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Integrating Climate Scenario Analysis into Investment Management:

A 2023 Update

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ABSTRACT

GIC and Ortec Finance's climate scenarios offer investors a practical tool to analyse the impact of climate risks on financial asset returns and the wider economy. Besides accounting for the timing and sufficiency of climate policies, and the extent of physical risk exposures, a unique feature of the GIC scenarios is their analysis of market risks, including whether markets price in future climate risks smoothly or disruptively, and whether these would lead to sentiment shocks.

Executive Summary

- For long-term investors such as GIC, climate change is a key concern given its imminent and considerable impact on the value of physical assets and companies over time. Hence, factoring climate risks into both our top-down and bottom-up processes is vital to ensuring a resilient portfolio.

- At the top-down level, GIC partnered with Ortec Finance and Cambridge Econometrics to quantify how climate change drivers affect long-term capital market assumptions. We stress-tested the portfolio against different climate scenarios, and identified areas with heightened risks. This exercise enabled us to focus our efforts on deeper analysis and mitigating strategies to make our portfolio more climate-resilient.

- In our analysis, the main climate-related risks outlined are: (i) the timing and sufficiency of climate policies (timely, delayed, late, or none, and whether they are sufficient to meet the Paris climate goals or not), (ii) extent of physical risks (both acute and chronic) and (iii) whether markets price in future climate-related drivers smoothly or disruptively, and whether these result in sentiment shocks. The exploration of the pricing-in effects of markets and sentiment shocks in relation to climate-related transition and physical risks is a key innovative feature of Ortec Finance's work on climate scenarios.

- Investors need to continually assess the evolution of long-term drivers of climate change and their impact on the portfolio. It is also crucial to incorporate potential new ways the long-term investment environment could play out and update modelling methodologies. Hence, this report provides an update to the paper 'The Role of Climate Change Scenarios in Investment Portfolios' that GIC and Ortec published in July 2021. **There are two new major features to highlight**:

    - **First, we included a new fourth scenario, titled 'Too Little Too Late'**, which is aligned with a 2-3ºC outcome. This scenario assumes both high transition and physical risks, given the delayed introduction of climate policies which fail to limit the physical impact of climate change. It offers a more extensive and nuanced narrative that reflects GIC's concerns as an investor and is not included in any climate scenario sets currently in the market.

- **Second, we updated the supply side effects of physical climate risks on inflation.** These are inflationary and counteract the deflationary impact of lower growth resulting from physical risks.

- The four climate scenarios we analysed are:
  - Net Zero (NZ)
  - Delayed Disorderly Transition (DDT),
  - Too Little Too Late (TLTL), and
  - Failed Transition (FT).[1]
- We believe it is important that investors take an active approach to the design of climate scenario analysis. GIC has therefore invested in developing a set of scenarios that can be referenced and compared to public scenario sets, but also incorporate specific nuanced views such as the potential for disruptive market pricing and the possibility of insufficient policy actions. The DDT and TLTL scenarios are customised for GIC, created by the fund in close collaboration with Ortec Finance and Cambridge Econometrics.
- Not all investors can develop custom scenarios tailored to their own needs. GIC believes that a range of high-quality climate scenarios, developed for investors and preferably by investors, should be made available for asset owners and managers to consider. If other investors are keen to use the parameters of the bespoke scenarios we have developed, they may approach Ortec Finance.
- Compared to our 2021 research, our current set of scenarios illustrate the increased volatility in macro variables more clearly. This is especially the case in the DDT and TLTL scenarios due to responses to extreme

[1] For the non-bespoke scenarios, GIC used the 2022 version of Ortec Finance's ClimateMAPS solution. Names and specifications of these scenarios may be subject to change in future versions.

weather and policy shocks as well as the effects of more disruptive market pricing-in mechanisms and sentiment shocks.

- The impact of climate change on broad market beta is expected to be negative, although there might be a potential upside for certain markets, sectors, companies, and business models. Opportunities span emerging markets with currently low exposure to low-carbon utilities, or decarbonisation and adaptation technologies that are currently nascent but could scale with more policy support and capital flows. Risk assets such as equities and real estate are more sensitive to climate change compared to bonds and cash.
- Based on a hypothetical global 60% equities and 40% bonds portfolio, returns may still be positive in the long run with climate change, but projected returns are meaningfully lower across all four scenarios versus a climate-uninformed baseline. Hence, long-term investors may be surprised by the underperformance of the portfolio relative to their expectations.
- In addition to transition risks, investors should account for the effects of climate-related physical risks on the portfolio and be prepared to navigate the potential increase in market volatility from climate-related shocks.
- As with the case of the impact on global GDP growth, the investment portfolio fared worst in the Failed Transition scenario where no new climate policies are introduced so transition risks are low but physical risks are the highest.
- Given GIC's long-term mandate, it is essential to prepare for managing climate-related transition, physical, and market risks in our portfolio. Climate scenario analysis plays a central role and can be incorporated into the investment process via top-down strategic asset allocation, stress-testing, and risk management, and through the bottom-up integration of scenario assumptions and implications into active investment processes.

Introduction – The growing importance of climate scenario analysis

Integrating climate scenario analysis into the investment process is becoming increasingly common. The International Sustainability Standards Board (ISSB), which works towards developing a global set of standards for sustainability reporting, will include the Task Force on Climate-Related Financial Disclosures (TCFD) requirement to use scenario analysis for assessing portfolio performance. The Network for Greening the Financial System (NGFS) [2], representing over 90 central banks and supervisors, has also advocated for the use of climate scenario analysis in assessing financial institutions' climate change-related risk exposures and the implications for financial stability. Additionally, some key jurisdictions such as the UK, the EU, Switzerland, Japan, Hong Kong, New Zealand, and Brazil, are making climate scenario analysis mandatory via TCFD disclosures.[3]

GIC welcomes the guidance published on climate change-related scenario analysis from both regulatory authorities and standard-setting bodies over the last few years. This work has socialised the value of climate scenario analysis among the wider financial community. It has also provided a starting reference point for investors who are looking into the complex task of integrating climate scenario analysis into their investment frameworks.

