency on sustainability within the financial markets in a standardized way, avoiding greenwashing (i.e., making false or misleading claims about the environmental benefits of a product, service, or technology) and ensuring comparability.

- Partnership for Carbon Accounting Financials (PCAF)[16]–this is setting methodology for calculation of emissions from loans and investments made by banks and other financial institutions. It works with a range of partners, including CDP, the Net-Zero Asset Owner Alliance and the Science Based Targets initiative (SBTi). The Global GHG Accounting and Reporting Standard for the Financial Industry also considers various metrics which are being developed to indicate sustainability.

3 Portfolio Analysis: Macro-economic Implications of Climate-Related Scenarios – "Top-Down"

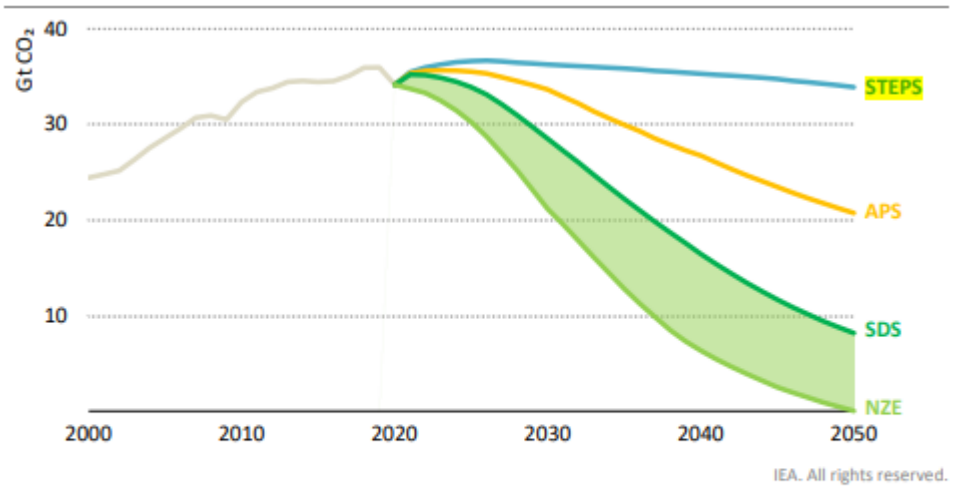
The top-down approach considers the impact of climate scenarios, government policies, regulations and the pace of the transition to a low-carbon economy on macro-economic parameters such as gross domestic product (GDP) and inflation. The focus is on the overall impact on portfolios and the consistency of assumptions between assets and liabilities.

In the next two sub-sections, information provided by two agencies, the IEA and the NGFS, which focus on the impact of climate scenarios on economic metrics like GDP growth and inflation, is provided. The IPCC is the leading source of research on climate change and global warming and the reader is referred to papers 2 and 3 for more details on its climate scenarios.

3.1 International Energy Agency Net Zero by 2050 Roadmap

A useful approach is to look at the information provided by the IEA through its Net Zero by 2050 Roadmap (Figure 4). Reducing global carbon dioxide (CO_2) emissions to net zero by 2050 requires a complete overhaul of how the world produces, transports and consumes energy. Given that the energy sector is the source of around three-quarters of GHG emissions today, it holds the key to averting the worst effects of climate change. The IEA crafted four scenarios which illustrate transition pathways for reducing emissions.

Figure 3: Projected Energy-Related and Industrial Process CO_2 Emissions



The APS pushes emissions down, but not until after 2030; the SDS goes further and faster to be aligned with the Paris Agreement; the NZE delivers net zero emissions by 2050

Note: APS = Announced Pledges Scenario; SDS = Sustainable Development Scenario; NZE = Net Zero Emissions by 2050 Scenario.

Source: IEA World Energy Outlook 2021 p.33 World Energy Outlook 2021 (windows.net)

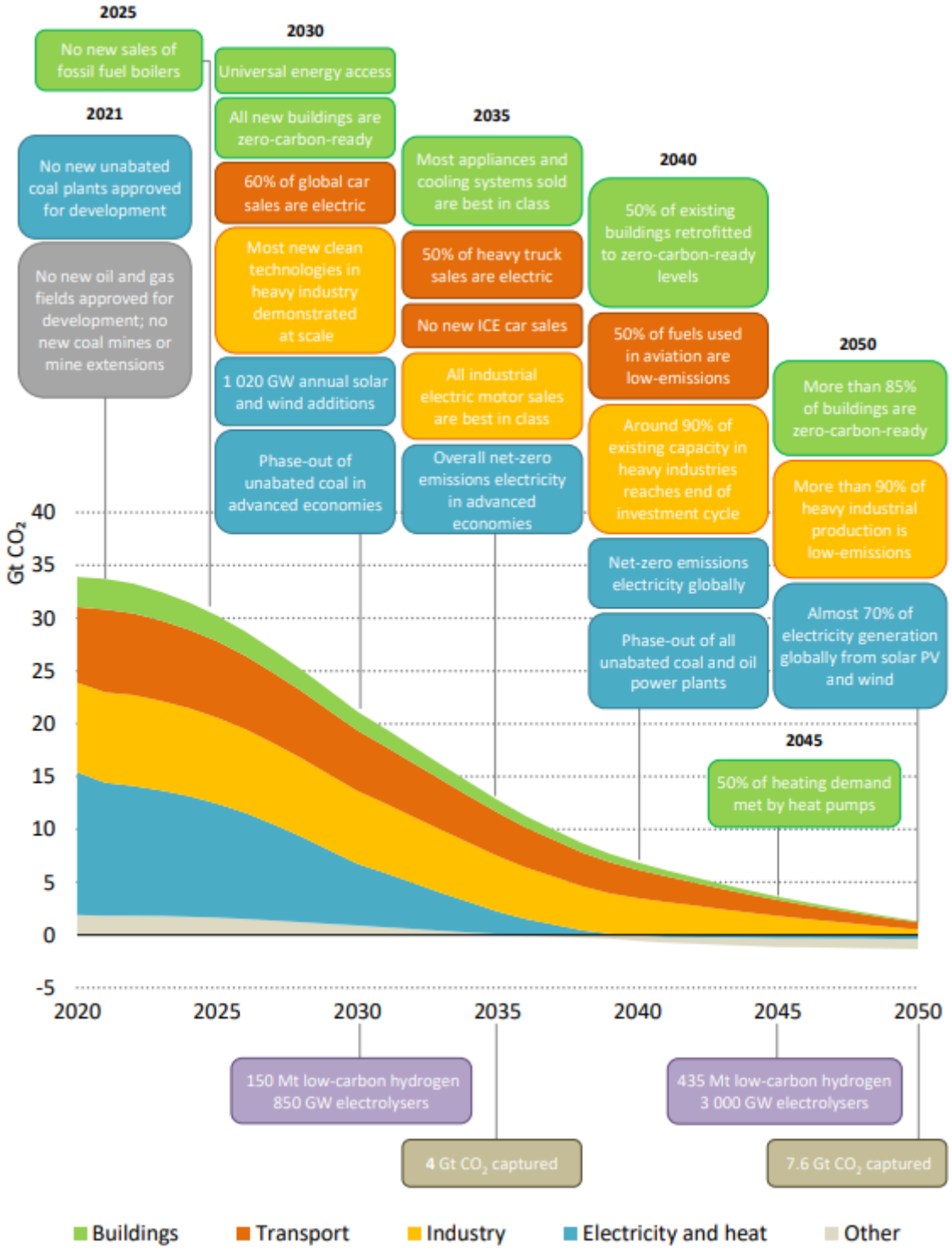
STEPS refers to Stated Policies Scenario". It is a conservative benchmark for the future because it does not assume that governments will reach all their announced emission reduction goals.

A May 2021 report by the IEA[17] offers a series of calls to action for policymakers, and asset managers and owners who will finance this transformation:

1. Make the 2020s the decade of massive clean-energy expansion.
2. Prepare for the next phase of the transition by boosting innovation.
3. Allow clean-energy jobs to grow strongly and to be spread widely.
4. Set near-term milestones to get on track for long-term targets.
5. Drive a historic surge in clean-energy investment.
6. Address emerging energy security risks now.
7. Take international cooperation to new heights.

These actions, if and when implemented, will shift asset values in the energy sector. For example, phasing out coal in advanced economies will obviously leave coal assets stranded. Substantial additional investment will also be needed in the clean-energy sector.

