Swiss Re Institute

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The economics of climate change: no action not an option

Executive summary

The world economy could be 10% smaller if the 2050 net-zero emissions and Paris Agreement targets on climate change are not met.

The world stands to lose close to 10% of total economic value by mid-century if climate change stays on the currently-anticipated trajectory, and the Paris Agreement and 2050 net-zero emissions targets are not met. Many emerging markets have most to gain if the world is able to rein in temperature gains. For example, action today to get back to the Paris temperature rise scenario would mean economies in southeast Asia could prevent around a quarter of the gross domestic product (GDP) loss by mid-century that they may otherwise suffer. Our analysis in this report is unique in explicitly simulating for the many uncertainties around the impacts of climate change. It shows that those economies most vulnerable to the potential physical risks of climate change stand to benefit most from keeping temperature rises in check. This includes some of the world's most dynamic emerging economies, the engines of global growth in the years to come. The message from the analysis is clear: no action on climate change is not an option.

Under the current trajectory, global GDP could be 11–14% less by mid-century than in a world without climate change. The loss under Paris Agreement targets would be significantly less (around 4%).

Recent scientific research indicates that current likely temperature-rise trajectories, supported by implementation of mitigation pledges, would entail 2.0–2.6°C global warming by mid-century. We use this as the baseline to simulate the impact of rising temperatures over time, while also modelling for the uncertainties around most severe possible physical outcomes. The result is that global GDP would be 11–14% less than in a world without climate change (ie, 0°C change). Under the same no climate change comparative, the Paris target too result in negative GDP impact, but less much so (–4.2%). We also consider a severe scenario in which temperatures rise by 3.2°C by mid-century, with society doing nothing to combat climate change. In this scenario, the global economy would be 18% smaller than in a world without warming, reinforcing the imperative of, if anything, more action on climate change.

Economies in south and southeast Asia are the most vulnerable to climate change effects; advanced economies in the northern hemisphere least so.

In terms of exposure to severe weather risks resulting from climate change, south east Asia and Latin America will likely be most susceptible to dry conditions. Many countries in north and eastern Europe, meanwhile, are set to see more excess precipitation and flood events. Combining these observations with our GDP-impact analysis, our Climate Economics Index indicates that many advanced economies in the northern hemisphere are least vulnerable to the overall effects of climate change, being both less exposed to the associated risks and better resourced to cope. The US, Canada and Germany are among the top 10 least vulnerable. Of the major economies, China ranks lower, in part due to lesser adaptive capacity in place today relative to peers. However, with rising investment in green energy and increasing awareness of climate risks, we believe China is on course for rapid catch-up here.

Climate change also poses transition risks: Asia may be most impacted.

In addition to physical, climate change also gives rise to transition risks. These can show in large shifts in asset values and higher cost of doing business as the world moves to a low-carbon economy. As a separate exercise, we use carbon-tax scenario analysis as a proxy to gauge the associated financial and economic impacts. We find that earnings in the utilities, materials and energy sectors would be the most impacted and lose between 40–80% of earnings per share by immediate imposition of a global carbon tax of USD 100 per metric ton. By region, revenue-weighted earnings would fall by about a fifth in Asia Pacific, and by 15% in the Americas and Europe. The scale of loss depends on the speed at which carbon taxes and mitigation actions are implemented, and the pace of technological adoption.

More than what is being pledged today is needed to achieve the Paris agreement. International convergence on data, standards, metrics and disclosure of roadmaps towards "net zero" are key.

Climate risk is a systemic risk, one that can be managed with coordinated global policy action. There exists a unique opportunity to green our economies. The public and private sectors, including insurers as providers of risk transfer capacity, risk knowledge and long-term investment, can facilitate transition to a low-carbon economy. Increasing transparency, data and disclosure to price and transfer risks is needed. To this end we should see more policy action on carbon pricing coupled with incentivising nature based and carbon-offsetting solutions. International convergence on the taxonomy on counts for green and sustainable investments is also needed. As part of corporate reporting, institutions should also disclose their roadmaps on how they intend to reach the Paris and 2050 net-zero targets.

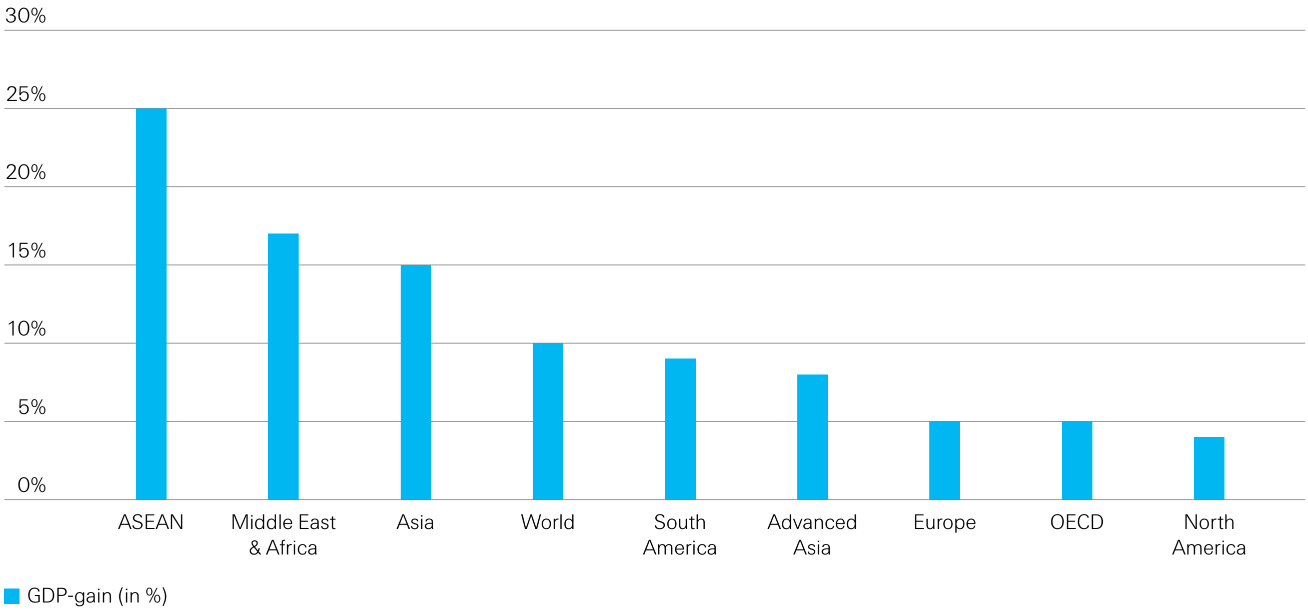
Key takeaways

Global temperature rises will negatively impact GDP in all regions by mid-century. The current trajectory of temperature increases, assuming action with respect to climate change mitigation pledges, points to global warming of 2.0–2.6°C by mid-century. The loss in global economic value in this scenario could be up to 10% higher than if the Paris Agreement of much less than 2°C rise in temperatures is reached. Economies in southeast Asia (ASEAN) countries would be hardest hit. In a severe scenario of a 3.2°C-rise in temperatures, the global GDP loss could be as much as 14% higher than that under the Paris targets.

	Temperature rise scenario, by mid-century			
	Well-below 2°C increase	2.0°C increase	2.6°C increase	3.2°C increase
	Paris target	*The likely range of global temperature gains*		*Severe case*
Simulating for economic loss impacts from rising temperatures in % GDP, relative to a world without climate change (0°C)				
World	–4.2%	–11.0%	–13.9%	–18.1%
OECD	–3.1%	–7.6%	–8.1%	–10.6%
North America	–3.1%	–6.9%	–7.4%	–9.5%
South America	–4.1%	–10.8%	–13.0%	–17.0%
Europe	–2.8%	–7.7%	–8.0%	–10.5%
Middle East & Africa	–4.7%	–14.0%	–21.5%	–27.6%
Asia	–5.5%	–14.9%	–20.4%	–26.5%
Advanced Asia	–3.3%	–9.5%	–11.7%	–15.4%
ASEAN	–4.2%	–17.0%	–29.0%	–37.4%
Oceania	–4.3%	–11.2%	–12.3%	–16.3%

Note: Temperature increases are from pre-industrial times to mid-century, and relate to increasing emissions and/or increasing climate sensitivity (reaction of temperatures to emissions) from left to right.
Source: Swiss Re Institute

Achieving the Paris Agreement temperature target is the most-desirable outcome. Compared to 2.6°C warming, if the Paris Agreement target of well below 2°C warming is met, up to 10% of anticipated mid-century global GDP loss could be prevented. As the figure below shows, in more exposed regions, the benefit in terms of mitigated or prevented GDP-loss by mid century if the Paris Agreement target is met as opposed to a 2.6°C rise in temperatures, could be as much as 25%. Many emerging markets would benefit most, with Indonesia, Thailand and Saudi Arabia among the biggest relative winners.