Nevertheless, investors should still take ownership of the assumptions used to develop scenarios as there are multiple pathways to possible future states of the investment environment. Investors should also consider risks relevant to the portfolio they are managing which may not be considered in the regulators' standard scenario sets. For instance, standard scenario sets often overlook how market pricing could reflect forward-looking expectations of physical and transition risks. Relying only on standard scenario sets could result in limited diversity of views across the industry about how future transition paths could evolve in markets. This can lead to a lack of preparedness for potential shocks and less portfolio resilience.

[2] The NGFS, of which MAS is a founding member, is a group of over 90 central banks and supervisors that share best practices and contribute to the development of environmental and climate risk management in the financial sector.
[3] Task Force on Climate-related Financial Disclosures (2021). *2021 Status Report*.

Following an earlier article on 'Why climate change matters for investors'[4] this paper looks at scenario analysis as one approach to measure the impact of climate change on the investment portfolio. It's an update of the original publication "The Role of Climate Change Scenarios In Investment Portfolios" published in June 2021.

The paper is organised into the following sections:

- How climate change impacts investments
- Challenges of using climate scenarios for financial analysis
- GIC's approach to climate scenario analysis
- Ortec Finance's top-down climate scenario modelling methodology
- Overview of the four climate scenarios
- Results and analysis: the impact on GDP growth and inflation, broad asset class returns, and a representative global portfolio
- Top-down modelling limitations
- Suggestions for integrating climate scenario analysis into investment processes

Climate risks and their impact on investments

Climate change affects investment portfolios through three channels — physical risks, transition risks, and market risks — that are expected to play out over different time horizons (see Figure 1).

[4] GIC (2020). *Why Climate Change Matters for Investors*.

Figure 1: The three channels of climate change impact on financial assets

1. Physical risks	Acute	Impact of extreme weather events like flooding, wildfires, hurricanes, typhoons on direct asset damages, business disruptions, long-term insurability of assets, and viability of local activities
	Chronic	Impact of rising temperatures on labour and agricultural productivity; impact from heat/water stress on business operations
2. Transition risks	Policy	Impact of policy shifts including carbon pricing, coal phase-out, EV/Transport Policy, fuel subsidies, energy efficiency programmes
	Technology	Impact from disruptive technologies such as renewable energy, green hydrogen, electric vehicles, mobility, battery, and carbon capture and storage (CCS)
3. Market risks	Pricing-In	When, how much, and over what time period markets will price in future climate change-related impacts (physical and transition)
	Sentiment shock	Whether markets will overreact to climate change-related shocks (e.g. extreme weather events or sudden policy changes)

Source: GIC, Ortec Finance

While understanding the three impact channels is straightforward qualitatively, articulating the transition pathways and quantifying their impact on financial assets is more complex. The impact of each climate risk factor is highly uncertain in terms of their magnitude, timing, and variability across geographies, sectors, and asset classes. **For long-term investors, scenario analysis provides a systematic framework for navigating this uncertainty.**

Challenges of using climate scenarios for financial analysis

While investors are used to conducting scenario analysis and stress-testing in their asset allocation and risk management processes, undertaking such an endeavour for climate change is challenging.[5] Despite improvements in recent years, models looking at how climate change drivers affect financial variables are still in the early stages of development. To do this effectively, investors need financial models that are:

- **Comprehensive** — Models need to assess the impact on not only the major asset classes for effective strategic asset

[5] General Circulation Models (GCMs) looking at the response of the environment's physical processes (e.g. temperature, sea level rises) to rising greenhouse gas emissions as well as Integrated Assessment Models (IAMs) focusing on the interaction of climate variables with climate policies and the economy have been around for many years. They have been increasing in sophistication and usefulness. However, these were developed with climate scientists and policymakers in mind, not financial investors.

allocation, but also on individual securities as each asset is affected by climate change-related factors differently and at different times depending on their geographic and sector exposures. They need to cover transition, physical, and market risks. The quantified outputs also need to be complemented with qualitative narratives and explanations to mitigate the constraint that not all climate-related risks can currently be captured quantitatively.

- **Flexible, consistent, and integrated** — Models should allow for flexibility in combining views about emissions pathways, temperature outcomes, government policies, technological mixes, the macroeconomic landscape, and financial markets in a consistent framework that accounts for feedback loops amongst these factors. For example, a policy measure such as carbon pricing will change the relative price of carbon, thereby affecting demand for fossil fuels and adoption of low-carbon technologies. This in turn will affect the emissions pathways and temperature outcomes.

- **Current** — Models should incorporate the latest scientific research such as the sensitivity of global temperatures to the amount of accumulated emissions, and the impact of global warming on economic activity. For instance, older versions of integrated assessment models use physical damage functions that are based on historical observations of activity and temperatures at the macro level of countries, which can significantly underestimate the physical impacts of global warming over the long term.[6] The latest research on chronic physical risks (using granular, local-level economic analysis) shows that there is a non-linear decline in labour and agriculture productivity beyond an optimal global temperature level.[7]

GIC's approach to climate scenario analysis

To achieve robust financial modelling of climate scenarios, **GIC's approach is to not rely on one single model, but to triangulate**

[6] International Monetary Fund (2019). *Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis*.
[7] National Bureau of Economic Research (2019). *Climatic Constraints on Aggregate Economic Output*.

between different top-down and bottom-up modelling methods.

- **Top-down** approaches look at how climate change-related drivers affect asset class returns and assess impacts at the country and sector levels.
- **Bottom-up** approaches look at the impact of climate change-related drivers (e.g. carbon prices) and how these drivers affect cash flows (e.g. revenues and costs) at the individual security level.[8]
- We compare our analyses with the results that other institutions have developed, considering differences in scenarios and modelling methodologies.

In this article, we are focusing on the top-down approach.[9] For the development of their bespoke climate scenarios and the top-down analysis of climate change-related impacts on investment portfolios, GIC and MAS partnered with Ortec Finance.[10] Their tool addressed most of our requirements regarding the financial modelling of climate change. For more information about ClimateMAPS, please see Annex A.