Figure 4: IEA – Key Milestones in the Pathway to Net Zero



Source: IEA (2021), Net Zero by 2050 Roadmap,p.20, www.iea.org/reports/net-zero-by-2050

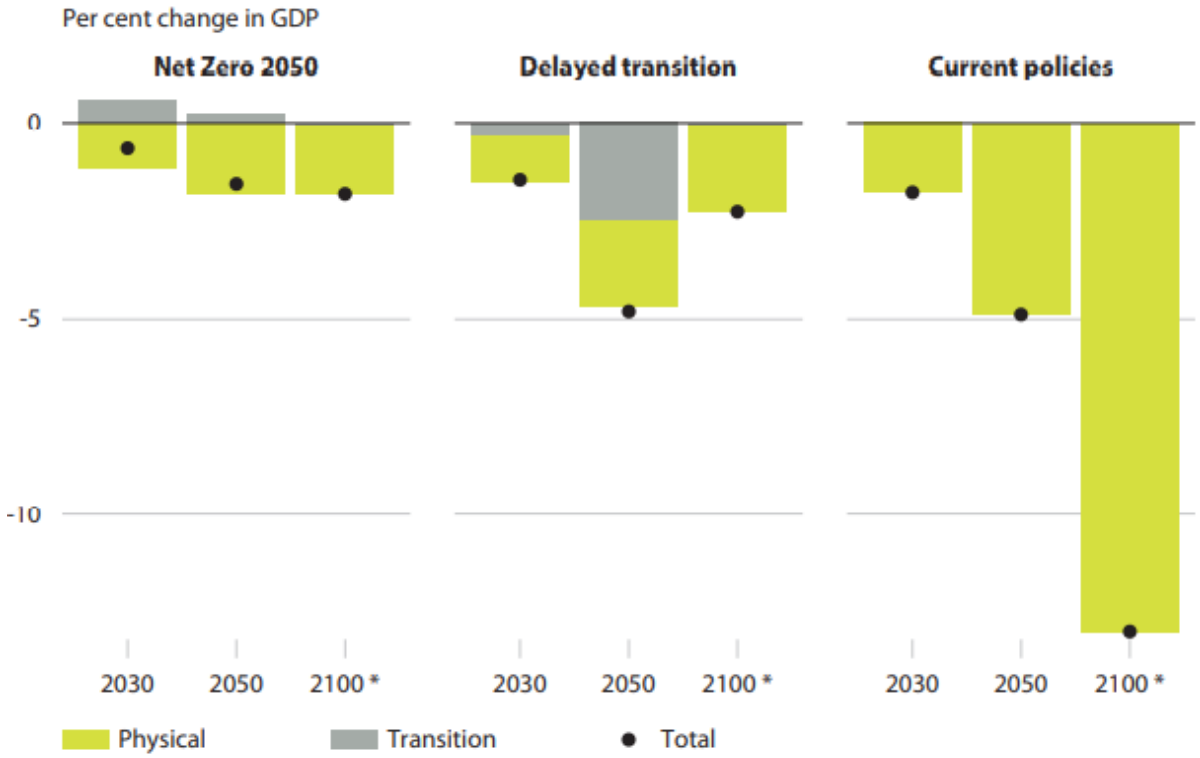
3.2 Network for Greening the Financial System Scenarios

Another valuable source for scenarios is the NGFS. In 2021, it published new global scenarios showing that the global GDP impact is most extreme under a current-policies scenario, driven by physical risk, with GDP relative to baseline 5% lower by 2050. Under a delayed-transition scenario, the GDP impact is of a similar magnitude; however, with half attributable to transition risk rather than physical climate-related risk. Extending the horizon

to 2100, a delayed transition is much less damaging than the more-than-10% decrease modelled under a current-policies scenario.

The NGFS forecasted economic impacts of the net zero (orderly), delayed-transition (disorderly) and current-policies (hothouse) scenarios are shown below:

Figure 5: GDP Impacts Relative to Prior Trend for Net Zero, Delayed (Sudden) Transition and Current-Policies Scenarios



Source: IIASANGFS Climate Scenarios Database, NiGEM based on REMIND. IAM data and damage estimates from Kalkuhl & Wenz (2020),
www.ngfs.net/sites/default/files/media/2021/08/27/ngfs_climate_scenarios_phase2_june2021.pdf

As might be expected, a continuation of the current-policies scenario has the most adverse impact on GDP long-term, while a delayed and sudden transition would have the highest transition cost. The NGFS "Net Zero 2050" scenario is the most optimistic scenario with GDP impacts limited to below 3% and mainly resulting from physical risk already locked in by historic emissions and a 1.5°C warmer temperature.

This global aggregation does mask substantial differences in impact at a country level. For example, Canada would have much more transition risk impact under a Net Zero 2050 scenario, while Europe would have much higher physical risk impact from flooding and wildfires under a "hothouse" scenario.

While GDP is a well-known and widely used metric for growth, there are severe shortcomings to the metric relating to sustainability and climate change. Broad welfare metrics are increasingly emerging (e.g., the United Nations Human Development Index and the EU Beyond GDP initiative) and look at societal health measures such as education, women's rights, and the quality of air and water. GDP may be increasing while air quality decreases due to the very industrial activity needed for GDP growth. A shortcoming specifically relating to physical climate-related risk is that the damages to assets are not included in the metric, while the investment to rebuild it is.

Regulation is also expected to have some medium-term effects on countries. The "Fit for 55" EU green deal announced on 14 July 2021 (intended to reduce emissions by 55% by 2030), includes a Carbon Border Adjustment Mechanism, for instance, which can be considered a trade tariff. Economic policies of this type could further exacerbate transition impacts on economies not willing or able to clean their production processes in time and on world trade generally.

A policy brief from the Peterson Institute for International Economics points out that climate policy is a macro-economic policy with major consequences.[18] Key takeaways from this briefing include:

- Macro-economic mainstreaming of the economics of the net zero transition is under way. But much remains to be done before the economic impacts of decarbonization strategies have been fully assessed.
- The transition to net zero will imply sizable relative price changes, accelerated obsolescence of the existing capital stock, significant reallocation of labour and a major investment push.
- In the transition to net zero:
  - The price of carbon[19] emissions is close to $10 per ton of carbon dioxide equivalent (or CO_2e) globally in 2020 but there is a wide variation by jurisdiction, influenced by policy (e.g., up to $100 in the EU Emissions Trading Scheme, or ETS). To be consistent with the goal of remaining within the carbon budget and limiting the rise in temperature to 2°C, it needs to increase to approximately $40–$80/ton CO_2e.
  - What the EU ETS represents is the trading of additional emission rights above the allocated budget. The price per total ton of emissions is lower. The price is also sensitive to policy changes. The price remained low for several years because there was an oversupply of traded rights. It started increasing in 2021 as a new phase with lower total emission rights started.
  - While a trading scheme is market-based, a different pricing mechanism is a tax on all or above-budget emissions per economic player, whether an individual or a company. Politically, a commitment to redistribute the proceeds from taxation dollar-for-dollar may be indispensable to dispel suspicions that carbon pricing is just a convenient pretext for increasing taxes.

Figure 6: The EU ETS Price

Source: EU ETS,https://group.vattenfall.com/press-and-media/newsroom/2021/the-eu-emissions-trading-system-shows-its-muscles

- If too gradual in the years to come, the transition is likely to prompt precipitous adjustments later. If unexpectedly swift, it is bound to entail large losses for business and hence investors, resulting from the accelerated obsolescence of existing capital stock and the limited availability of cost-reducing innovations.
- The transition will trigger an investment boom but reduce consumption. There is an unavoidable trade-off between current consumption and future well-being.
- The IEA Net Zero by 2050 - A Roadmap for the Global Energy Sector (2021) estimates that a global transition to net zero by 2050 would imply increasing global investment in green energy from 2.5% of world GDP in 2016–20 to 4.5% by 2030, after which it would gradually return to 2.5% by 2050 (omitting agriculture and services). The net increase should therefore amount to at least 2% of GDP in 2030. Estimates by the European Commission are broadly similar.

There is uncertainty about how climate change might affect interest rates and inflation since there has not yet been much research in this area, and the available evidence is mixed. Historically, inflation and interest rates have generally been lower when economic growth is low. Existing research on how climate change affects financial market volatility is limited and inconclusive. With increasing market focus on climate risks and opportunities, shocks can still arise if precipitated by climate tipping points such as large-scale glacial loss or unexpected changes in government policies. There is also a concern that economic projections of the impact of climate change are failing to take account of indirect effects such as increases in migration and conflict.