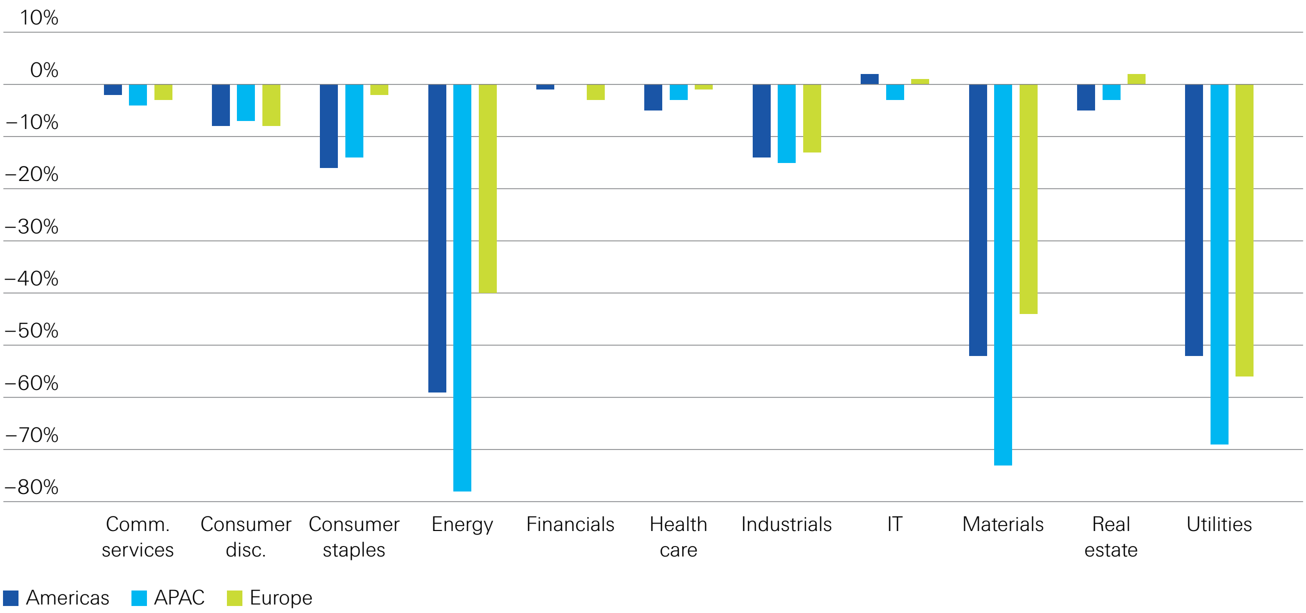
Note: Here, we simulate for severe economic impacts/uncertainties from climate change. The figures shown represent the difference of the 2.6°C scenario and the Paris scenario, as % of GDP in a world without climate change.
Source: Swiss Re Institute

Top- and bottom-five Climate Economics Index rankings. Economies in south and southeast Asia are particularly vulnerable to adverse effects of climate change, and advanced economies in the northern hemisphere least so. In simple ranking terms, our index considers the GDP impact of the physical risks emanating from gradual climate change over time, and vulnerability to extreme weather risks (wet and dry conditions). The index also factors in countries' existing levels of adaptive capacity.

Rank	Country	Physical risk rankings			Current adaptive capability rankings**	Climate Economics Index
		GDP impact	Extreme weather risk*			
			Dry	Wet		
1	Finland	3	8	32	8	11.3
2	Switzerland	4	12	37	2	11.6
3	Austria	7	15	41	6	15.1
4	Portugal	9	21	30	10	15.9
5	Canada	12	18	20	16	16.0
...						
44	Thailand	45	43	11	39	36.0
45	India	42	37	13	46	36.4
46	Philippines	46	48	5	43	37.3
47	Malaysia	48	47	23	33	38.3
48	Indonesia	44	45	19	44	39.2

*Extreme weather risk is proxied by Swiss Re Institute's climate risk scores that reflect individual country potential exposures to extreme dry and wet weather conditions/events on account of changes to the climate. **The adaptive capacity ranking are based on the Climate Change Adaptive Capacity Index from Verisk Maplecroft. Our sample analysis covers 48 countries accounting for 90% of global GDP in 2019.
Source: Verisk Maplecroft, Swiss Re Institute

Transition risk. Imposition of a global carbon tax of USD 100 per metric ton would impact the energy, materials and utilities sectors most. By region, revenue-weighted earnings would fall by a fifth in Asia Pacific, and by 15% in the Americas and Europe.



Source: Blackrock *Carbon Tax Impact Model*, Swiss Re Institute

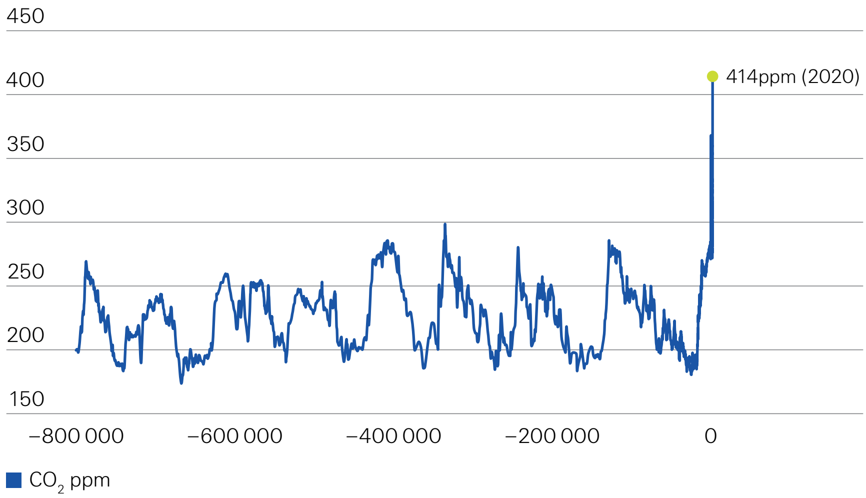
Climate change: economic risks and uncertainties

It's happening

Rising concentrations of greenhouse gases lead to climate change.

Climate change manifests in the trend of rising global temperatures and more extreme weather events. Since the industrial revolution, human activity has continuously driven up greenhouse gas (GHG) emissions, changing the temperature and variables such as precipitation, wind and cloud. In 2020, the concentration of carbon dioxide (CO_2) in the atmosphere reached more than 414 parts per million.

Figure 1
Atmospheric concentration of CO_2 over past 800 000 years (parts/million, ppm)



Source: National Oceanic and Atmospheric Administration (NOAA), Swiss Re Institute

The IPCC's Representative Concentration Pathways plot different trajectories of GHG concentations, and have associated ranges of global temperature rise.

To project GHG emissions and atmospheric concentrations, in its *Fifth Assessment Report* (AR 5) in 2014, the Intergovernmental Panel on Climate Change (IPCC) defined a range of "Representative Concentration Pathway" (RCP) scenarios (see Table 1). Under the RCP 2.6 pathway, actions to mitigate climate change would restrict average global temperature rise to below 2°C by 2100 from pre-industrial times. In the severe "business-as-usual" RCP 8.5 scenario, in which no efforts to cut GHG emissions are made, global temperatures rise by more than 4°C by 2100.

Table 1
Representative Concentration Pathway scenario descriptions

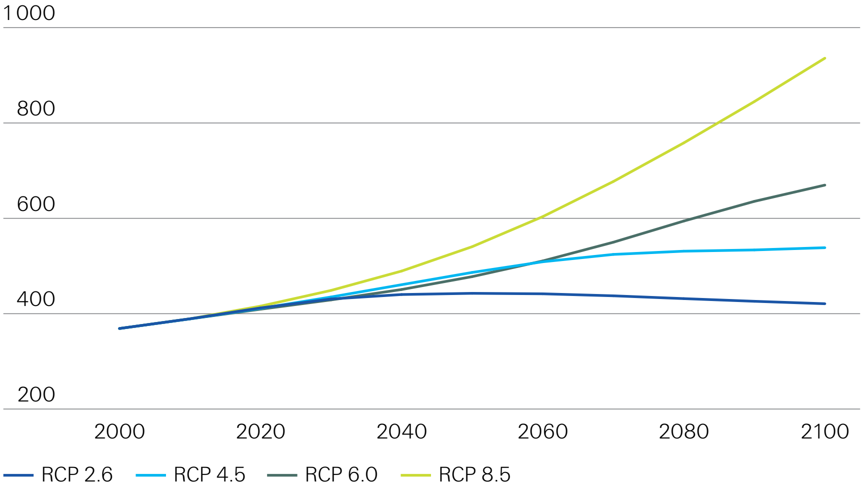
Pathway	Scenario description
RCP 2.6	Under RCP 2.6, carbon concentration delivers radiative forces at an average of 2.6 watts per square meter (W/m2). According to the IPCC, under "a very stringent" RCP 2.6 pathway, average global temperature rise will remain below 2°C by 2100. This is the Paris Agreement's long-term target, alongside an "aspirational" goal of a limit of a 1.5°C increase.
RCP 4.5	The IPCC says RCP 4.5 is an intermediate scenario. Emissions in the atmosphere peak at around 2040 and then decline. Under the RCP 4.5 pathway, global temperatures will rise by between 1.7–3.2°C by 2100. For mid-century (2046–2065) this means a likely range of 1.5–2.6°C warming.
RCP 6.0	In RCP 6.0, emissions peak around 2080 and then decline. In this scenario, global temperatures will rise by between 2.0–3.7°C between the years 2081–2100 from pre-industrial times.
RCP 8.5	This pathway assumes no action is taken to reduce GHG emissions. In this scenario, according to the IPCC, global temperatures will rise by between 3.2–5.4°C between the years 2081–2100 from pre-industrial times. For mid-cenury, the likely range is 2.0–3.2°C warming. Our severe scenario assumes the higher end of 3.2°C warming by mid-century.

Source: IPCC, Swiss Re Institute

More recent models suggest climate sensitivity to GHG emissions may be higher than that presented in the RCPs.