Ortec Finance's ClimateMAPS modelling methodology

The ClimateMAPS tool has been jointly developed by Ortec Finance and Cambridge Econometrics. It combines climate science modelling with energy-environment-economy (E3ME) macro modelling, extreme weather risk modelling (ClimatePREDICT), and stochastic financial modelling of broad asset classes. The model specialises in capturing economic and financial interlinkages and feedback loops,[11] by using empirically-based climate and financial modelling to best reflect how the real world works. Figure 2 illustrates this process:

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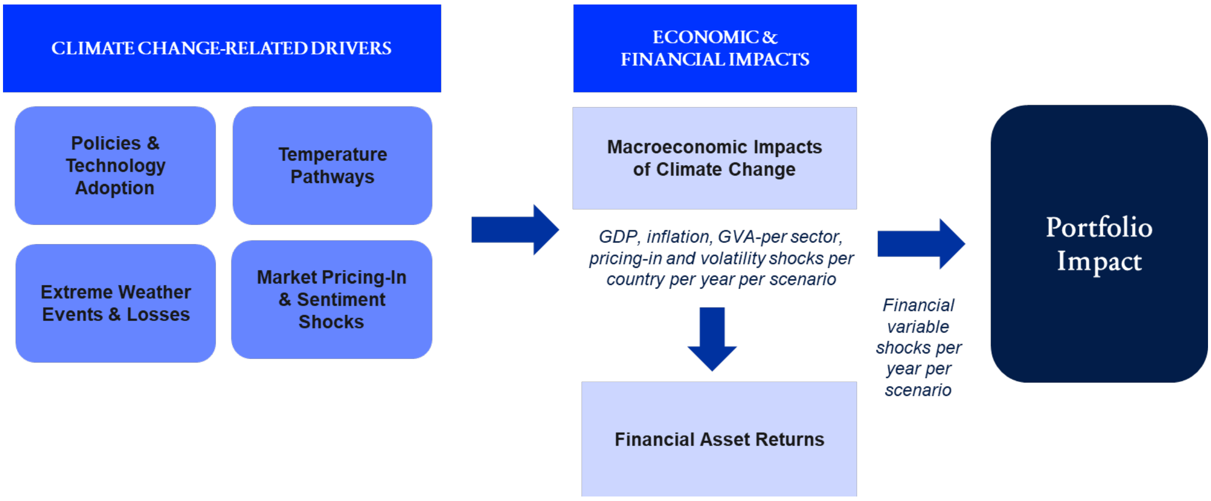
[8] One of the bottom-up models GIC developed is the Carbon Earnings-at-risk Scenario Analysis (CESA) where we assessed the impact of a range of possible carbon prices on the earnings of individual companies. We outlined our methodology in GIC (2022). *Carbon Earnings-at-risk Scenario Analysis (CESA)*.

[9] GIC's Carbon Earnings-at-risk Scenario Analysis methodology is one of the bottom-up approaches to assessing the impact of a key transition risk factor (e.g. carbon prices) on the valuations of investments in the portfolio. In a forthcoming paper, we will also discuss the implications of the assumptions made in each scenario for the cash flows of companies to derive the "climate value-at -risk" for individual companies and investment portfolios.

[10] This scenario analysis project was done in close partnership with MAS (Monetary Authority of Singapore) as part of a larger collaboration to assess the impact of climate change on investment portfolios under the management of MAS and GIC respectively.

[11] For example, less demand for a country's fossil fuel exports will not only be felt by the fossil fuel manufacturing companies, but also in areas such as employment, government revenues and all the sectors related to the fossil fuel industry.

Figure 2: Process for translating climate scenarios into portfolio impacts (ClimateMAPS tool)



Source: GIC, Ortec Finance

- First, we use a set of inputs based on different climate scenario narratives we developed. These include temperature and carbon emissions pathways, policy and technological assumptions, extreme weather events and losses, as well as views about how smoothly or disruptively markets will price in climate change-related shocks. These are outlined in Figure 1 of the paper.

- Second, the economic impacts from these different climate change-related drivers are estimated using an econometric model that looks at the interactions between issues related to the environment, energy, and the economy. This integrated Cambridge Econometrics E3ME model then assesses the macro impacts from climate change including how real GDP growth, inflation, labour productivity, and sector and country-level gross value-added growth are affected.

- Third, extreme weather event assumptions are developed using Ortec Finance's proprietary extreme weather risk model, ClimatePREDICT. Inputs to this model include Munich RE's NatCatService, as well as UN population and climate data.[12]

- Fourth, GDP and inflation shocks from the macro and extreme weather models, market pricing-in risks and

[12] They feed Ortec Finance's own urbanisation-based risk algorithm and Economic Amplification Ratios. These are used to calculate forward-looking direct and second-order GDP impacts from extreme weather risks.

sentiment shocks are combined in Ortec Finance's stochastic financial model to derive the climate change-driven impact on risk-return parameters (e.g. return and volatility) of asset classes.

- Lastly, the stochastic financial model produces outputs at the sector and regional level, which can then be used to calculate aggregate portfolio impacts.

The ClimateMAPS tool is able to break down the climate change-related impact on macroeconomic variables and asset class returns into the various drivers of climate change (as outlined in Figure 1):

- Gradual (or chronic) physical risks
- Acute physical risks (extreme weather)
- Transition risks, including both policy and disruptive technology impacts
- Market pricing-in risks and sentiment shocks

A key characteristic of ClimateMAPS is its holistic approach. This is expressed in the following manner:

- **Broad coverage of climate-related risks;**
- **Coverage of all asset classes on the basis of a consistent set of assumptions;**
- **Capture of 'systemic risk at a granular level'**[13]

Another important attribute of the ClimateMAPS tool is the use of empirically-based climate and financial modelling to best reflect how the real world works in practice:[14]

- **Assumption about market efficiency**: The macro model does not assume perfectly efficient markets and is able to capture the dynamics of loans and investment.[15]
- **Empirically based**: The financial model is based on more than 100 years of econometric data.

[13] The model is built up of granular technology and policy developments that translate to economic and financial impacts at the sector and regional level. The model specialises in capturing economic-financial interlinkages and feedback loops.
[14] See Climate scenario analysis: An illustration of potential long-term economic & financial market impacts (British Actuarial Journal Cambridge Core) and Climate scenario analysis for pension schemes: a UK case study (British Actuarial Journal, Cambridge Core).
[15] The Cambridge Econometrics model allow for the economy to increase credit and debt to finance the transition which is expansionary and is accommodated by monetary policy settings. However, there is a repayment period in the medium to long-term which is contractionary for the economy, and again this dynamic is allowed to play out in the model without compensatory monetary policy to support the economy.