3.3 Company-Level Consistency of Climate-Related Risk Modelling Between Assets and Liabilities

Climate-related risks impact a regulated organization like a bank, insurance company or pension fund broadly in two main ways: firstly, regarding the direct impact or anticipated impact on its assets and liabilities, and secondly as a consequence of actions taken by regulators to take account of these risks. In the former category will be risks to its investment portfolio – for example, from potential "stranded assets" – and for a general insurer, potential increases in the frequency and severity of claims. In the latter category will be additional regulation requiring further risk assessment, including scenario analysis, and

its disclosure, possibly leading to further prudential requirements, as illustrated by the *Application Paper on the Supervision of Climate-related Risks in the Insurance Sector* from the International Association of Insurance Supervisors.[20]

The main actuarial focus of asset/liability modelling has been with institutions with long-term liabilities like pension funds and life assurers, but the nature of climate-related risks implies a wider scope. The asset and liability sides of a company's balance sheet should be modelled consistently per scenario, considering the projection horizon and knock-on economic variables as a set.

The discount rate used to determine contributions and value long-term liabilities of both life insurers and pension funds is a leading example. It needs to be reviewed in different climate and economic scenarios. Long-term investment returns could be impacted adversely, which, if reflected in reduced discount rates, will lead to increases in the value of liabilities. At the same time, asset values could be reduced, depending on the extent to which physical, transition or liability risks have not been fully reflected in asset prices. Long-term investment returns are also impacted by government policies, as the historically low interest rates generally maintained during the COVID-19 pandemic illustrate. Hence the importance of considering a range of impacts in constructing consistent climate scenarios.

One of the methods to determine a discount rate is an expected rate of return on assets based on passive investment. Therefore, how overall markets are expected to be affected by the transition may also impact the liability side. In the case studies at the end of this paper, an example is shown of the impact on both the asset and the liability sides of an insurer's and pension fund's balance sheet.

Inflation is another assumption with a material impact and long-term liability and a strong link to transition risk. A high-transition, low-temperature pathway may be linked to high inflation and higher liability risk.

For a general insurer, providing cover on a one-year basis, its liabilities still have an unpredictable climate element, and its assets may be exposed to physical climate-related risks and transition risks arising from government actions and market sentiment reactions.

A pension fund would carefully examine the potential climate impacts on its assets, and the merits of alternative investment strategies. Its future assets will normally include future contributions from sponsoring employers; therefore, the climate impacts on these employers need to be considered in assessing the value of their commitments. The impact on liabilities will depend on their nature: whether Defined Benefits (DB) or Defined Contributions (DC), and whether they remain linked to future inflation. In turn, some DB pension funds are relatively large compared to the sponsoring employer, and the climate impact on the pension fund could be more severe than on the company itself. In a DC plan, the managers would also want to ensure that they provide resilient long-term benefits.

A top-down economy-wide analysis would also impact on pricing, profitability and sustainability of new life and health products. In addition to macro-economic impacts, new as well as in-force life and health products can be exposed to increased claims due to heat stress and different disease vectors in a high-temperature, increased-physical-risk scenario. These are not in the scope of this paper but would be considered as part of the holistic considerations of company-level climate risk analysis– for example, in an Own Risk and Solvency Assessment (ORSA).

3.4 Open-Source Tools

It is worth noting that various open-source tools are being developed to enable investors to analyze the climate performance of portfolios and companies, align investment with temperature targets and undertake more effective engagement with firms. This type of

community-based project coordinates contributions from hundreds and often thousands of individuals. The same concept has accelerated innovation and has driven major breakthroughs across the tech and life sciences sectors, such as COVID-19 vaccine development, the Human Genome Project, the Internet of Things (IoT) and blockchain.

To assist those engaging in scenario analysis and to facilitate comparisons, the PRI (the Principles of Responsible Investment supported by the United Nations) provides a database[21] of publicly available tools and organizations which can assist, some on a commercial basis.

Examples of open-source projects are the:

- Science Based Targets initiative[22]

  The SBTi champions science-based target-setting as a powerful way of boosting companies' competitive advantage in the transition to the low-carbon economy. It is a collaboration between CDP[23], the World Resources Institute, the World Wide Fund for Nature (WWF) and the United Nations Global Compact.

- LF Climate Finance Foundation[24]

  The LF Climate Finance Foundation (LFCF) is an initiative aimed at empowering investors, banks, insurers, companies, governments, non-governmental organizations and academia with artificial-intelligence-enhanced open-source analytics and open data to address climate-related risk and opportunity. The LFCF planning team consists of representatives from the WWF, Ceres and the Sustainability Accounting Standards Board (SASB), and Allianz, Amazon, Microsoft and S&P Global have already committed to be founding members.

- University of Oxford Environmental Change Institute[25]

  The Environmental Change Institute was established in 1991 to organize and promote interdisciplinary research on the nature, causes and impact of environmental change and to contribute to the development of management strategies for coping with future environmental change.

- PACTA Climate Scenario Analysis Program

  This is methodology and a tool which measures financial portfolios' alignment with various climate scenarios consistent with the Paris Agreement.

- Climate Central's Program on Sea Level Rise

  The program provides granular information about sea-level rise and coastal flood hazards.[26]

3.5 Climate-Related Risk Data Providers

In October 2021, the TCFD issued a further status report that looked at the progress companies and investors had made in terms of understanding and reporting on climate-related financial risks. The report showed that there had been a significant increase in disclosures since 2017, but gaps still existed, especially in the area of elevating climate-related issues to be on par with other operational risks, as this requires the involvement of multiple business functions across an organization. In response to this and earlier reports, data providers started issuing a range of metrics and solutions to help clients understand the climate resilience of an organization. Data sets included, for example, information on:

- Carbon footprints/emissions related to a company or its investments;
- A company's preparedness for future carbon pricing;

- Physical risks and the exposure of an asset base to climate-related issues;
- Exposure to fossil fuels and stranded assets; and
- Portfolio alignment with net zero emissions by 2050.

The goal is to help asset managers and asset owners improve their decision making and increase the transparency of climate-related issues in capital markets.[27]

A recent study[28] of providers of metrics measuring company-level physical risk shows that results diverge substantially from one provider to the next. This divergence raises doubts about whether investors have the necessary information to reflect physical climate-related risks in the prices of corporate stocks and bonds. Therefore, decision makers would avoid placing too much confidence in a single score. The competitive environment under which these providers operate discourages sharing of underlying data. The TCFD is looking for policymakers to accelerate the development of physical climate-related risk metrics by facilitating access to open data, by requiring corporations to disclose climate-related risks and relevant performance indicators.

Advantages and disadvantages of a top-down approach

Using the top-down approach, the macro-economic implications of climate-related scenarios are considered holistically, and it is easier to ensure that assumptions are consistent with one another. However, a potential problem is that offsetting positive and negative impacts may not be apparent. For example, the occurrence of a devastating natural disaster may depress economic growth, while the rebuilding efforts, and upgrading infrastructure to be more climate-resilient, could potentially drive economic growth. The structural change may involve less personal consumption and more investment, perhaps financed by taxation. Such nuances may not be apparent when modelling the impact on GDP under the top-down approach, but it could be reflected in asset-class or security valuations under the bottom-up approach.

4 Considerations for Different Asset Classes

While modelling the impact of climate-related risk at the security level could give a more precise result, firms may prefer to model a high-level impact at the asset-class level. This section discusses an overview of some approaches that firms can use to model the impact on equities, bonds, real estate and infrastructure. In general, equity, real estate and infrastructure investments have the potential to be impacted by both opportunities and risks arising from climate change, whereas bonds are generally more susceptible to downside climate-related risks. Asset-class analysis also provides the opportunity to consider correlations between securities and between asset classes, an important issue in looking to mitigate risks and volatility.

4.1 Fixed Income

Insurers often hold a majority of their investment portfolio in bonds to match their liabilities. While bonds provide relatively stable yields, the uncertainty of cash flows increases with the duration, and long-term bonds are more susceptible to climate-related risks. This is especially so given that the effects of climate change tend to be more pronounced over the long term. Also, the risk of default due to a climate event may be difficult to evaluate long-term, both for corporations and in relation to government bonds, given the potential for unprecedented impacts. In this situation the liquidity of bonds, the ability to change portfolios as risk evaluations change, is a key issue.