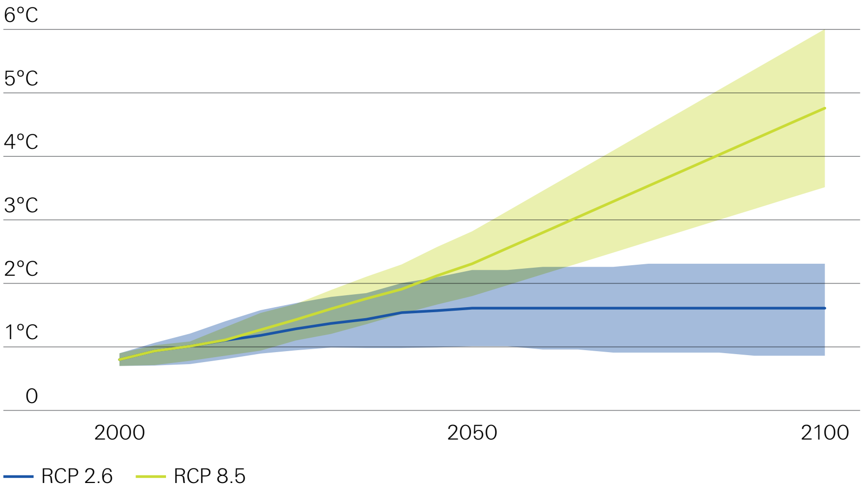
Figure 2 shows the CO_2 concentration path of the different RCP scenarios over time. Figure 3 shows the path of the RCP 2.6 and 8.5 scenarios, and the predicted likely ranges (in other words, the uncertainties) of associated temperature warming for each towards the end of this century. While these charts represent the IPCC's *AR5* report, newer climate models show that the climate sensitivity to CO_2 concentrations is higher. This means that the likely temperature warming to a given level of carbon concentration could be even higher than shown below.

Figure 2
RCP trajectories for CO_2 concentrations (ppm) between 2000-2100



Source: IPCC *AR5*, Swiss Re Institute

Figure 3
Projected temperature warming ranges (uncertainty) associated with RCP 2.6 and 8.5 scenarios



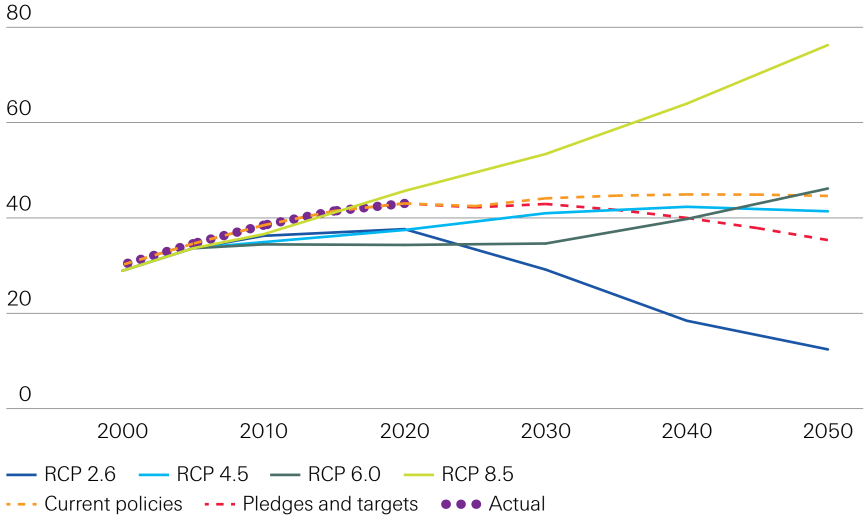
Note: The shaded areas depict the projected likely temperature range; the solid line represents the average
Source: IPCC *AR5*

Readings suggest there has been some slowing of GHG emissions in recent years, reflecting mitigation efforts.

Figure 4 shows the historic actual path of annual emissions against the IPCC scenarios. Post 2000, emissions tracked what would be expected in the RCP 8.5 scenario for a number of years. Annual readings in more recent years suggest slowing, reflecting some of the mitigation efforts that have since been implemented. Estimates indicate that from 2019, annual emissions will rise by 4% under existing mitigation policy measures. If today's pledges and targets are fully achieved, annual emissions would decline by 18% by mid-century.[1] Both outcomes follow the range of projections for the RCP 4.5 scenario. The associated and currently projected trajectory for temperature rise is 2–0–2.6°C by mid-century. We use this as the baseline temperature-rise scenario for comparison in our report.

[1] Mid-range estimates of annual carbon-equivalent GHG emissions based on *Climate Action Tracker* data.

Figure 4
Annual carbon emissions (in gigatons) according to IPCC RCP, compared to historical and alternative paths based on policies and pledges



Note: We use Climate Action Tracker data, averages of the 'high' and 'low' paths of CO_2-equivalents to approximate CO_2 emissions paths starting from the last historic observation in 2019.
Source: IPCC *AR5*, Statista, Climate Action Tracker

Climate change impacts economies through associated physical and transition risks.

Climate change impacts economies systemically through *physical* and *transition* risks. Among others, physical risks include property damage, disruption to trade due to climate shocks (eg, severe weather events such as storms, floods and droughts), and lost productivity due to rising average temperatures. Transition risks result from the adjustment to a low-carbon economy, like changes to how society deploys resources, uses technology and rolls out regulation.[2] These prompt reassessment of asset values, generate "stranded" assets such as fossil fuel deposits or coal reserves, and bring systemic devaluation risk to the world financial industry.

There are three traditional model types to assess the relationship between climate change and economic loss.

Approaches to assess economic damage resulting from climate change typically fall into one of three categories: (1) Integrated Assessment Models (IAMs) were the first to explore the relationship, and formed the basis of the IPCC's 2014 risk assessment;[3] (2) newer-panel data models, which seek to address shortcomings in IAMs (see the appendix 1 for more detail of different model approaches and associated implications); and (3) bottom-up, case-study based analysis showing more activity at risk from climate change than either IAMs or panel data methods. The Stern Review from 2006 was one of the first study to comprehensively review the impact from climate change on several growth and development channels.[4]

The Stern Review estimated that unmitigated climate change would lead to global per-capita economic loss of up to 13.8% by 2200...

The Stern Review
This review analysed a number of impact channels from climate change, including water distribution, crop yields, food insecurity, health impacts from malnutrition, heat stress and vector-borne diseases. It used an IAM to quantify aggregate impact and concluded that, depending on the scale of climate-system feedback loops, and including non-market damages, global warming would lead to estimated average losses of between 5.3% and 13.8% of world per-capita GDP in 2200.

...a threat to "the basic elements of life."

The report stated that "climate change threatens the basic elements of life for people around the world". It said the risk of the worst impacts of climate change could be reduced substantially if GHG levels in the atmosphere could be stabilised at between 450 and 550ppm CO_2 equivalent. Estimates of the annual cost of achieving stabilisation between 500 and 550ppm CO_2 equivalent were around 1% of global GDP, with immediate strong action. Any delay would be dangerous and more costly.

[2] As such, transition risks also affect productivity; it's less clear in which direction on a net basis.
[3] *Assessment Report 5 (AR5)*, IPCC, 2014.
[4] N Stern, *The Economics of Climate Change- The Stern Review*, 30 October 2006.

Challenges: accounting for uncertainties

Climate modelling is an exercise involving many uncertainties, and tail outcomes matter.

There are many uncertainties in modelling the outcomes – economic and other – of climate change. This is because of the complexities of biophysical science parameters and their distributions, and how these might change. Much climate change analysis focuses on the expected averages of GHG concentration and temperature changes, but the distribution around these estimates is very wide.

Assessing the physical risks, and related uncertainties

We undertake complementary scenario analyses of the physical risks that economies face due to climate change.

Models of the economic impact of climate change typically deal with average expected GDP losses. Besides negative feedback loops and other effects, the models tend not to account for high-impact disasters, such as drought and severe precipitation, which can significantly alter the degree of GDP loss. In this report, we further existing research to capture and assess the economic impact of this broader scale of physical risks and uncertainties. On the physical risks front, we do this through a novel and complementary three-step approach (see Figure 5):

1) First, through scenario analysis, we simulate the economic outcomes of the physical risks associated with ongoing and gradual climate change over time. These are known as the *chronic* physical risks associated with climate change. Our scenario analysis builds on existing research by also factoring in impact variables not included in previous investigations, such as the impact of supply chain disruptions and migration. Our adjustments to previous research findings target more inclusive quantification of all potential physical impacts that an ongoing and gradual rise in global temperatures can inflict.

2) As a second step, we assess the exposure of countries, based on their geographical location, to the physical risks of ongoing and gradual climate change, and also to severe weather events that could result from the more intense "wet" and "dry" climate conditions that global temperature rise could deliver. These are the *acute* physical risks associated with climate change.

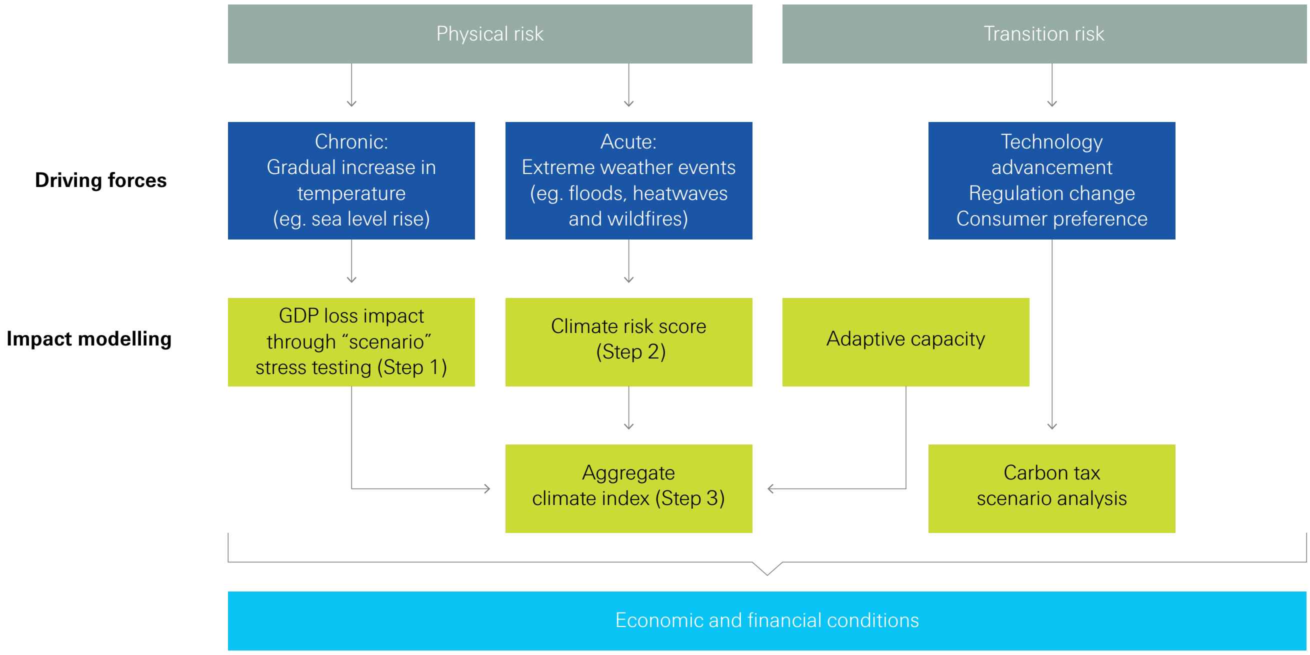
3) In step 3, we build our Climate Economics Index, a combination of the chronic and acute physical risk exposures coupled with a measure of countries' existing levels of adaptive capacity to cope with climate change effects. The index ranks economies according to overall vulnerability to climate change risks.