- **Incorporation of the latest climate science research and modelling**: The model is rooted in strong climate science using the most recent literature.
- **Conservative damage function**: the slow-onset physical risk damage function used in ClimateMAPS assumes that a higher temperature level has a negative impact on GDP growth rate. It also assumes a non-linear relationship between increased temperatures and the GDP impact. This results in larger impacts estimated from physical risks compared to other scenarios available in the market. Given the significant uncertainties around the impact of warming on Earth's natural systems, including the ecosystems that make up biodiversity, this is a prudent approach. Note that this model does not explicitly account for the impact of tipping points.

Analysis from the four key climate scenarios

Our four climate scenarios are shaped by assumptions about how the different climate change-related drivers outlined in Table 1 evolve:

Updated Ortec Finance standard scenarios:

- **Net Zero (NZ)**: This is characterised by an early, orderly, and ambitious transition to a 1.5˚C warming trajectory by 2100. Global emissions reach net zero by 2050. The scenario accounts for the physical risks associated with 1.5˚C. The market's pricing-in of transition and physical risks are smoothed out.

- **Failed Transition (FT)**: This scenario assumes only currently implemented policies. Climate change-related physical impacts — both chronic and acute — are extremely severe as the average global temperature increases to over 4ºC above pre-industrial levels by 2100. In this scenario, we see markets pricing in physical risks including those occurring in the post-2050 period so that financial impacts are felt even before the physical risks manifest.

These scenarios are 'bookend' scenarios exploring both an optimistic and a pessimistic outcome.

New bespoke scenarios:

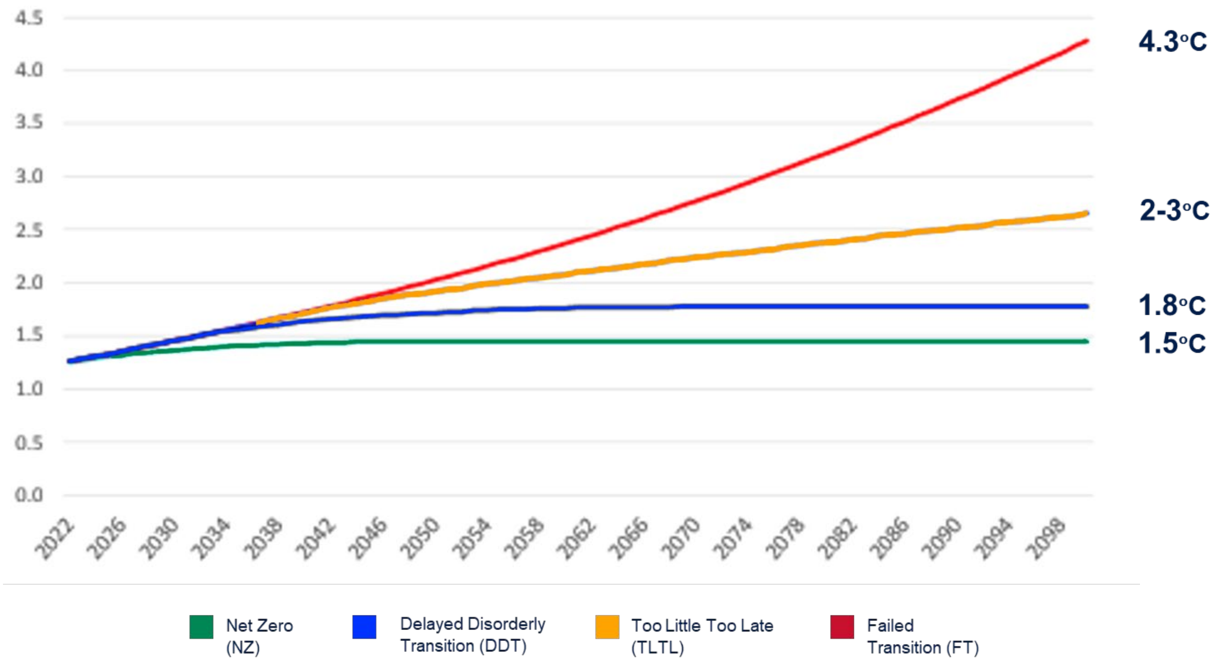
- **Delayed Disorderly Transition (DDT)**: This scenario assumes that the world is slow to implement climate policies until a surge in extreme weather events occurs that is historically unprecedented in terms of frequency and intensity but within the range of scientific forecasts. These events result in a global recession. The world shifts gear and acts. Policies required, such as regionally-differentiated carbon pricing and subsidies for clean technologies, are much more substantial compared to what is needed in the Net Zero scenario due to the delay in taking climate mitigation actions. The climate policies are ultimately sufficient to reduce emissions and keep global warming below 2ºC by 2100. Markets price in future climate change-related risks over a much shorter period compared to the Net Zero scenario. There is also a sharp sentiment shock as markets overreact to sudden extreme weather and policy shocks. The transition is thus disorderly with equity markets falling sharply. However, over time the sentiment shock (which is not fundamentally driven) dissipates and economies and markets recover.

- **Too Little Too Late (TLTL)**: Like the DDT scenario, the TLTL scenario assumes that policymakers are forced to act only when public pressures rise in response to severe extreme weather shocks. However, unlike DDT, responses by policymakers are insufficient to cut emissions sufficiently to keep global warming below 2ºC. Only a series of intensifying extreme weather shocks over a decade will compel sufficient policy actions to reach peak global emissions.[16] However, this is too late for the world to keep within the 1.5ºC carbon budget. Global average temperature reaches ~ 2 to 3ºC by the end of the century. GIC decided to explore this highly disruptive scenario because, as investors, we need to contemplate a world of insufficient policy actions as a potential outcome. The 2022 Emissions Gap Report by the UN Environment Programme (UNEP)[17] estimates that based on current committed policies, the expected 2100 temperature outcome ranges from 2.4ºC to 2.8ºC. This is also a scenario that examines a world with both rising and disruptive transition and physical risks which investors should prepare for.