Regarding government bonds, there are various organizations which evaluate each country's potential vulnerability to the negative effects of climate change and their readiness to adapt. One example is the Notre Dame Global Adaptation Initiative[29] by the University of Notre

Dame. Generally, the countries which are highly vulnerable to physical risks and less financially resilient are in South Asia and Africa. Hence, an extreme physical risk scenario could affect the risk of government bonds in such countries. On the other hand, transition risk could affect other countries (especially developed countries) to a greater extent, as they are likely to spend more on climate-related mitigation and adaptation in the long term. The climate-related risk drivers for corporate bonds are similar to those for equity; that is, country- and industry-level impacts. One key difference is that the risks could be more muted for corporate bonds given that bondholders enjoy higher priority but do not enjoy similar capital appreciation if climate change provides more opportunities for the company. With higher uncertainty, credit spreads, including illiquidity risk premium (the higher yield the market requires), may grow to be wider for existing bonds in affected sectors.

4.2 Equity

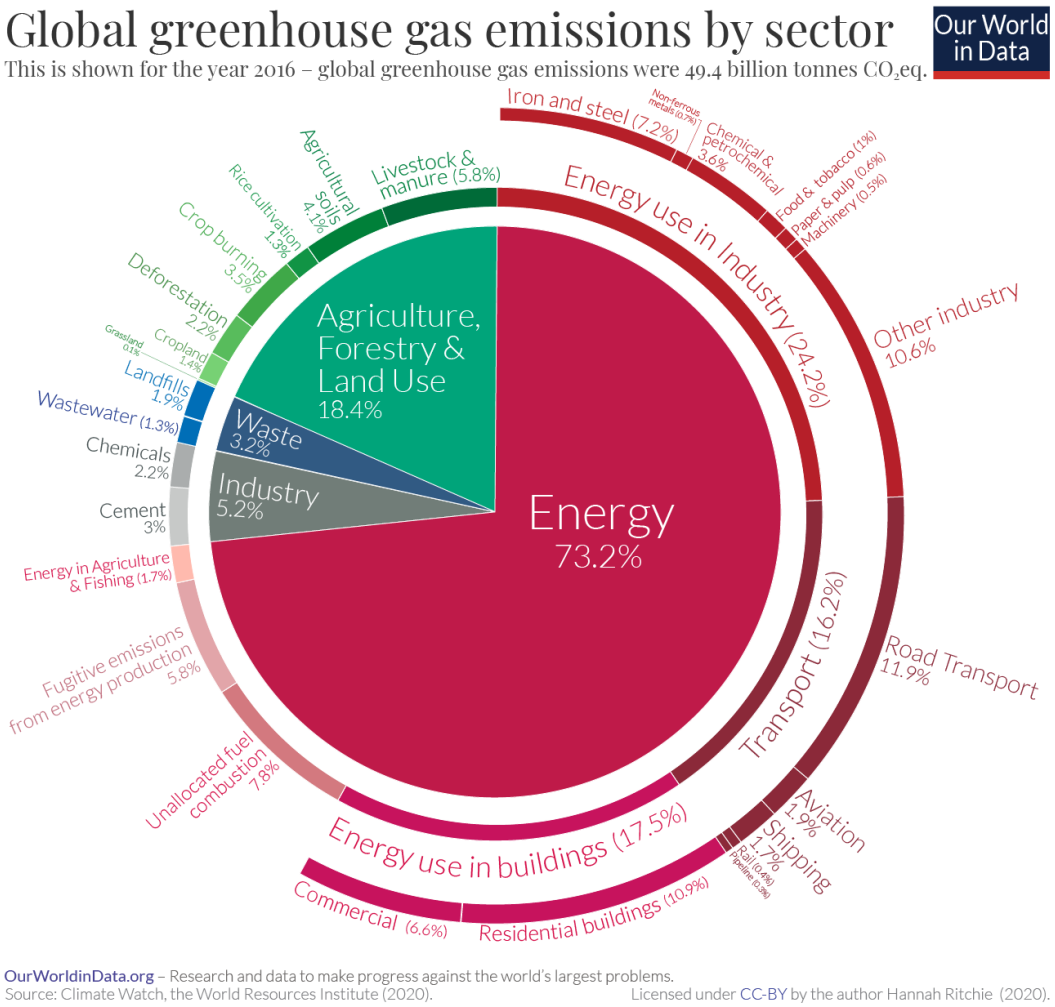
Global equity managers typically include country and sector analysis as part of their investment process. Climate-related considerations by country and by sector can be integrated into the investment process. GHG emissions and climate-related impacts vary significantly by sector. For example, the finance and transport industries clearly have different emission profiles, and even within a sector there can be great variability in intensity of emissions –fossil-fuel and renewable generation being an illustration from the energy sector.

As a starting point, investment managers can slice their portfolio by country and by sectors or even sub-sectors wherever possible, and review for countries and sectors which are more sensitive to physical risks or transition risks. Next, they can seek to quantify the impact of physical risks and transition risks for key countries and sectors. Finally, weighted average portfolio return and risk metrics can be calculated. The scarcity of data could make the intermediate step of quantifying country- or sector-level impact challenging.

In terms of transition risks, the most adversely impacted sectors are typically carbon-intensive firms in the energy, transport, materials and buildings, and agricultural sectors – see Figure 7. They will need to make extensive and sustained efforts to reduce GHG emissions. However, this impact could be offset by the technological opportunities if the firms pivot to rely on low-carbon production methods or products, such as clean tech or renewable energy.

Emissions by sector

Figure 7: Global GHG Emissions by Sector



Source: https://ourworldindata.org/emissions-by-sector

The impact of physical risk on equity differs from that of transition risk. For example, physical risk is more spread out over various sectors. The main driver of physical risk exposure is the location of the firm's physical assets. Nonetheless, the impact on the energy and food production industries is generally large, given that extreme weather could affect the infrastructure of energy providers as well as food productivity.

In the private equity space, investors might find that there is less transparency regarding the climate-related risks of the portfolio companies. Hence, investors or asset owners would need to perform more due diligence and urge more disclosures from private equity fund managers, who are more likely to consider climate-related risks if regulators and investors demand it. A secondary issue is that the high level of concentration associated with private equity strategies means that it generates more company-specific risk exposures to climate change. Hence, it is critical to obtain more information from the private equity fund manager and perform analysis at the company level within the fund, instead of treating private equity as an asset class.

4.3 Real Estate

Financial Institutions usually invest in real estate with the intent of holding it for a long horizon, making it more susceptible to long-term physical and transition risks. The physical

impacts of climate change on real estate naturally depend on the location. For instance, real estate located in a coastal area could be affected by floods, lower occupancy rates due to emigration and higher insurance premiums. By the 2070s, the total value of assets exposed to coastal flooding could grow more than 10 times current levels and reach USD 35,000 billion, which is roughly 9% of projected annual GDP in this period.[30]

Particular types of real estate such as agriculture and timberland also have greater sensitivities to the impact of physical damages and resource availability; for example, storm damage to coastal assets, plus floods and wildfires. As a secondary consideration, transition risks could also affect the building and operating costs of real estate, as they contribute to one-third of global final energy consumption.

Climate-change-related migration is an emerging research area. Preliminary expectations are that migration patterns will also impact the asset values of cities and areas. Also, in areas which benefit from climate change and are less affected by physical risks – for example, extending agricultural growing areas – demand for real estate and prices may increase.

Table 2: Top 20 Cities Ranked by Assets Exposed to Coastal Flooding in the Present Day and by the 2070s

Rank	Country	Urban Agglomeration	Exposed Assets Current ($Billion)	Exposed Assets Future ($Billion)
1	USA	Miami	416.29	3,513.04
2	CHINA	Guangzhou	84.17	3,357.72
3	USA	New York-Newark	320.20	2,147.35
4	INDIA	Kolkata (Calcutta)	31.99	1,961.44
5	CHINA	Shanghai	72.86	1,771.17
6	INDIA	Mumbai	46.20	1,598.05
7	CHINA	Tianjin	29.62	1,231.48
8	JAPAN	Tokyo	174.29	1,207.07
9	CHINA,	Hong Kong	35.94	1,163.89
10	THAILAND	Bangkok	38.72	1,117.54
11	CHINA	Ningbo	9.26	1,073.93
12	USA	New Orleans	233.69	1,013.45
13	JAPAN	Osaka-Kobe	215.62	968.96
14	NETHERLANDS	Amsterdam	128.33	843.70
15	NETHERLANDS	Rotterdam	114.89	825.68
16	VIETNAM	Ho Chi Minh City	26.86	652.82
17	JAPAN	Nagoya	109.22	623.42
18	CHINA	Qingdao	2.72	601.59
19	USA	Virginia Beach	84.64	581.69
20	EGYPT	Alexandria	28.46	563.28

Source:https://climate-adapt.eea.europa.eu/metadata/publications/ranking-of-the-worlds-cities-to-coastal-flooding/11240357

4.4 Infrastructure

Insurance companies and pension funds view favourably the potential for predictable earnings and cash flows from infrastructure assets. Similar to equity, the impact of climate change on infrastructure could be double-edged. Climate change policy is likely to reduce the value of some assets that are less advanced or unable to adapt. Some assets (such as coal-powered utilities and transport/support infrastructure which depends on coal mines) could become "stranded" as they succumb to obsolescence due to new regulations, greener alternatives or technological innovations. On the other hand, asset owners are increasingly willing to provide project financing for the development or construction of real green assets, such as solar power generation or windfarms. There could also be increased demand for new or enhanced infrastructure which is more resilient or adaptable to physical risks.