Assessing transition risks through carbon-tax scenario analysis

Using imposition of a carbon tax as a proxy, we also assess the economic transition risks of climate change.

As a separate exercise (see Figure 5), we assess the transition risks associated with climate change through carbon-tax scenario analysis, a proxy to gauge the financial and economic impacts of the imposition of such a tax across industries and regions. The degree of risk (and associated uncertainties) depends on the choices adopted by policymakers and their timing, and the pace and breadth of technological advancements.

Figure 5
Our approach to assessing the economic impact of the physical and transition risks associated with climate change



Source: Swiss Re Institute

Assessing the economic impacts of climate change

Economic impact scenarios of physical (chronic) climate change risks

The world will be significantly less well off if Paris Agreement and net zero emission targets are not met.

Our analysis highlights the risk of complacency: the global economy could be impacted by an additional 10% loss in GDP by mid-century under the baseline 2–2.6°C temperature-rise scenario compared to if the Paris Agreement and net-zero emissions targets are achieved. By getting back to the Paris Agreement target, countries in southeast Asia would benefit most – by saving around a quarter of GDP-loss. These are the findings of our scenario analysis, which simulates for many uncertainties – (un)known unknowns – that other research does not consider.

Our scenario analysis assesses the economc impact of chronic climate change risks and associated uncertainties.

As a starting point, we work with the findings of an existing model from Moody's Analytics that quantifies the gradual effects of climate change over time based on six chronic risk "impact channels".[5] These impact channels, quantified in the work of Roson and Sartori, are the effect of rising temperatures on agricultural productivity (eg, more droughts); on human health (morbidity and mortality); on labour productivity (heat stress); on sea level rise and the increased risk of flooding of areas of economic activity; on tourism flows; and on household demand for energy.[6]

We simulate for 2.6°C and 3.2°C rises in global temperatures by mid-century.

Step 1: scenario analysis set-up
Using the values from the Moody's Analytics model as a starting point, we extend the analysis by making the following adjustments:

- **we simulate for a 2.6°C temperature increase by mid-century.** That approximates to the expected range of temperature rise from pre-industrial times that will have occurred by mid-century.[7]
- **we also simulate a severe scenario of a 3.2°C temperature increase by mid-century,** to profile the increased scale of impact that greater warming could have on GDP outcomes. A 3.2°C rise by 2050 is the ceiling of the range of likely outcomes under the RCP 8.5 scenario (see Figure 6).
- **we simulate for uncertainty factors** around expected economic outcomes. First, we approximate the effect of economic impact channels not covered by the six chronic risks in the Moody's Analytics model. Omitted channels include but are not limited to, for example, disruption to global supply chains and trade, migration and biodiversity.[8] Then, we acknowledge the potential for tail risk parameter uncertainty which we call *(un)known unknowns*.[9] To represent increasing severity of potential outcomes from these (un)known unknowns, we simulate two scenarios by applying multiplicative factors of x5 (for moderate) and x10 (severe outcomes) to the accumulated economic impact from the quantified and proxied physical risk channels.

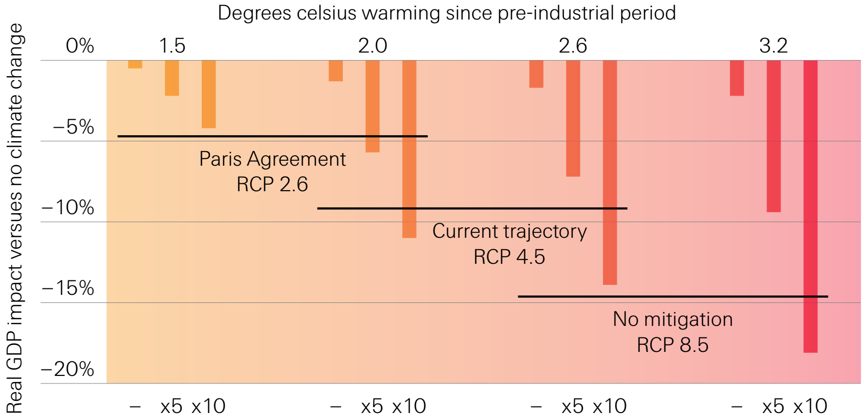
For a full explanation of our methodology, please see Appendix 2.

In a severe scenario of a 3.2°C rise in temperatures, global GDP could be 18% less in 2048 than in a no-climate change world.

Outcome: there are no winners
Our analysis indicates that significant economic damage will occur, even with fulfilment of pledges and targets on climate change. The associated and baseline temperature-rise scenario by mid-century (2°C to 2.6°C and x10 multiplicative for (un)known unknowns), shows a loss of global economic output relative to a world without climate change of 11% and 14%, respectively. The regional discrepancies are large, and a clear north-south divide emerges. However, no country is immune to climate change. In a more extreme scenario, one of unmitigated climate change and above-average 3.2°C warming, losses could amount up to 18% by mid-century.

5 *The Economic Implications of Climate Change,* Moody's Analytics, 2019.
6 R. Roson and M. Sartori, "Estimation of Climate Change Damage Functions for 140 Regions in the GTAP9 Database", *World Bank Group Policy Research Working Paper 7728*, June 2016.
7 *AR5*, IPCC, 2014, op. cit.
8 For more on biodiversity impacts, see *Biodiversity and ecosystems services; a business case for insurance*, Swiss Re Institute, September 2020.
9 As can be seen from the primary research by Roson and Sartori, it is not possible to estimate non-linear relationships between temperature increases and economic activity for all channels, especially for temperature increases that have not been observed yet.

Figure 6
Overview of climate change impacts on world real GDP by mid-century



Note: – refers to no simulated parameter uncertainty. x5 and x10 represent the increasing severity of potential outcomes from (un)known unknowns.
Source: IPCC *AR5*, Swiss Re Institute

If the Paris Agreement target is met, the economic loss would be much less.

Both outcomes can be contrasted with the result that the Paris Agreement target would achieve. Under otherwise similar assumptions for the (un)known unknowns but with restricting temperature rises to well below 2°C, global GDP would be 4.2% lower than in a no-climate change world. Note, however, if temperature gains are restricted to well below 2°C, the likelihood of severely negative feedback loops is much reduced. Assuming no adverse (un)known unknown outcomes in the Paris Agreement scenario, global GDP would be just 0.5% lower.

In our severe scenario, some countries in southeast Asia stand to lose 50% of their GDP by 2048.

In the baseline 2–2.6°C temperature-rise scenario, emerging economies in hot regions and oil producers would be most affected by rising temperatures over time.[10] At higher severity of (un)known unknown physical outcomes (x10 factor), the greatest negative impact shifts from oil producers to emerging Asia. This would result from the growing adverse impacts such as reductions in labour and agricultural productivity. Malaysia, Thailand and the Philippines would lose 33–36% of GDP by 2048. Should the more severe 3.2°C temperature scenario play out, the potential output loss of most affected countries could increase up to 45% of GDP.

In the baseline scenario,the world's major economies would contract too, by as much as 6% or more.

Of the world's major economies, the US, Canada and the UK would lose around 6–7% of GDP by mid-century in the baseline scenario with x10 factor for (un)known knowns (and up to 9% in the 3.2°C temperature-rise scenario). The euro area would suffer slightly more (8%), with economies like Germany less exposed than southern peers (eg, Italy). China would fare worse and could see 15–18% lower GDP levels under the baseline scenario.

Countries in eastern and northern Europe would be least impacted.

In relative terms, a few countries would fare better. Our analysis indicates that countries in eastern Europe and Scandinavia (eg, Denmark and Finland) are less sensitive to rising temperatures, with GDP losses ranging from 1% to 4% in the baseline temperature-rise scenario with 10x factor relative to a no-climate change world. One factor could be that higher tourism income flows to those countries offset other adverse impacts.[11]

With a 2.6°C rise in termperatures, the most impacted countries could lose five years' worth of today's economic output.

When we add the increasing annual GDP shortfalls up until mid-century of all the 48 sample countries in our analysis, the 10% most affected nations will have lost five years' worth of today's economic output with a 2.6°C rise in temperatures. Among those, vulnerable ASEAN countries would be the worst-hit, with an average 29% lower output around mid-century. This implies these countries losing economic output totalling more than seven times their 2019 GDP by 2050.

[10] Higher temperatures will lead to lower energy demand for heating purposes and on aggregate drive down oil prices.
[11] Future global tourism revenues will depend on the overall economic impact from climate change and its distribution. The more extreme the impact, the more tourism will likely shrink.