The temperature pathways associated with these four scenarios and a brief overview of the key drivers of the scenarios are presented in Figures 3 and 4. Three of the scenarios — NZ, DDT and FT — map broadly to the reference scenarios recommended by the NGFS in September 2022.[18] However, while the benefits of developing a bespoke TLTL scenario were discussed by NGFS, this scenario is currently not explored by other climate scenario analysis work we have seen.

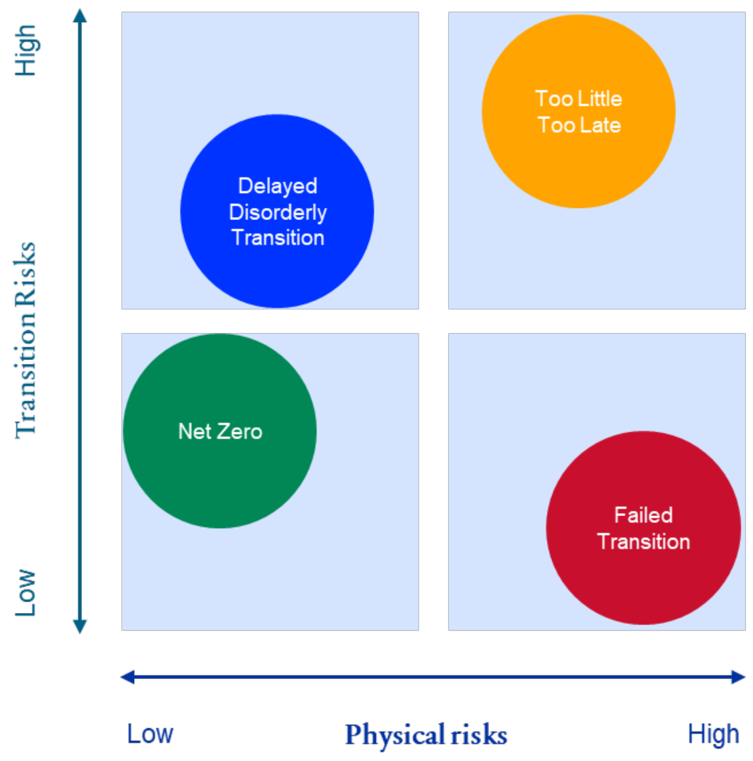
[16] Each "extreme weather shock – policy actions – and market reaction and pricing-in" cycle is more severe than the one before.
[17] United Nations Environment Programme (2022). *Emissions Gap Report 2022*.
[18] Network for Greening the Financial System (2022). *NGFS Climate Scenarios for central banks and supervisors*.

Figure 3: Expected temperature change above pre-industrial levels in the four climate scenarios



Source: GIC, Ortec Finance

Figure 4: Physical vs transition risks impacts in GIC's climate scenario sets



Source: GIC, Ortec Finance

Figure 5: Overview of GIC's climate scenarios

Drivers	Net Zero (NZ)	Delayed Disorderly Transition (DDT)	Too Little Too Late (TLTL)	Failed Transition (FT)
Global warming outcome	1.5ºC	Below 2ºC	2-3ºC	~4ºC
Net-zero emissions year	2050	2070	Not reached within 2100	Not reached within 2100
Extreme weather shock	No sudden surges in extreme weather events (EWEs)	Surge in EWEs in 2030	A series of EWEs shocks in the 2030s with each shock having a larger impact than the previous shock	EWEs rise in frequency and severity over time as temperatures rise
Policy and technology	Early policy action and adoption of low-carbon technologies	Delayed and sudden policy action to push adoption of low-carbon technologies	Delayed and cascading policy intensity with escalating impacts resulting in multiple abrupt policy changes to decarbonise the economy in the 2030s	Only current policy measures and technologies are implemented
Market pricing-in risk	Transition and physical risks priced in smoothly between 2022-25	Sharp pricing in of physical and transition impacts within a short period of time	Successively sharper pricing in of physical and transition risks over 2030s	Only physical risks are priced in and are more severe than in other scenarios
Sentiment shock	None	Large sentiment shock triggered by sudden policy action	Sentiment shocks corresponding with policy actions	None

Source: GIC, Ortec Finance

Results and key insights

We applied the scenarios and methodology outlined above to a simplified global investment portfolio of 60% global equities and 40% global bonds (60/40).[19] The key impacts on the economy, capital markets, and the 60/40 portfolio are summarised in the subsequent sections.

Impact on global growth

Compared to our scenarios work published in 2021, our current set of scenarios illustrates increased volatility in macro variables more clearly. This is especially the case in the DDT and TLTL scenarios due to responses to extreme weather and policy shocks as well as the effects of more disruptive market pricing mechanisms and sentiment shocks.

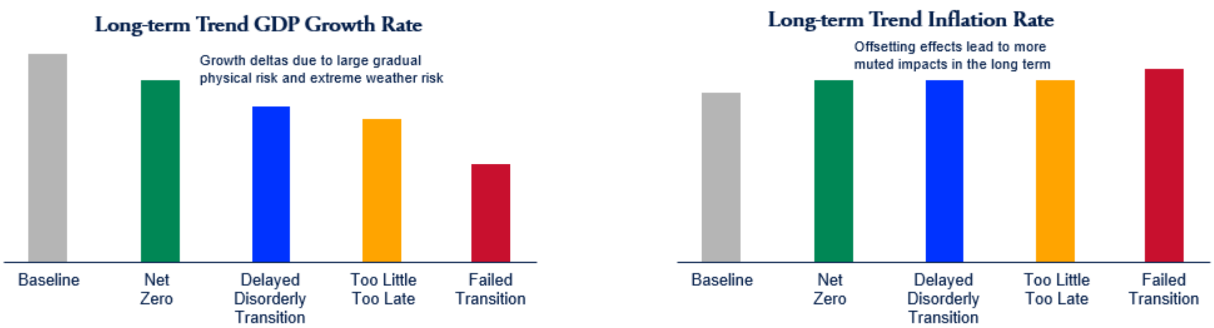
Climate change-related drivers are likely to have a negative long-term impact on global GDP when compared to a climate-uninformed baseline, due mainly to physical risks (see Figure 5).