4.5 Other Asset Classes: Derivatives, Agriculture Assets and ESG Indices

Derivatives can be used as a risk-transfer as well as a risk-mitigation tool. As a transfer tool, it can be used to relate product pay-outs to a weather-related index, and in future likely a carbon intensity index. As a mitigation tool, it can be used to immunize a portfolio against the downside impacts on an asset class without divesting from the underlying asset class. An example of this action is the WWF pension fund, which instead of divesting from fossil fuels used derivatives to protect against the downside risk.

Agricultural assets are drawing attention in climate discussions for various reasons– primarily due to the direct emissions of methane from beef and dairy farming, as well as land-use changes with deforestation. There could be future regulatory and border tariff development impacting the value of investments in mega agriculture projects. In addition to flying and driving, beef consumption is becoming a consumer-driven topic.

As an offset to portfolio emissions, investments in regenerative agriculture practices and forestry carbon capture, which reduce the total emissions of a portfolio, are increasingly discussed. Practices such as minimum tillage retain more carbon in the soil.

Nitrogen leakage is not directly related to an increase in climate; however, it is a consideration in the wider ESG investment landscape.

ESG-themed indices and funds are also becoming mainstream both as investments for insurers/banks/pension funds and as financial products they may offer. A risk introduced by the indices is that of reputation – that they are also fulfilling the promise they make and do not engage in greenwashing or simply relabelling existing investments and funnelling funds away from real energy-transition investments.

4.6 Green Asset Classes

In order to mitigate the impact of climate-related risks on assets, potential solutions include, but are not limited to, negative screening (e.g., avoiding fossil-fuel suppliers), positive screening (e.g., minimum investment in forestry), integration of ESG factors into the investment process, ESG-themed funds and green assets. Given that green assets are increasingly prominent and emerging as a new asset class for investors, this section outlines the definition of green assets, key variations and investment characteristics. Climate-aware investment is merely a subset of wider sustainability- and ESG-related considerations. Under the case studies below, an example is included showing potentially lower risk to life insurers if they are more ESG-oriented in their investment strategy.

The most commonly available green assets are green bonds, green infrastructure and green real estate. The main challenge is to assess whether an investment qualifies as “green”. To build a common definition, the EU created a Taxonomy for Sustainable Activities, which is summarized below.

Taxonomies

The following definition is a summary from the EU website:[31]

> The EU taxonomy is a classification system, establishing a list of environmentally sustainable economic activities. It is an important enabler to scale up sustainable investment and to implement the European Green Deal. By providing appropriate definitions to companies, investors and policymakers on which economic activities can be considered environmentally sustainable, it is expected to create security for investors, protect private investors from greenwashing, help companies to plan the transition, mitigate market fragmentation and eventually help shift investments to where they are most needed.

The overarching EU Taxonomy Regulations were published in 2020 with six environmental objectives:

1. Climate change mitigation;
2. Climate change adaptation;
3. The sustainable use and protection of water and marine resources;
4. The transition to a circular economy;
5. Pollution prevention and control; and
6. The protection and restoration of biodiversity and ecosystems.

With 27 countries in the EU, many at different stages of development and reliant on different energy sources, finalization and implementation of the Taxonomy is a complex economic and political exercise. For example, nuclear energy, which France uses heavily, is presently the subject of assessment as to whether it can be included as "environmentally sustainable". Nevertheless, the EU is providing global leadership in looking to provide clarity in this area. This is in the context that a reliable methodology is required to identify unjustified environmental claims and "greenwashing".

Aside from the EU, the UK is developing its own taxonomy, but is likely to be closely aligned with the EU version. And China and the EU announced a "Common Ground Taxonomy" in November 2021, demonstrating some consistency in their respective approaches.

In the bond area, the International Capital Market Association (ICMA) has developed its voluntary Green Bond Principles to establish a reliable benchmark for bond issuers and investors. The ICMA encourages corporations to subsequently report on the green activities so financed when monies have been invested.

In the US, the Securities and Exchange Commission has been consulting[32] (November 2021) on requiring further climate and wider ESG disclosures. The UK legislated to require large pension funds to disclose in accordance with the TCFD recommendations from October 2021. The International Organization of Securities Commissions consulted (September 2021) on ESG ratings against the background that some organizations claiming a high rating have subsequently been criticized for aspects of their ESG policies.[33]

4.7 Other Sustainability Assets

The Monetary Authority of Singapore launched its Green and Sustainability Loans Grant Scheme as well as its Sustainability Bond Grant Scheme to encourage the issuance of sustainability-related assets. Unlike green bonds, whereby the proceeds are ring-fenced for specific green purposes, sustainability-linked bonds may be used for general corporate purposes. The issuer will pay investors extra if the sustainability performance targets are not met. In June 2021, Enel, an Italian energy group, issued a EUR 3.5 billion sustainability-linked bond, which was linked to the achievement of Enel's objective to reduce direct GHG emissions (Scope 1). The issue was oversubscribed 3.5 times, representing the largest sustainability-linked transaction priced in the fixed-income capital markets to date.

Often, it could be challenging for emission-intensive sectors to issue bonds that meet the strict criteria of green or sustainability-linked bonds. In such cases, transition bonds can help high-carbon companies transition toward net zero emissions. They fill a gap where objectives may not fit into the green assets or sustainability-linked assets categories. In August 2019, Marfrig, a Brazilian beef producer, issued a USD 500 million transition bond, committing to channel proceeds toward cattle farmers who had not engaged in deforestation.

4.8 Investment Characteristics of Green Assets

Green assets are a relatively new asset class, and climate risk an emerging risk. It is therefore necessary for risk-return considerations to include a forward-looking perspective, not only historical statistics. The main differences with non-green assets are that:

1. They are normally linked to an underlying climate or environmentally friendly activity; for example, renewable energy investments or schemes to reduce energy usage in heating or transport.
2. Green bonds often have a "greenium" or "green premium" (lower yield for those raising capital), which increases with demand as investors may be willing to accept lower yields on such investments. The presence and extent of "greeniums" is under debate. Based on a study performed by Nordea Markets[34] on a group of corporate bond issuers with both ordinary and green bonds, more than 60% of the issuers had green bonds that had tighter credit spreads than their ordinary bonds (so they provided lower yields). The difference was more significant for euro bonds and less so for Swedish bonds. For equity there is potentially an opposite effect, where investors could require a higher yield if there is more uncertainty over future returns; for example, with new technology or applications.
3. Green assets represent a small, albeit rapidly growing, market, potentially subject to low liquidity. They might be more suitable for firms that tend to hold assets long-term, or until maturity in the case of bonds.
4. Green assets have to an extent been funded via private markets rather than publicly traded markets, and disclosure requirements may not be as extensive or stringent. This is changing as public interest in ESG issues has escalated.
5. While governments finance specific sustainability projects, whether conventional government bonds –which make up a significant portion of investments held by insurance companies – are considered green assets or not remains debatable. Hence, insurance companies may have to shift their assets if they wish to increase their green asset allocation.

4.9 Barriers to Green Investment

Given their fiduciary duty, pension funds in particular may need to consider the scope of the discretion they have to invest in assets where investment returns may be compromised in order to also meet green objectives. This may of course be a false dichotomy where taking account of environmental issues may enhance returns in the long term. It is a complex area recently reviewed in the comprehensive report *A Legal Framework for Impact: Sustainability Impact in Investor Decision-Making*[35] from Freshfields, a law firm, on behalf of the PRI and other parties. For insurers, regulatory restrictions and the attitudes of shareholders will need to be considered.

Other barriers include greenwashing, lack of sufficient data or research to support the sustainability aspects of investment process as well as lack of internal expertise in green investments, especially for smaller and mid-sized institutional investors (including many pension funds).

5 Portfolio-Level Risk Measures and Metrics

Climate-related risks at the portfolio level can be captured in a summary risk measure. Examples are discussed in this section.