Table 2
Mid-century GDP changes with different temperature rises and economic impact severity, relative to a no-climate change world

Temperature path	Well below 2°C increase			2.0°C increase			2.6°C increase			3.2°C increase		
	Paris target			*The likely range of global temperature gains*						*Severe case*		
Omitted channels	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(Un)known unknowns	✗	✓x5	✓x10	✗	✓x5	✓x10	✗	✓x5	✓x10	✗	✓x5	✓x10
World	−0.5%	−2.2%	−4.2%	−1.3%	−5.7%	−11.0%	−1.7%	−7.2%	−13.9%	−2.2%	−9.4%	−18.1%
OECD	−0.4%	−1.6%	−3.1%	−0.8%	−3.9%	−7.6%	−0.9%	−4.1%	−8.1%	−1.1%	−5.4%	−10.6%
North America	−0.5%	−1.7%	−3.1%	−0.9%	−3.7%	−6.9%	−1.0%	−4.0%	−7.4%	−1.2%	−5.1%	−9.5%
South America	−0.4%	−2.0%	−4.1%	−1.1%	−5.5%	−10.8%	−1.4%	−6.6%	−13.0%	−1.8%	−8.6%	−17.0%
Europe	−0.2%	−1.4%	−2.8%	−0.7%	−3.8%	−7.7%	−0.8%	−4.0%	−8.0%	−1.0%	−5.2%	−10.5%
Middle East & Africa	−0.7%	−2.5%	−4.7%	−2.4%	−7.6%	−14.0%	−4.6%	−12.1%	−21.5%	−5.2%	−15.0%	−27.6%
Asia	−0.7%	−2.8%	−5.5%	−1.7%	−7.7%	−14.9%	−2.4%	−10.5%	−20.4%	−3.0%	−13.7%	−26.5%
Advanced Asia	−0.4%	−1.7%	−3.3%	−1.1%	−4.8%	−9.5%	−1.3%	−5.9%	−11.7%	−1.7%	−7.7%	−15.4%
ASEAN	−0.8%	−2.3%	−4.2%	−2.4%	−9.0%	−17.0%	−4.1%	−15.4%	−29.0%	−5.0%	−19.7%	−37.4%
Oceania	−0.5%	−2.2%	−4.3%	−1.3%	−5.8%	−11.2%	−1.7%	−6.5%	−12.3%	−2.0%	−8.3%	−16.3%
Argentina	−0.4%	−1.6%	−3.1%	−0.8%	−3.9%	−7.7%	−0.9%	−4.3%	−8.6%	−1.2%	−5.7%	−11.3%
Australia	−0.5%	−2.2%	−4.4%	−1.4%	−5.8%	−11.3%	−1.7%	−6.6%	−12.5%	−2.1%	−8.4%	−16.5%
Austria	0.1%	−0.8%	−2.0%	0.0%	−2.6%	−5.9%	0.4%	−2.3%	−5.7%	0.2%	−3.3%	−7.9%
Belgium	−0.1%	−1.2%	−2.5%	−0.4%	−3.0%	−6.4%	−0.2%	−2.9%	−6.3%	−0.4%	−4.0%	−8.5%
Brazil	−0.4%	−1.9%	−3.7%	−1.0%	−5.1%	−10.3%	−1.2%	−6.3%	−12.8%	−1.6%	−8.4%	−16.8%
Canada	−0.3%	−1.4%	−2.8%	−0.7%	−3.4%	−6.8%	−0.6%	−3.5%	−6.9%	−0.9%	−4.6%	−8.9%
Chile	−0.9%	−4.1%	−8.0%	−2.1%	−9.9%	−19.2%	−2.3%	−10.8%	−21.0%	−3.0%	−14.1%	−27.0%
China	−0.7%	−3.3%	−6.6%	−1.6%	−7.7%	−15.1%	−1.9%	−9.2%	−18.1%	−2.5%	−12.1%	−23.5%
Colombia	−0.6%	−2.5%	−4.8%	−1.7%	−7.4%	−14.2%	−2.1%	−8.8%	−16.7%	−2.7%	−11.4%	−21.7%
Czech Republic	−0.1%	−1.3%	−2.9%	−0.5%	−4.0%	−8.5%	−0.3%	−3.8%	−8.3%	−0.5%	−5.2%	−11.1%
Denmark	0.1%	−0.3%	−0.8%	0.0%	−1.4%	−3.1%	0.3%	−1.1%	−2.8%	0.2%	−1.6%	−3.9%
Egypt	−0.8%	−2.0%	−3.5%	−1.3%	−4.3%	−7.9%	−1.6%	−5.2%	−9.6%	−1.9%	−6.7%	−12.4%
Finland	−0.1%	−0.7%	−1.4%	−0.2%	−2.1%	−4.4%	0.0%	−1.8%	−4.1%	−0.1%	−2.5%	−5.5%
France	−0.3%	−1.7%	−3.5%	−0.9%	−4.9%	−9.9%	−0.9%	−4.9%	−10.0%	−1.2%	−6.5%	−13.1%
Germany	−0.3%	−1.6%	−3.3%	−0.7%	−4.0%	−8.1%	−0.6%	−4.0%	−8.3%	−0.9%	−5.4%	−11.1%
Greece	−0.5%	−1.7%	−3.2%	−1.3%	−4.9%	−9.3%	−1.6%	−5.4%	−10.1%	−1.9%	−6.8%	−13.1%
Hong Kong	−2.6%	−3.0%	−3.8%	−3.9%	−6.4%	−10.1%	−5.9%	−10.3%	−16.3%	−6.3%	−12.0%	−21.2%
Hungary	−0.2%	−1.5%	−3.0%	−0.7%	−4.2%	−8.5%	−0.6%	−4.1%	−8.6%	−0.9%	−5.5%	−11.4%
India	−0.8%	−3.0%	−5.7%	−2.0%	−8.9%	−17.4%	−3.2%	−13.9%	−27.0%	−4.0%	−18.0%	−35.1%
Indonesia	−0.6%	−2.1%	−4.0%	−2.0%	−8.5%	−16.7%	−3.4%	−15.4%	−30.2%	−4.4%	−20.0%	−39.5%
Italy	−0.5%	−2.3%	−4.5%	−1.2%	−5.6%	−11.0%	−1.3%	−5.9%	−11.4%	−1.7%	−7.7%	−14.8%
Japan	−0.3%	−1.6%	−3.2%	−0.8%	−4.2%	−8.4%	−0.8%	−4.5%	−9.1%	−1.1%	−6.0%	−12.0%
Malaysia	−1.2%	−2.8%	−4.8%	−4.0%	−12.3%	−22.3%	−6.8%	−20.1%	−36.3%	−7.8%	−25.2%	−46.2%
Mexico	−0.5%	−1.9%	−3.6%	−1.1%	−4.4%	−8.5%	−1.4%	−5.2%	−9.8%	−1.7%	−6.7%	−12.6%
Netherlands	−0.1%	−0.8%	−1.8%	−0.3%	−2.4%	−5.2%	−0.1%	−2.3%	−5.1%	−0.3%	−3.2%	−7.0%
New Zealand	−0.4%	−1.9%	−3.7%	−1.0%	−4.9%	−9.7%	−1.1%	−5.2%	−10.4%	−1.4%	−6.9%	−13.6%
Norway	0.1%	−0.8%	−1.9%	−0.2%	−2.4%	−5.2%	−0.4%	−2.6%	−5.4%	−0.5%	−3.5%	−7.3%
Peru	−0.5%	−2.5%	−5.1%	−1.0%	−5.1%	−10.0%	−1.1%	−5.7%	−11.3%	−1.4%	−6.9%	−13.7%
Philippines	−1.3%	−3.1%	−5.4%	−3.5%	−11.8%	−21.6%	−5.8%	−19.5%	−35.0%	−6.9%	−24.6%	−43.9%
Poland	−0.2%	−1.4%	−3.0%	−0.6%	−3.8%	−7.9%	−0.5%	−3.8%	−7.9%	−0.8%	−5.1%	−10.6%
Portugal	−0.4%	−1.3%	−2.3%	−0.9%	−3.2%	−6.2%	−1.0%	−3.3%	−6.3%	−1.2%	−4.3%	−8.4%
Romania	−0.5%	−1.8%	−3.3%	−1.1%	−4.5%	−8.7%	−1.3%	−4.7%	−8.9%	−1.6%	−6.0%	−11.5%
Russia	−0.2%	−1.5%	−3.2%	−1.3%	−4.7%	−8.9%	−2.3%	−5.8%	−10.1%	−2.6%	−7.2%	−12.8%
Saudi Arabia	−0.9%	−2.9%	−5.3%	−4.8%	−10.7%	−17.8%	−11.6%	−19.4%	−29.2%	−12.2%	−22.5%	−35.5%
Singapore	−1.0%	−2.7%	−4.9%	−2.9%	−10.6%	−20.2%	−5.0%	−18.6%	−35.6%	−6.1%	−23.9%	−46.4%
South Africa	−0.8%	−3.5%	−6.9%	−1.7%	−7.7%	−14.9%	−2.1%	−9.2%	−17.8%	−2.7%	−12.0%	−23.1%
South Korea	−0.2%	−1.3%	−2.7%	−0.8%	−4.2%	−8.5%	−0.8%	−4.7%	−9.7%	−1.1%	−6.3%	−12.8%
Spain	−0.4%	−1.3%	−2.5%	−0.9%	−3.6%	−7.0%	−1.0%	−3.8%	−7.3%	−1.2%	−4.9%	−9.7%
Sweden	0.0%	−1.1%	−2.5%	−0.3%	−3.1%	−6.6%	0.0%	−2.8%	−6.5%	−0.2%	−4.0%	−8.8%
Switzerland	0.0%	−0.6%	−1.4%	−0.1%	−1.9%	−4.2%	0.1%	−1.8%	−4.4%	0.0%	−2.6%	−6.1%
Taiwan	−0.6%	−2.6%	−5.2%	−1.7%	−7.5%	−14.8%	−2.6%	−11.3%	−22.2%	−3.3%	−14.7%	−29.2%
Thailand	−1.2%	−2.9%	−4.9%	−3.0%	−10.4%	−19.5%	−4.9%	−17.8%	−33.7%	−6.0%	−22.9%	−43.6%
Turkey	−0.2%	−1.2%	−2.5%	−0.6%	−3.3%	−6.7%	−0.6%	−3.8%	−7.8%	−0.9%	−5.0%	−10.3%
UAE	−0.9%	−3.0%	−5.5%	−2.1%	−8.5%	−16.6%	−3.3%	−13.3%	−25.8%	−4.1%	−17.3%	−33.7%
UK	−0.1%	−1.1%	−2.4%	−0.5%	−3.2%	−6.6%	−0.3%	−3.1%	−6.5%	−0.6%	−4.2%	−8.7%
Ukraine	0.2%	0.0%	−0.2%	0.0%	−1.5%	−3.7%	0.3%	−1.3%	−3.6%	0.2%	−1.9%	−5.6%
US	−0.5%	−1.7%	−3.1%	−0.9%	−3.6%	−6.8%	−1.0%	−3.9%	−7.2%	−1.2%	−5.0%	−9.2%
Venezuela	−0.3%	−1.4%	−2.7%	−0.9%	−4.6%	−9.2%	−1.2%	−6.3%	−12.4%	−1.6%	−8.2%	−16.2%