[19] The equities portfolio comprises of markets in the US, Canada, Europe, Japan, developed markets (Pacific) and emerging markets. Fixed income includes nominal government bonds issued in US, Japan, France, Italy, Germany and the UK. The returns data series from these markets are based on the benchmark indices in Ortec's financial model.

Gradual (or chronic) physical risks have long-term adverse effects on labour and economic productivity. The impact of extreme weather events (or acute physical risks) is also negative on macroeconomic growth but to a much smaller degree than gradual physical risks. However, current climate models have not been able to incorporate the impact of adaptation on long-term physical risks, which could temper the negative impact of rising global temperatures.

Overall, global transition impacts on long-term trend growth are small due to the transient nature of transition risks. Transition risk impacts are positive up to around 2030, driven by the stimulus effects of investments in decarbonisation solutions as well as positive changes in real consumer incomes due to the recycling of carbon taxes. With time, the stimulus effects dissipate and loans to finance the energy transition are paid back.

Figure 6: Expected impact of climate change drivers on long-term trend growth and inflation



Source: GIC, Ortec Finance

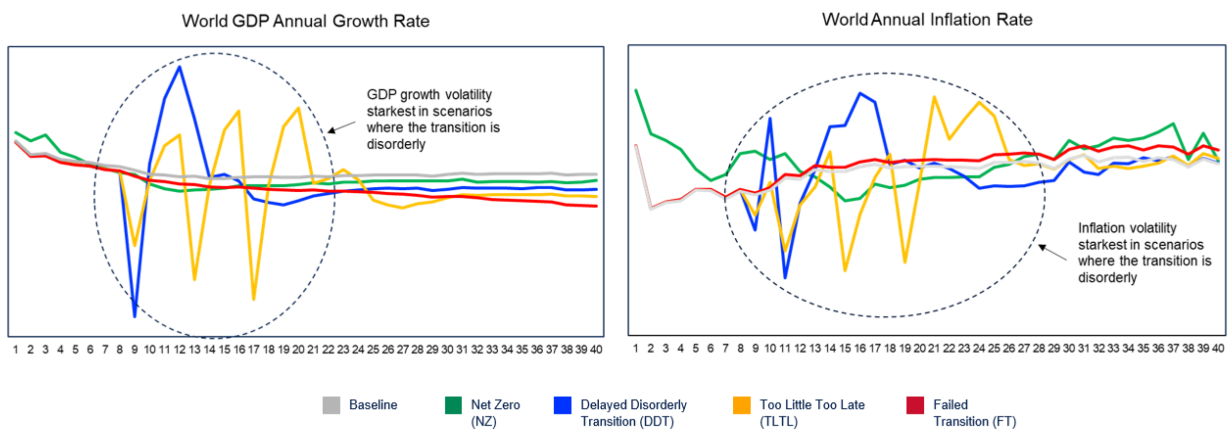
Impact on global inflation

Climate change has a neutral impact on trend inflation in the long term as the opposing effects of climate change-related drivers eventually balance each other out. Greater volatility is observed in line with the responses of the macro economy to climate-related physical and policy shocks (see Figure 6).

The impact of transition risks on inflation depends on the time horizon. In the shorter term, transition policies result in an upward impact on demand-pull inflation due to higher carbon prices and an increase in investment spending on clean technologies. In the medium term, the switch to cheap renewables leads to declining electricity prices. However, in the long term, the application of expensive carbon capture and storage (CCS) and bioenergy with carbon capture and storage (BECCS) puts upward pressure on inflation again. When the energy transition is complete, transition risks should exert an overall neutral impact on long-term trend inflation rates. Hence, it is important for investors to identify the various underlying drivers of inflation from transition risks and be able the navigate the different portfolio pathways over time.

Physical risks exert opposing effects on inflation in the long term, but the net outcome in terms of trend inflation rate is marginally positive especially in the scenario with high physical risks (e.g. Failed Transition). On the one hand, physical risks have a negative impact on growth and aggregate demand, which exerts downward pressure on inflation. On the other hand, global warming leads to decreasing crop yields for most crop types, due to volatile precipitation and stronger summer heat waves. This increases the prices of agricultural products, food, and the general price level of the economy, placing an upward pressure on inflation. Countries with a high food share in household expenditure and those with diets based on heat-sensitive food types are more affected.

Figure 7: Volatility in both GDP growth and inflation in climate scenarios, especially DDT and TLT



Source: GIC, Ortec Finance

Macro volatility resulting from market dynamics

Exploring how markets price in climate-related transition and physical risks, including potential sentiment shocks, is a key innovative feature of Ortec Finance's work on climate scenarios. Sentiment shocks are the essential but complex features of the model. Ortec Finance scenarios illustrate that when markets price in transition and physical risks suddenly, they tend to overshoot and then recover. This leads to significant additional volatility in scenarios with disruptive pricing-in dynamics such as DDT and TLTL.

Finally, our analysis shows that there is a wide dispersion of growth impacts across countries, and winners and losers also vary according to the different scenarios. For example:

- In the transition scenarios, net fossil fuel exporters would see a higher negative growth impact due to the energy transition compared to net fossil fuel importers.
- In the FT scenario, negative physical impacts are greater in countries with higher starting average temperatures. While countries near the poles are expected to see relatively faster warming, the impact on economic growth is smaller given their lower starting temperatures. Some countries may even benefit from previously uninhabitable cold regions becoming more productive.

Impact on capital markets

Physical and transition risks have a mostly negative impact across all asset classes compared to a climate-uninformed baseline. Risk assets such as equities and real estate are more sensitive to climate change compared to bonds and cash. This results in capital market lines being flatter in the four climate scenarios relative to the climate-uninformed baseline (see Figure 8).