Some innovations in the measurement of climate-related risks include the advent of forward-looking metrics, albeit with some inherent limitations. For more details on these refer to the TCFD 2021 status report.[36] The main types of metrics are summarized below but there are wide variations in practice, especially for the more sophisticated approaches which are

highly complex and difficult to compare. "Portfolio alignment" typically refers to the strategic objectives of the 2015 Paris climate agreement: limiting the global temperature increase to well below 2°C and net zero emissions by 2050.

In addition to transition risk driven by underlying portfolio emissions, investors also face physical risk. Real estate investors model physical risk to understand location risk.

Considering the high uncertainty of climate change pathways, diversification as a principle may be considered by actuaries while analyzing or constructing their portfolio. Measures of diversification when disclosed would help the beneficiaries or stakeholders compare across companies.

5.1 Overall Portfolio Alignment

At a basic level "overall portfolio alignment" refers to the proportion of the portfolio committed to "net zero by 2050". So, each investment is assessed to ascertain whether the company has made this commitment. Hence it is a relatively simple and transparent method but there is no forward-looking analysis of each company's strategy to achieve the target, how that will unfold in the intervening years or how it might be impacted by different climate and transition scenarios. Exposure metrics disclose the percentage of the portfolio (based on fair market value) invested in carbon-related sectors. This is a TCFD-recommended metric. Many asset managers are also disclosing the inverse of this – the amount invested in "green" assets.

5.2 Portfolio Emissions

Disclosures can be made, and targets set for the overall GHG emissions generated by the companies in a portfolio (reduced according to the extent of the fund's shareholding in each company). Emissions intensity – for example, in terms of emission per unit of each company's revenue, weighted according to market value within the portfolio – may also be used. Such metrics depend on the availability of emissions data from companies, which has improved in recent years for scopes 1 and 2. The methodologies being relatively simple, comparisons are likely to be reasonably reliable and trends indicative.

A danger with simple targets is the potential adverse impact on investment strategy and performance; for example, by unduly favouring relatively low-carbon areas such as the service sector and parts of the financial sector, while switching from higher-growth areas actively reducing emissions. This can be addressed by measuring performance and balancing portfolio risk by referring to both market- and climate-related benchmarks. Portfolio objectives would benefit from being clear about the extent to which positive change is sought and tolerance of tracking errors relative to market benchmarks.

For services and financial sectors, Scope 3 emissions are the largest share of emissions.

Another potential concern is the purchase of carbon offsets to reduce headline emissions figures, which leads to a lack of comparability in reported figures.

5.3 Implied Temperature Rise

An Implied Temperature Rise (ITR) metric attempts in broad terms to estimate the global temperature rise associated with the GHG emissions of a portfolio if the global economy experienced the same emissions pathway as that portfolio. ITR incorporates current GHG emissions or other data and scenarios to estimate expected future emissions associated with the portfolio. Then, the estimates are translated into a projected increase in global average temperature above pre-industrial levels (in °C).

There are two ways to compute an implied temperature score of an asset:

- Assuming that every company in the world operates on the same carbon intensity (emissions/revenue) as this asset, what is the implied projected global average temperature increase?
- Using that asset's current carbon-emissions levels and their reduction targets, what degrees-of-global-warming pathway is the company aligned to?

The ITR metric is relatively new and still evolving. There are major technical and methodological challenges related to calculating ITR, and no commonly agreed terminology. This also results in a lack of transparency and comparability, both between portfolios and over time (as methodologies evolve and are refined).[37]Scope is a key concern: for example, some insurers report an ITR only on their surplus (Own Funds, for EU Solvency II).

5.4 Climate Value-at-Risk

Climate Value-at-Risk (VaR) quantifies the size of loss attributable to climate-related financial risks by comparing the value of assets in a world with climate change relative to the same world without climate change. MSCI Climate Value-At-Risk is what comes closer to a market standard at the moment. A bottom-up approach would be built around a relatively detailed portfolio-analysis model, which takes as its input various macro-economic variables and goes on to model the returns to different asset classes in different countries or regions. It is model- and data-intensive, so lacks transparency and comparability.

Another potential shortfall with this metric is that the scenarios used, and calibration of these scenarios, could potentially be quite different by company, which would make it difficult for investors to understand what these figures represent. The potential usefulness of this metric could be that climate VaR may be reinsurance/insurance-adjusted, which would help demonstrate the company's resilience to climate-related events.

5.5 Limitations and Other Metrics

While some of the difficulties with portfolio metrics are mentioned, such metrics fulfil a vital need in demonstrating climate progress, and it is important transparency and comparability continue to improve. The main limitations on these metrics relate to data availability, comparability, transparency and intensity. Predictive accuracy incorporating forward-looking and historical statistics and correct interpretations of data will be key.

The focus of this section has been on metrics relating to emissions and hence transition risk. Real estate investors and banks are continuously developing metrics to measure location-based physical risk. Future updates of this paper are expected to look more deeply into the physical as well as climate-related migration impacts on real estate and the metrics to measure them.

Stochastic simulation, such as Monte Carlo analysis, is increasingly mentioned for climate-related risk assessments. The "effort" at this stage will likely be placed on developing consistent methodologies and scenarios and addressing data gaps. It is expected to develop fast and is used in the case studies below. Hence for completeness, its main limitations are included here.

- There is significant uncertainty associated with future climate change impacts. This uncertainty widens as the time horizon extends further into the future, and dynamic systems with feedback loops can exacerbate this.
- Uncertainty regarding appropriate ranges and distributions for model parameters introduces subjectivity into the analysis.
- Finally, for climate-related risk analysis to benefit decision making, considerable efforts are to be invested to ensure that risk assessment is combined with societal preferences, risk aversion, indirect impacts and tipping points, and risk strategy within the larger

context of risk management. These complexities in the financial system need to be fleshed out first.

6 Typical Portfolios and Related Case Studies

6.1 General Insurers

General insurers are exposed to the physical impacts as underwriters of perils such as flooding, wildfires and hurricanes. While general insurers often have long-term business and operations strategies, they predominantly underwrite short-duration and annually renewable contracts. Therefore, they generally have shorter-duration assets under management. The portfolios are much more heavily weighted toward cash and other highly liquid assets. Again, the level of equities depends on the investment philosophy of the insurer and the extent of free reserves not needed to cover regulatory requirements. Hence for general insurers, physical risk is more prominent, and manifests on the liability side as claim levels and business operations impact the insurer's income statement. Some operational climate-related risks are unique to general insurers and are often designed for resilience, such as the ability to assess and adjudicate property claims stemming from natural disasters.

General (and life) insurers will investigate the impact of climate on their physical assets. Operations might be impacted in the short term by extreme weather events restricting access or power to the facilities. If the insurer's operations are dependent on transportation services, such as postal services or movement of physical assets from one location to another, these exposures and risks need to be considered. Also, part of the operations process may be dependent on any supply chains or value chains that bring materials into the company operations or receive output from the operations to deliver to distributors or clients.

6.2 Life Insurers

Life insurers traditionally have large portfolios with mainly low-risk assets matched to the cash flows underlying their technical reserves. With-profit and investment-linked products may be backed by equities and other riskier asset classes. In some jurisdictions, such as the UK, life insurers are also heavily involved in providing investment management services to customers through unit-linked products. Climate-related risks for these products are mainly borne by the customer, dictating investment strategies through the available fund choices.

In addition to assets required to back their liabilities, life insurers hold required capital (solvency capital requirement in the EU, risk-based capital in the US, for example) as well as assets in excess of solvency requirements. To reduce capital requirements and to meet matching requirements, life insurers often have portfolios consisting primarily of fixed-income government or corporate bonds. Hence a large part of the climate-related risk exposure for a life insurer would be that of a bond portfolio and the macro-economic impacts on these assets. A smaller part of life insurers' asset portfolios would be allocated to cash, equities and other niche investments – for example, catastrophe bonds – depending on the extent of shareholders' capital and reserves not required to meet solvency requirements. The transmission channel of climate-related risk to such a traditional life insurer would be mainly credit and market risk with limited impact on the liability side. Common features of life companies implementing climate-related risk analysis are summarized below. Key areas that life companies focus on include the following key categories:

- Investment: Life companies will review their portfolio of investments for exposure to climate-related risks. As noted in this paper, the largest and most common analysis will be to investigate the impact of short- and long-term climate events and changing climate conditions on the value and income-producing capabilities of their investment.