Note: Temperature increases are from pre-industrial times to mid-century. Columns labelling indicate specific variable adjustments in our scenario analysis: inclusion of omitted channels (ie, channels that have not been quantified in previous research), and multiplicative factors (x5 and x10) for potentially increased severity of unknown unknowns.
Source: Swiss Re Institute

The economic impacts of climate change will accelerate and accumulate over time...

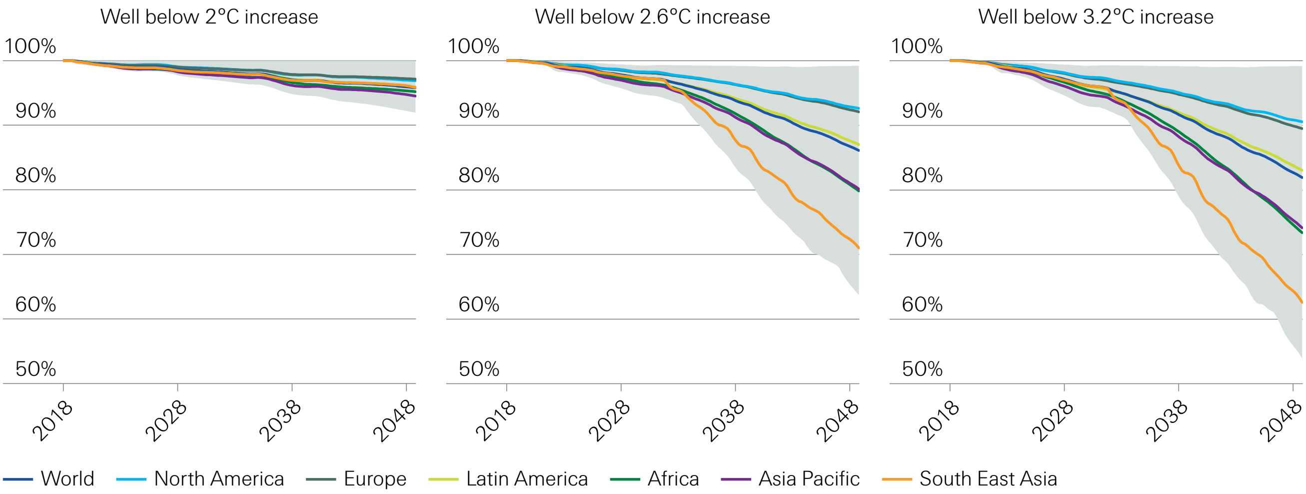
Economic pain will grow over time

In the baseline 2–2.6°C and severe 3.2°C temperature-rise scenarios, with multiplicative factors, the impacts of climate change intensify over time, and very notably relative to the Paris Agreement target. There are two phases. First, countries maintain similar GDP growth rates as in the past. Emerging economies continue to catch up with advanced markets at high speed. With temperatures slowly rising, economic impacts start to become more noticeable, especially in more exposed regions. However, in many economies growth rates are still positive by mid-century.

...with a second phase of slowdown starting from around 2050.

A second phase of slowdown in real GDP would start from around 2050, with the impact in terms of reduced economic growth becoming more pronounced in the second half of the century.[12] With the possibility of tipping points being triggered, such as the melting of ice caps or biosphere collapses, leading to irreversible change in climate systems, the tail risks of catastrophic economic impacts would become even more pronounced towards the end of the century or later. [13] Our scenario analysis data estimates do not extend beyond 2048. However, as directional guide, Figure 7 illustrates how climate change increasingly puts the break on economic growth in the latter half of this century. The dispersion of outcomes for different countries widens as the climate effects get more severe.

Figure 7
Deviations of scenarios versus no-climate change real GDP



Note: Shown scenarios adjust for omitted channels and account for (un)known unknowns of potentially increased severity of economic outcomes of physical risks with the factor 10. Temperature rises are from pre-industrial times to mid-21st century. The grey shaded area represents the dispersion of cross-country results.
Source; Swiss Re Institute

Our scenario analysis simulates for a broader range of impact channels and tail uncertainties than other research.

Our scenario analysis compared with external research

In addition to a climate baseline, our analysis illustrates the potential outcomes from unmitigated climate change. For example, our results show more severe tail risks than in other studies. This is because a key differentiator of our analysis is to adjust for omitted impact channels and (un)known unknowns, which other models typically do not do. This is why we also simulate the severe 3.2°C temperature-rise scenario, based on RCP 8.5, reflecting a high-emissions, no-mitigation world. Our motivation is not to be alarmist, but to profile the severity of potential risks, including of tail exposures, if society does nothing about climate change. For policy response, it is important that both public and private sector stakeholders do not underestimate the full loss potential that climate risks pose.

[12] Even if emissions should freeze in a given year, the climate will still become warmer until it reaches an equilibrium such as indicated by the Equilibrium Climate Sensitivity (ECS).
[13] T.M. Lenton, J. Rockström, et al, "Climate tipping points: too risky to bet against", *Nature*, vol 575, 2019.

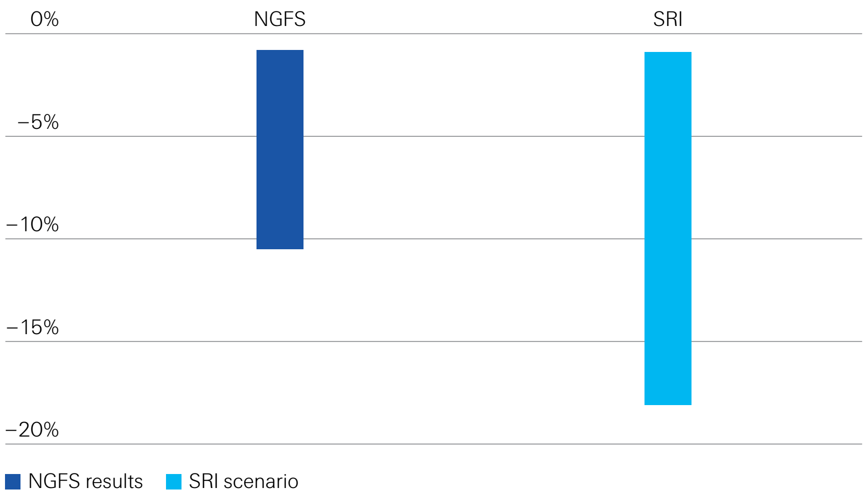
Hence our estimates show a larger range of extreme adverse outcomes.

The unique insights in our model become clearer when we compare our findings with those from other quantitative studies assessing a similar emissions scenario. For example, the Network for Greening the Financial System (NGFS) recently published an overview of relevant studies highlighting the variance of impact estimates.[14] Its "hot-house world" scenario features limited mitigation and significant warming, which corresponds to our unmitigated climate change scenarios. The three employed damage functions show global GDP impacts of up to -10%, by mid-century. In contrast, our estimates show a larger range due to more impact channels and parameter uncertainty/(un)known unknowns being used (see Figure 8).[15]

The comparison of results affirms the challenges in understanding where the economic impacts of climate change lie.

Given the nature of the topic, climate studies come with certain trade-offs. Like most econometric approaches, the NGFS estimates are based on historic data. With rising temperatures, the applicability of impact estimates to previously unobserved levels of sustained warming is limited. Adding missing pieces such as typically omitted channels and adjusting for (un)known unknowns suggests more severe economic impacts. In other words, the comparison between the NGFS results and our estimates confirm today's modelling challenges of where the true economic impact could land should we fail to mitigate climate change.

Figure 8
GDP impact range in a no-policy scenario by mid-century; comparing the NGFS results (including uncertainty bands) with the SRI scenario approach, GDP loss in %



Source: NGFS, Swiss Re Institute

No action is not an option

Climate change will have economic costs even if Paris Agreement goals are met.