The response of risk assets (equities and real estate) to physical risk drivers is negative, similarly to what we observe in the real economy.[20]

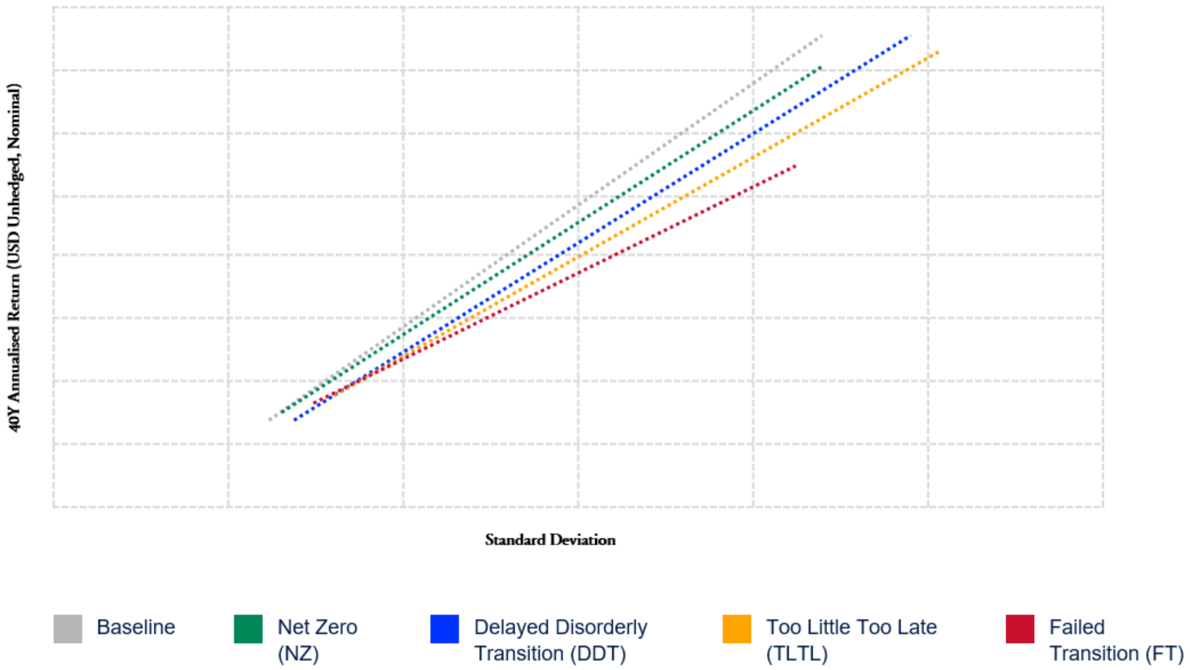
The global equity market sees a negative impact from transition risks because it currently has a higher exposure to the US, which is a fossil fuel exporter,[21] and is adversely affected by climate-related transition risks.

Within the equity markets, most sectors see downside risks, except for low-carbon electric utilities (wind, solar, and bio-based

[20] However, the impact of adaptation on company returns may not be fully captured by current models, including whether it could mitigate the impact of physical risks or provide a potential upside to markets.
[21] U.S. Energy Information Administration (EIA). U.S. energy facts explained.

electricity, especially bioenergy with carbon capture and storage (BECCS)). We observe that equity markets with currently low exposures to low-carbon electric utilities, such as certain large emerging markets, have more potential to outperform in the transition scenarios as the room for the sector to grow is much larger than those which already have established low-carbon electric utilities.

Figure 8: 40-year capital markets line



Source: GIC, Ortec Finance

Impact on investment portfolios

Climate change is projected to have a long-term negative impact on a global 60/40 portfolio in the order of minus 10-40% versus a climate-uninformed baseline, largely driven by physical risks.

The annualised nominal returns over a 40-year period for the 60/40 portfolio ranges from 3.4 to 4.3% in the four scenarios, versus 4.6% in a climate-uninformed baseline (see Figure 7a). This is significant as it translates to cumulative returns being 10% to nearly 40% lower in the climate scenarios versus the baseline over the 40-year horizon (see Figure 7b).

Figure 9a: 40-year annualised absolute returns (USD, nominal)

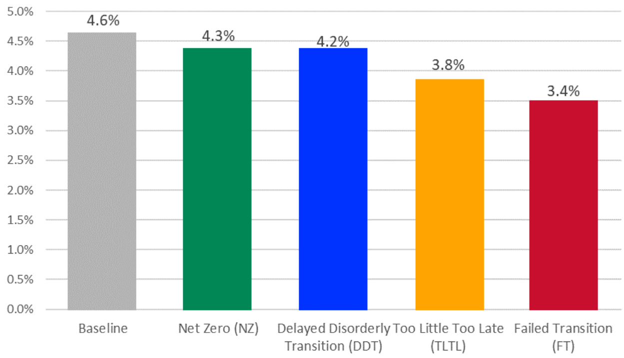
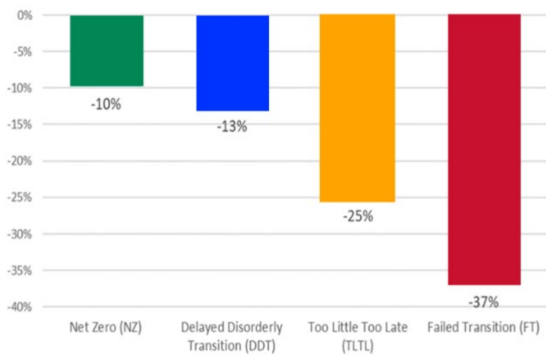


Figure 9b: 40-year cumulative returns shown as a difference from baseline (USD, nominal)



Source: GIC, Ortec Finance

While risk assets may still deliver positive returns in the long term even with climate change, the returns are likely to be lower than in a climate-uninformed baseline. Hence, investors may be surprised by the long-term underperformance of the portfolio relative to their expectations.

While the need to account for transition risks in the investment portfolio is generally accepted, long-term physical risks, especially chronic physical risks, may have a much more significant impact on investments. With growing investor awareness and more data and physical risk assessment methodologies made available, physical risk impacts can be increasingly incorporated into analyses.

In the medium term, climate-related shocks could result in increased market volatility that long-term investors should prepare to navigate. When and how much markets will price in future climate change-related risks, and whether markets over-react to climate change-related policies and news can affect volatility levels in markets.