Like other institutional investors, life companies as shareholders will be managing their investments to maximize long-term returns. For their larger holdings, perhaps in association with other shareholders, this may involve engagement with company boards to ensure that climate-related risks are being properly managed on a strategic basis.

- Operations, including the types of operations and location of facilities: For operational risks, please refer to the comments made above for general insurers as they are equally applicable to life insurers.
- Products and services: Life companies will consider if any climate-related risks may impact the nature of the products or services they provide, including the potential impact of having climate events or trends impact higher-level claims from product exposures. Physical climate risks may increase claim exposures for life insurers, such as the potential for increased mortality and morbidity risk from exposure to heatwaves and air pollution from wildfires.

Companies will turn to enacting adaptation and mitigation activities for all these risk areas and use scenario analysis to identify financial impacts and create plans to follow in case of an extreme event.

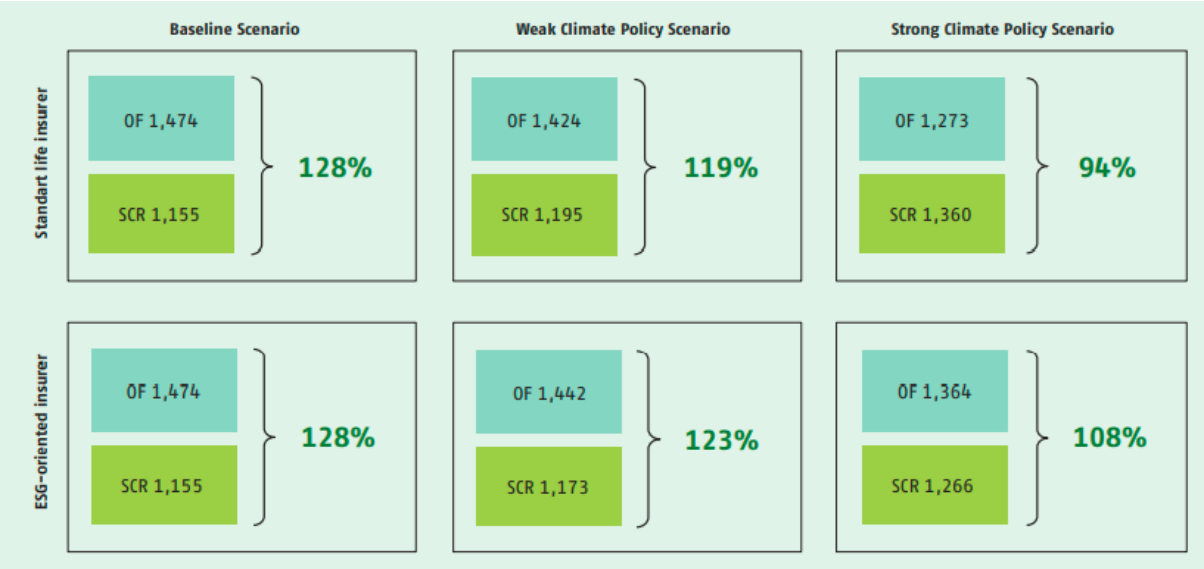
After performing internal analysis on the impact of climate-related risks on asset portfolios, companies will then identify preferred ways to report and disclose their findings in reports. Regulators may ask for specific formats, and companies will often use their annual report to shareholders or policyholders as an additional place to disclose climate-related risk strategies and findings. These risk analyses are often incorporated into a company's overall enterprise risk management processes. For climate-related risk analyses on asset portfolios, some commonly used practices include:[38]

- Disclose specific definitions of short-, medium- and long-term time horizons.
- Disclose specific climate-related risk scenarios used in the analysis.
- Disclose GHG emissions from the portfolio, including preferred emissions targets that the company is striving to achieve.
- Disclose the role of the company management team in assessing and managing climate-related risks to the asset portfolio.
- Disclose the processes and frequency by which the board (or board committees) is informed about climate-related issues.
- Identify what reporting and oversight is carried out, and decisions are made, through interaction with the company board.
- Identify how climate-related risk analysis led to changes to the company portfolio and were reported.

Survey Results

A quantitative impact study for ORSA scenarios conducted by Oliver Wyman focused on the upward shock of an increase in the carbon price. The adverse change in asset values following this shock is reflected via the Own Funds side of an insurer's balance sheet, as well as an increase in the credit risk of the required capital side. The table below illustrates the impact on a "standard" life insurer and an ESG-oriented life insurer, with a change in Solvency Ratio of as much as -34% in a strong climate policy scenario[39] (in this context "strong" means early and higher transition costs through government actions).

Figure 8: Solvency II Ratio Impacts in Weak and Strong Policy Scenarios for a Standard Versus an ESG-Oriented Insurer



Source: De Actuaris *magazine*,www.ag-ai.nl/bibliotheek-1.php?action=view&Content_Id=5340

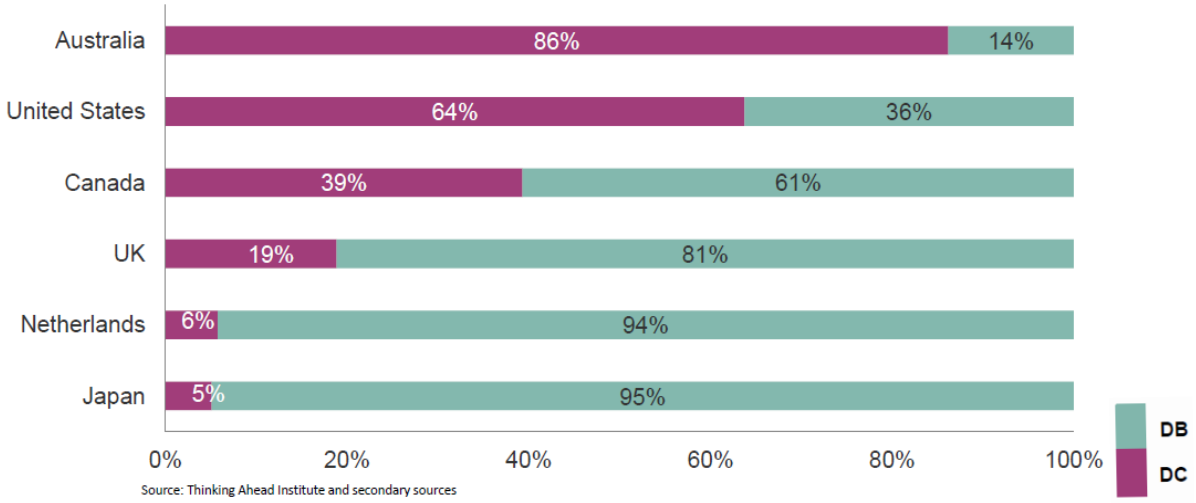
6.3 Pension Funds

Pension fund portfolios are constructed by pension plan trustees taking liabilities and any local regulatory requirements into consideration, such as limits on equity investment or requiring minimum proportions in government stock, and by the availability of suitable investments, particularly if there are also limits on international holdings. After that, the main issue is the nature of the liabilities: whether the pension fund provides defined benefits or whether benefits are just determined by the investment return on contributions.

DB pension funds around the world are being replaced by DC funds to reduce risk for employers, except in the public sector. A growing number of DB plans are being closed to new members and possibly to future service-related benefit increases. Despite these trends, substantial funds will remain in DB pension funds for many years. The total value of DC funds now exceeds DB according to the Thinking Ahead Institute's Global Pension Assets Study.[40] Whereas open DB funds would historically have generally adopted an equity-rich investment strategy, reflecting the long-term and inflation-linked nature of their liabilities (being typically related to members' salaries near retirement), the closure of these funds, aging of the membership and desire to reduce risk mean that many funds use liability-driven investment (LDI), and hold mainly fixed-income assets. DC pension funds, on the other hand, tend to be expanding relatively quickly and would have a portfolio intended to maximize long-term investment returns, normally including a relatively high equity content, perhaps reducing it as members approach retirement. DC pension fiduciaries consider how the investment options will contribute to delivering a retirement income for plan members. Individual participants in the plan may also drive the choice of which investment options or investment strategies they will use, and there may be demand from the plan participants to build portfolios with a particular climate change focus.