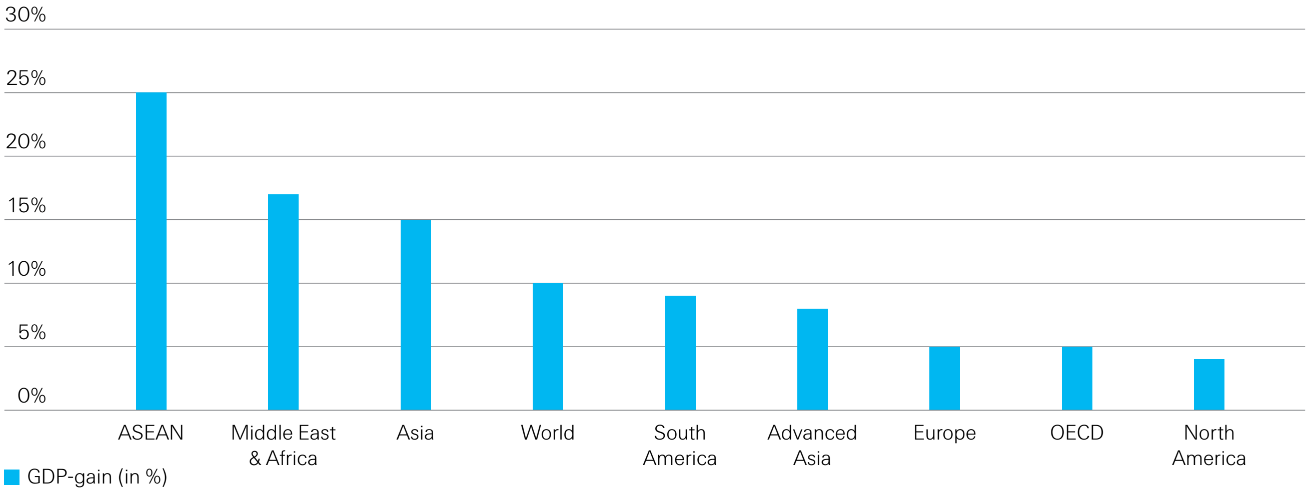
The world cannot afford continually rising and unmitigated GHG emissions. The planet has already warmed by 1°C from the pre-industrial period. Even if the Paris Agreement's goal of limiting global warming to well below 2°C this century is met, the economic costs will be very real. In this scenario, we estimate that global GDP at-mid-century would be up to 4.2% lower than in a no-climate change world.[16]

Complying with Paris targets is the best achievable outcome.

Figure 9 shows the degree of mitigated GDP loss (ie, a relative benefit) if the Paris Agreement target is met. Compared to the baseline scenario (2.6°C increase) with x10 multiplicative factor, under the Paris Agreement with the same multiplicative factor for (un)known unknowns, global economic output could be 10% higher in 2048, and more than 25% higher in more exposed regions. Emerging markets would avoid a large part of the expected economic damages, with Indonesia, Thailand and Saudi Arabia the biggest relative winners.

[14] *NGFS Climate Scenarios for Central Banks and Supervisors*, Network for Greening the Financial System, 2020.
[15] M. Kalkuhl and L. Wenz, "The Impact of Climate Conditions on Economic Production. Evidence from a Global Panel of Regions", *Journal of Environmental Economics and Management*, vol 103, 2020.
[16] Largest producers of fossil fuel CO_2 emissions worldwide in 2018, by share of emissions", *statista.com*, 7 September 2020.

Figure 9
Mitigated GDP loss by 2048 when Paris Agreement target of well below 2°C temperature rise is met, compared to the 2.6°C temperature rise scenario (x10 factor)



Source: Swiss Re Institute

Coordination among the world's largest emitters of carbon will be crucial.

More action to mitigate climate change is an imperative. Long-term tail risks need to be managed through coordinated global action, including investment in green infrastructure. Coordination between the top three carbon emitters (China 28%, US 15%, India 7%), which account for roughly half of all emissions, is crucial. India and China are more at risk from climate change than the US. With no further mitigation action, in a severe scenario India could lose up to 35% of GDP by mid-century.

Assessing country exposures to severe (acute) weather risks

Climate change also leads to acute physical risk exposures.

Our scenario analysis above assesses the GDP impact of different physical chronic climate risk scenarios. As a next step, we assess the potential outcomes of severe weather events (acute) risks by constructing an index of hazard-based climate risk scores, reflecting the relative exposure of different locations to extreme dry and wet conditions in the environment of gradual climate change.[17]

Step 2: Climate Risk Scores (CRS) – index construction

Our climate risk scores reflect country exposures to severe weather events.

- The CRS assesses the hazard risk (ie, the exposure to severe weather events), of geographical locations at different latitudes and longitudes on a scale from zero (lowest) to 10 (highest) risk.[18]
- The CRS combine two sub-scores representing: 1) changes in extreme and mean temperatures (dry scores); and 2) changes to extreme and mean precipitation (wet scores). The two CRS sub-scores are proxies for actual weather-related catastrophes: wildfires, heat waves and droughts (dry score); and river and flash floods (wet score).[19]

[17] Lüthi, S., Gloor, M., and Walz, M., *Climate risk score – a framework to quantify an insurance portfolio's exposure and contribution to climate change*, EGU General Assembly 2020, Online, 4–8 May 2020.
[18] Locations are categorised into altitude-gridded distribution with grid resolution spaces at 1.75 degree (about 195 km at the equator and 125 km at mid latitudes), and then translated to national aggregates.
[19] One cautionary note, the wet score mainly reflects the impact of river and flash flood events resulting from extreme events such as hurricanes and typhoons. Other features of such events like wind damage are not accounted for.

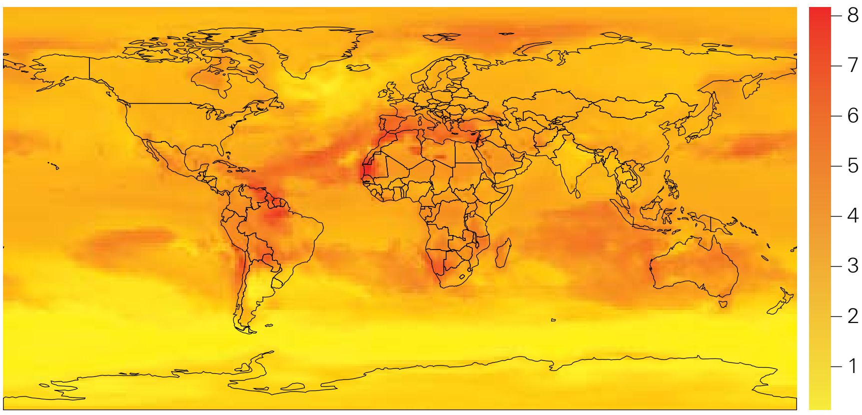
- While our scenario analysis in the previous section considers the impact of rising temperature on an annual basis, the CRS scores measure severe weather events at much higher frequency: monthly or daily temperature and precipitation data. All CRS values are constructed relative to current mean values and transformed to capture extreme volatility in climate variables. [20] Technically, the temperature and precipitation input variables are derived from a large range of models.[21]

CRS increase with emission scenarios and differ greatly for different countries.

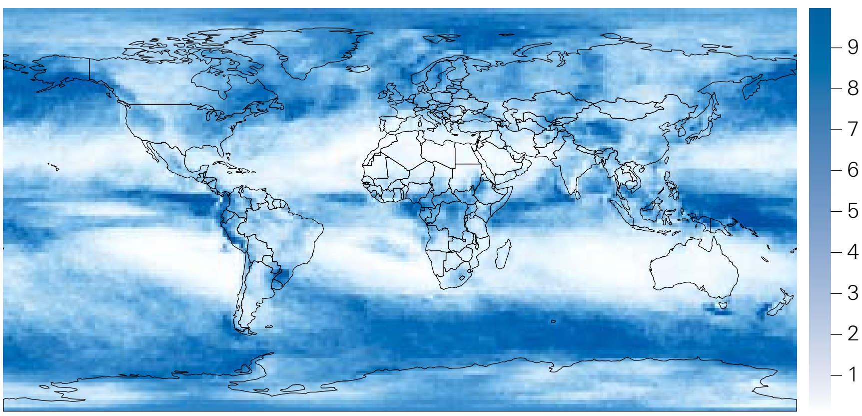
According to CRS values, the risk of severe climate conditions is much higher in the high GHG-emission RCP 8.5 scenario than RCP 2.6 (low emissions). Under RCP 8.5, the world would potentially experience more extreme weather events resulting from both severe dry and wet conditions. As Figure 10 indicates, rising temperatures will likely cause more drought in Southeast Asia and Latin America. A number of northern and eastern European countries, meanwhile, will likely experience more excess precipitation and flooding events. The UK is vulnerable to both severe dry and wet conditions as global temperatures rise over time. For some large countries which span several climates (eg, Russia, Australia, China), the regional disparity also exists given the diverse nature of different locations within each country. For instance, more dry conditions are expected in the southeastern Australia, while the north is expected to get wetter, especially during summer times.

Figure 10
World map of dry and wet Climate Risk Scores, RCP 8.5, year 2050

Dry score 2050, scenario RCP8.5



Wet score 2050, scenario RCP8.5



Source: Swiss Re Institute

[20] For example, given the existing situation of higher mean temperature in Australia, it may not get as hotter and drier as in Japan or UK in the future, as compared to the current environment.
[21] The models stem from the World Climate Research Programme's (WCRP) CMIP5 (Coupled Model Intercomparison Project Phase 5) and range from RCP 2.6 to RCP 8.5.

Losses resulting from severe weather and other natural catastrophe events have been rising.

Our Climate Economics Index: a measure of overall country vulnerability
The climate risk scores provide an assessment of the exposure to the severe weather events. As a pure hazard indicator, however, the scores do not provide indication of the economic impact of those events. The link between GHG emissions and natural catastrophe occurrence is not yet well understood, but there is mounting evidence that due to climate change, an increasing frequency and severity of secondary peril disaster events has contributed to increasing resulting losses over the last decade. Also, the rising loss tallies from severe weather events are due to more people moving to peril-prone regions including in coastal regions, and as economic assets accumulate.[22] This is one shortcoming of our approach. Given the methodological constraints, at this stage we are unable to fully map specific economic outputs and developments across all regions of the world which could then be combined with the climate risk scores.[23]

We introduce the aggregate Climate Economics Index to capture countries' vulnerability to the overall physical risks emanating from climate change.