- In the DDT scenario, volatility spikes when a surge in extreme weather events hits the world. This rise in extreme weather events causes a sharp pricing-in shock in financial markets in anticipation of further increases in physical risks in the future. This sudden market reaction triggers a sentiment shock and market overreaction that has a significant negative impact on all risk assets within the portfolio, followed by a positive effect in later years as markets gradually recover.[22] In the TLTL scenario, a similar chain of events also occurs – a rise in weather extremes triggers sharp pricing-in and sentiment shocks in markets but it's repeated multiple times until policymakers implement sufficient transition policies to achieve peak emissions, which happens too late to meet the global temperature goals.

Top-down model limitations

By applying climate scenario analysis to their portfolios today, investors can more comprehensively articulate the potential impact of climate-related risks and be in a better position to consider the necessary measures to make their portfolios more climate-resilient in the future.

There are, however, limitations to the top-down scenario approach:

- Climate science models have not fully incorporated **feedback loops and tipping points** from warmer temperatures accelerating the melting of ice sheets, which would increase the sensitivity of average temperatures to greenhouse gas emissions.
- Climate impact models do not account for the implications of **climate change-related migration** on economies and markets.
- Physical damage functions have also not fully incorporated the ability and willingness of countries to invest in **adaptation**.
- Ortec Finance's financial models are not yet able to properly price the **impact of *extreme* weather on scarcity** and the implications for inflation and related assets.
- Modelling the impact on **private assets** is more challenging as there is less information available on country-sector exposures.

Investors should thus keep updated with the latest research to inform the design of plausible climate scenarios and accurately quantify their impact on portfolios. Top-down analysis should also

[22] While this chain of extreme weather shock followed by disruptive market pricing-in of future climate-related risks occur once in DDT, it happens multiple times over a decade in TLTL as the scenario assumes that policies are initially insufficient until public pressures intensify to cause the cumulative transition policy response to eventually cause a peak in global carbon emissions.

be complemented by bottom-up due diligence for a more comprehensive assessment and integration of transition and physical risks.

Conclusion

What we have outlined is a top-down approach to estimating the impact of climate change-related risks on long-term investment portfolios with the use of climate scenarios. The four scenarios, including GIC's bespoke DDT and TLTL scenarios, provide a useful reference for long-term investors contemplating the adoption of climate scenario analysis. Examples for how investors can use these outputs include:

- **First, in asset allocation**, incorporating climate change-related scenarios into the asset allocation process can help assess the impact of climate change on the expected returns of different asset classes. Scenario analysis is a well-established process and a fundamental building block that GIC uses for its top-down and bottom-up capital allocation processes. [23] It is a forward-looking assessment and helps GIC better anticipate the range of upside and downside risks that could affect markets. This is also aligned with one of GIC's investment principles, which is to prepare for, and not predict, possible states of the future.

- **Second, in risk management**, applying the most disruptive climate scenario(s) as a stress test for the resilience of the investment portfolio enables investors to better prepare for the potential volatility that could affect markets. Scenario analysis with sufficient granularity in terms of how different countries and sectors are affected, helps to identify where the most vulnerable parts of the portfolio are. Deeper dives can then be conducted on these countries and sectors.

- **Third, in climate change integration into active investment processes**, bottom-up investment teams can incorporate the assumption inputs (e.g. carbon pricing) and intermediate outputs (e.g. demand for energy sources like coal, oil, gas, renewables as well as adoption rates of decarbonisation solutions like electric vehicles) into their

[23] See GIC (2021). *Scenario Planning for Portfolio Resilience in an Uncertain World*.

assessment of companies. For example, forward-looking carbon prices can be combined with data on companies' carbon emissions to estimate the impact of carbon pricing on companies' earnings and valuations.

Ultimately, GIC recommends combining a top-down and bottom-up modelling approach to provide a more holistic assessment of climate change-related impacts on investment portfolios. Notwithstanding, we hope that the sharing of our perspectives from the top-down scenario process can contribute to accelerating the integration of climate change-related considerations into investment processes around the world.

ANNEX A: The benefits of Ortec Finance's ClimateMAPS methodology

A key characteristic of ClimateMAPS is that it is holistic in its approach. This is expressed in the following manner:

- **Broad coverage of climate-related risks:** ClimateMAPS models transition-related risks and opportunities as well as physical risks (both slow onset and extreme weather impacts). It also takes into account the potential effects of markets pricing in future transition and physical risks.
- **Covers all asset classes on the basis of a consistent set of assumptions:** The modelling techniques used ensure that all the asset classes are 'climate-shocked' on the basis of a consistent set of assumptions. Therefore, more granular outcomes at, for example, the sector, region or asset class level can safely be aggregated to the level of the whole portfolio.
- **Captures 'systemic risk at a granular level':** The model is built up of granular technology and policy developments that translate to economic and financial impacts at the sector and regional levels. The model specialises in capturing economic and financial interlinkages and feedback loops. For example, less demand for a country's fossil fuel exports will be felt far beyond the fossil fuel manufacturing companies themselves. Effects will reverberate in areas such as employment, government revenues and all the sectors related to the fossil fuel industry. The tool is therefore able to more accurately reflect climate-related economic risks and opportunities in their totality in a given market compared to an approach that is based on the aggregation of the risks faced by individual companies or assets.

Another important attribute of the ClimateMAPS tool is the use of empirically-based climate and financial modelling to best reflect how the real world works in practice:

- **Assumption about market efficiency:** The macro model does not assume perfectly efficient markets and is able to capture the dynamics of loans and investments.
- **Empirically based:** The financial model is based on more than 100 years of econometric data.
- **Incorporation of latest climate science research and modelling:** The model is rooted in strong climate science using the latest literature. An example is the relationship between temperature rise and economic, agricultural and industrial productivity. The model also takes into account the 'latitude effect' when modelling physical risks. The latitude effects show that the Earth's poles are prone to relatively faster warming. Finally, the tool makes use of a proprietary algorithm, ClimatePREDICT, that intelligently scales extreme weather events and associated financial impacts in line with warming and urbanisation trends.

As is the case with all models, ClimateMAPS has its limitations: There are some specific areas that require further research including, for example, land-use emissions, the impact of scarcity on inflation, impacts of migration and social conflict, biodiversity loss and climate tipping points.

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