The relative importance of DB and DC pension funds around the world is shown by the following chart from the Thinking Ahead Institute study (mainly relating to 2020):

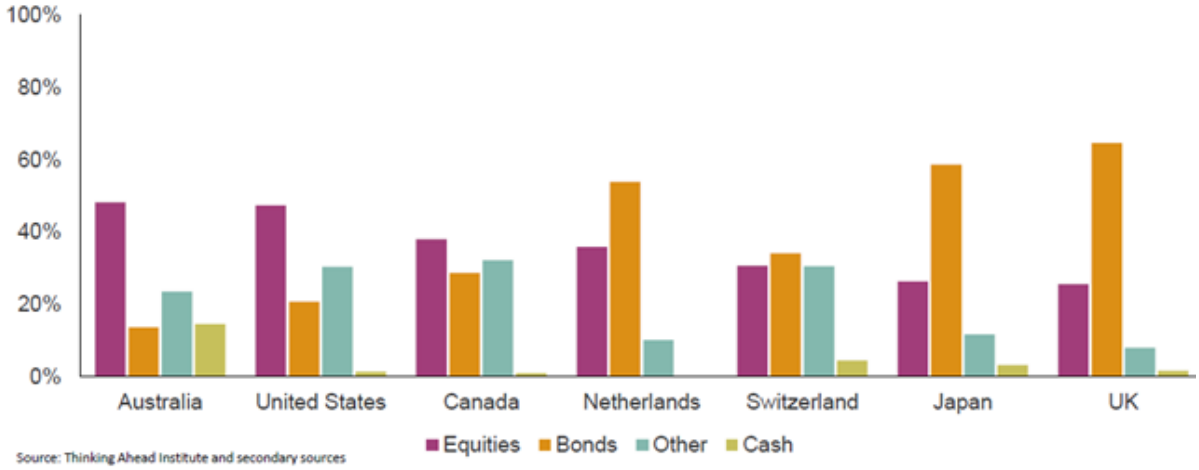
Figure 9: Share of DC and DB Pension Funds Around the World



Source: Thinking Ahead Institute and secondary sources,
www.thinkingaheadinstitute.org/content/uploads/2021/02/GPAS__2021.pdf

The chart below shows the impact of DB pension fund maturity on bond investment in those countries where these funds still make up a substantial proportion (the "Other" category includes property and presumably private equity, agriculture, renewable energy and infrastructure).

Figure 10: Pension Fund Asset Allocation 2020 (DB/DC Combined)



Source: Thinking Ahead Institute and secondary sources,
www.thinkingaheadinstitute.org/content/uploads/2021/02/GPAS__2021.pdf

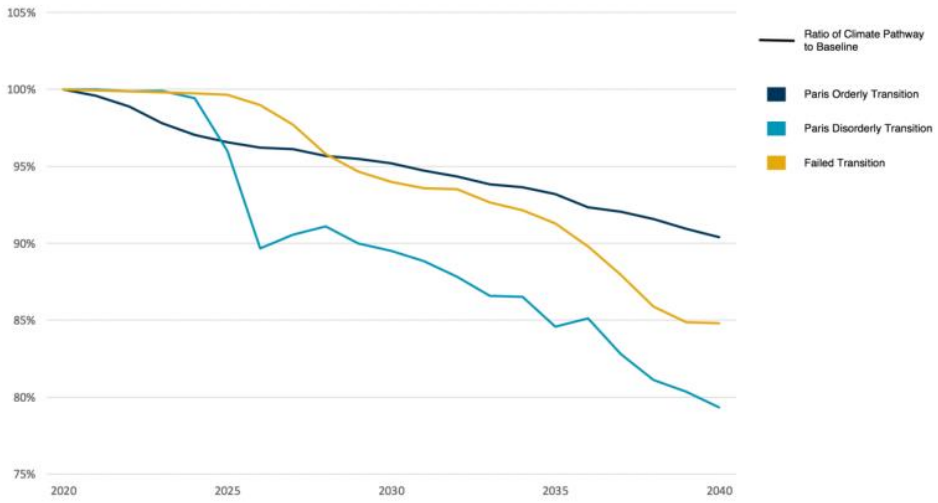
The application of scenario analysis to a UK DB pension fund is described in a 2020 IFoA paper[41] and a June 2021 article from *The Actuary* magazine.[42]

The first stage assesses the economic impact of three climate scenarios, then translates the impacts of climate-adjusted GDP for the following climate pathways onto a wide range of financial and economic variables, on a stochastic basis:

- Paris Orderly (coordinated action to limit global average temperature rises to 2°C which financial markets price in gradually);
- Paris Disorderly (the same real-world outcomes as the Paris Orderly pathway, but financial markets' reactions are delayed and abrupt); and

- Failed Transition (no additional climate policies are implemented and global average temperature rises by 4°C by 2100).

Figure 11: Funding Level Projections– Focus on Median Outcomes (Depicted as Difference to Climate-Uninformed Baseline)



Source: www.actuaries.org.uk/system/files/field/document/Climate%20scenario%20analysis%20for%20pension%20schemes%20-%20UK%20Case%20Study.pdf*, p. 18*

Note: Difference to baseline is calculated as the ratio of climate-informed median and baseline at each year.

In this particular case study, the "Paris Disorderly" scenario produced the worst result, with a funding ratio down 20% compared to baseline by 2040. The driver is likely abrupt, unanticipated financial market reaction. Under the "Failed Transition" scenario, it was assumed that the pension fund would reduce risk earlier, resulting in only a 15% drop in funding ratio compared to baseline. These drops in funding level would increase the risk of the respective employers, and in turn their risk as an investment.

The authors of the 2020 IFoA paper make the point that there is material uncertainty in all aspects of climate scenario modelling and their model is not able to fully capture all the risks. For example, it does not incorporate environmental tipping points and knock-on effects, such as climate-change-related migration and conflict, and is highly dependent on the assumptions used to translate the climate adjustments from GDP onto the other variables. Climate change scenarios could have different impacts on covered populations and insured cohorts in complex ways. In addition:

- There are some plausible climate pathways (not included in these three) where real bond yields fall rapidly, and so the liabilities could be impacted more extremely.
- Even when the scheme has reduced its investment risks, some climate-related risks will remain since matching assets are not immune to climate-related risks (particularly corporate debt due to credit risk) and cannot match uncertain cashflows exactly.
- Financial market volatility might increase as the physical and transition impacts of climate change unfold, particularly if this happens in an unpredictable manner. For maturing pension schemes, market volatility is likely to increase the chance of being a forced seller of assets and cause a drag on investment returns.
- In all cases, the extent of the sponsoring employer's exposure to climate-related risks is relevant. The greater a scheme's climate-related risk exposure through the sponsor

covenant (future contributions), the lower its capacity to tolerate climate-related risk exposure through its assets and liabilities (all else being equal).

Due to the long-term nature of climate-related risks, the time horizon is longer than typical periods utilized by pension schemes. The case study analysis covers projections over 40 years (until 2060 with an end of December 2019 baseline).

Further examples are contained in the October 2021 TCFD Status Report.[43] Page 42 shows the impact of three alternative scenarios on the business of Australian property group Lendlease. On page 43 is a summary of the impact of two alternative scenarios on sectors of the investment portfolio of German insurer Allianz.

6.4 Lending Banks

Banks are exposed to climate-related risks mainly through physical risk to financed (mortgaged) underlying assets; in a similar manner a general insurer is exposed to the insurance of these exposures. Location-based physical risk could cause physical risk as well as business interruption, impacting the ability of a borrower to repay their debt, and increasing credit and counterparty default risk on loans to both households (mortgages) and corporate bonds. Banks are less exposed to the risks of holding an asset (market risk) than a typical life insurer would be. Banks are also an important facilitator of the green transition through governance and strategy decisions regarding finance for certain industries and projects; for example, coal plants. The risk of stranded assets is therefore relevant to a bank's portfolio. With the implementation of TCFD disclosure, banks were at the forefront of developing and implementing the methodology, with the Bank of England leading as one of the first regulators to make this disclosure mandatory.

7 Next Steps for the IAA Climate Risk Task Force

This paper is the fourth in a series of papers that the IAA Climate Risk Task Force has committed to develop over the coming years. The first paper was entitled *Importance of Climate-Related Risks for Actuaries* and was an introduction to the series. The second was *Introduction to Climate-Related Scenarios*. The third was *Climate-Related Scenarios Applied to Insurers and Other Financial Institutions*. To address the needs of actuaries, more papers are scheduled to be released over the following years, such as papers on:

- Climate-related risk management and addressing emerging third-party regulatory/reporting/disclosure requirements;
- The potential effects of transition and adaptation steps; and
- The link between climate-related risk scenarios and social security.

A review of existing IAA publications is also planned to identify and address any gaps related to climate-related risks.

The IAA also plans to refresh the papers in this series periodically, given the rapid pace of change in the climate-related risk space.

The IAA Climate Risk Task Force welcomes and encourages input and involvement in these activities.

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