As a third step in our assessment of the overall physical effects from climate change, we bring together the economic vulnerability of countries to both the chronic risks associated with global temperature rises, and the acute risks that severe weather events present. As above, we first estimate the GDP impact through climate scenario analysis. Second, we compare country-specific vulnerabilities to severe weather events (our climate risk scores), based on their geographical location and aggregated to national averages. Although the country-level aggregation does not fully reflect the granularity of the underlying climate risks scores at individual sites, the averaging of score values provides an assessment of average riskiness which is comparable across countries with different sizes. Lastly, we also provide an overview of the current status of preparedness to cope with the fallout from adverse climate change impact according to countries' existing levels of adaptive capacity. Combining these three measures yields our Climate Economics Index rankings.

Step 3: Climate Economics Index – construction

- We use a simple ranking method to build an aggregate Climate Economics Index. This index captures the economic impact estimates, our climate risk scores of exposure to severe weather events across geographies, and countries' current adaptive capacity to climate change.

- We assign a 70% index weight to the physical risk space, divided between chronic and acute risks. While this weight is arbitrary, we view physical risk as the driving factor of economic outcomes globally. In addition, country rankings are robust to different weighting approaches.

- Based on results of the economic scenario analysis, the chronic risk index (30% of overall index) ranks countries by size of aggregate negative GDP-impact from climate change, subject to a parameter uncertainty stress-test multiple of x10 (as in Table 2). [24] We use the percentage loss of GDP to proxy for the relative riskiness of different countries to adverse economic outcomes of climate change. The GDP impact is least severe in Denmark (GDP -2.8% by mid-century, rank 1) and most severe in Malaysia (GDP -36.3%, rank 48).

[22] *sigma* 2/2020, op. cit.
[23] For example, McKinsey applies some case studies to investigate the socioeconomic impacts of climate hazards across major geographies and sectors. See *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020.
[24] The country rankings in the aggregate climate economics index are robust to different multiplicative stress factors that we take for the average temperature path under the RCP 8.5 scenario.

- As revealed in the country-aggregated climate risk scores, the category for exposure to severe weather events (acute physical risks, 40% of overall index) is broken down further. We assign a 50:50 weighting to each of the dry and wet CRS scores for each country (20% of total index each). We rank the dry and wet scores from lowest (1) to highest (48).

- Lastly, our index also includes a proxy to measure a country's current capacity to cope with the negative impact from climate change: the "Climate Change Adaptive Capacity" index from Verisk Maplecroft. This is a composite index with multiple input factors including strength of existing institutional set-up (eg, government stability, presence of a national disaster management ministry, agency or body), level of education and innovation, management of resources (eg. average dietary supply adequacy, pressure from future population growth), degree of reliance on a vulnerable economy (ie, agriculture value added as a percentage of GDP), public awareness, and scope of existing finances and burdens (mainly measured through GDP per capita). We assign it a 30% weight in the total index, and rank countries from strongest (Germany, 1) to weakest adaptive capacity (Venezuela, 48).

The findings show in Table 3. Countries with lower total index scores are more resilient to climate change effects; those with higher scores are more vulnerable.

Lower-income countries are most exposed

Some advanced economies rank higher in the Climate Economics Index, a reflection also of their existing levels of adaptive capability.

In relative terms, many of the large economies in advanced markets are strongest positioned to withstand the negative impacts of climate change. For example, Canada, the US and Germany are all within the Top 10 in terms of climate resilience. They are all located at higher latitude, suggesting less stress on productivity from rising temperatures. They also have more robust mitigation infrastructure. China and India rank relatively weak (41 and 45, respectively). This reflects the heavy GDP-impact loss projected in our scenario analysis (China, GDP -18.1% by mid-century; India, GDP -27%, see Table 2), and also, to date, low levels of adaptive capacity. In the case of China, the 30% weighting afforded to the Maplecroft index for current adaptive capabilities plays a significant role. As a leader in green energy initiatives and along with the rising awareness on climate risk (as evidenced by the emphasis of green transformation stipulated in China's newest 14th five-year plan), we believe China will climb up and place much higher in the index rankings in the coming years.

Countries most negatively affected are often those least equipped to mitigate climate change effects.

The index rankings show that climate change tends to have a larger negative impact on developing countries with lower per-capita income. For example, countries in Southeast Asia, Latin American, the Middle East and Africa rank low in terms of aggregate physical risk and adaptation capacity. An exception is Singapore. Though not a developing economy, as a small island city-state, it is highly exposed to multiple physical perils (eg, sea level rise, heat stress). At the same time, it has a high degree of readiness in terms of adaptive capacity to combat the adverse effect of climate change. At an overall level, this makes Singapore more resilient to the effect of global warming than its ASEAN peers. For most-exposed countries, improving their capacity to counter the economic damages will support sustainable growth in the long run. This is important as climate change risks can also have adverse effects on sovereign credit ratings.[25] It suggests a critical and potentially dangerous financial feedback loop for the physically- and economically-most vulnerable countries. Building robust infrastructure and strong institutions can alleviate the GDP loss from catastrophe hits and facilitate swift recovery post-event.

[25] *Why Climate Change Vulnerability Is Bad for Sovereign Credit Ratings*, IMF Blog, 2021

Table 3
Climate Economics Index: mid-of-century

Rank	Country	Physical risk (70%)			Current adaptive capacity (30%)	Climate Economics Index
		Chronic risk (GDP impact) (30%)	Acute risk (extreme weather risk)			
			Dry climate risk score (20%)	Wet climate risk score (20%)		
1	Finland	3	8	32	8	11.3
2	Switzerland	4	12	37	2	11.6
3	Austria	7	15	41	6	15.1
4	Portugal	9	21	30	10	15.9
5	Canada	12	18	20	16	16.0
6	Norway	6	29	34	10	17.4
7	US	13	34	12	16	17.9
8	Sweden	10	28	36	7	17.9
9	Denmark	1	40	48	3	18.8
10	Germany	17	25	45	1	19.4
11	Japan	22	35	16	9	19.5
12	Spain	14	17	31	19	19.5
13	Greece	28	3	25	21	20.3
14	Australia	33	16	17	13	20.4
15	UK	11	36	47	4	21.1
16	Turkey	15	4	26	36	21.3
17	Netherlands	5	26	46	18	21.3
18	New Zealand	29	2	27	24	21.7
19	Italy	31	7	33	15	21.8
20	Korea	24	30	14	20	22.0
21	Hungary	19	9	39	23	22.2
22	UAE	21	5	35	27	22.4
23	Hong Kong	41	6	1	29	22.4
24	Romania	8	27	42	21	22.5
25	Belgium	35	39	2	13	22.6
26	Ukraine	2	10	38	42	22.8
27	France	26	19	40	12	23.2
28	Argentina	20	22	10	37	23.5
29	Mexico	25	20	15	31	23.8
30	Egypt	23	11	3	47	23.8
31	Russia	27	13	28	32	25.9
32	Poland	16	24	44	25	25.9
33	Czech	18	23	43	26	26.4
34	Saudi Arabia	43	14	4	38	27.9
35	South Africa	37	1	18	45	28.4
36	Chile	39	31	9	30	28.7
37	Taiwan	40	41	6	28	29.8
38	Brazil	34	42	8	33	30.1
39	Singapore	47	44	29	5	30.2
40	Peru	30	46	7	41	31.9
41	China	38	33	21	35	32.7
42	Colombia	36	38	22	40	34.8
43	Venezuela	32	32	24	48	35.2
44	Thailand	45	43	11	39	36.0
45	India	42	37	13	46	36.4
46	Philippines	46	48	5	43	37.3
47	Malaysia	48	47	23	33	38.3
48	Indonesia	44	45	19	44	39.2

Note: All measures are constructed on the basis of the RCP 8.5 scenario. The ranking of chronic physical risk refers to the percentage loss of GDP by mid-century under the average 2.6°C warming scenario but with x10 stress-tested factors, as specified in Table 2. The ranking for adaptive capacity are derived from Maplecroft, where it serves as one proxy for transition risk. Table colours denote the different degrees of vulnerability to climate change, with dark green indicating the most resilient and dark red the countries most severely impacted. Source: Verisk Maplecroft, Swiss Re Institute

Stories behind the numbers for the least and most vulnerable, and major economies in between

Country	Total Index	Overall rank	Descriptive narrative
Finland	11.3	**1**	**Least vulnerable:** as one of the northern-most countries in Europe, global warming will likely not inflict notable impact in terms of productivity losses. The tourism industry could even benefit from the rising temperatures. The main vulnerability is indicated by a relatively high CRS wet score, which suggests an increase in occurrence of heavy precipitation events. The economy in Finland will also benefit from the country's high existing level of adaptive capacity.
US	17.9	**7**	The US has experienced heavy precipitation in recent years due to severe weather events, particularly during the North Atlantic hurricane season. This has led to widespread flooding, also as a result of storm surges, in coastal areas of high population and economic asset density. Sea-level rise could lead to more extreme flood events. The CRS dry score for the US is also high, and related heat stress could negatively impact labour productivity. Nonetheless, the total economic output of the US is less dependent on natural resources-related agriculture sector, and it has developed more advanced service sectors which can be shielded from the adverse impact of global warming, such as tourism.
Japan	19.5	**11**	As an island nation in east Asia, Japan is particularly exposed to sea-level rise risk. This is coupled with frequent typhoons on the Pacific coast side of Honshū where most of the population lives, (although our CRS does not fully capture typhoon events, as the score mainly applies to secondary peril risks). Crop yields will suffer in rising temperatures and heat stress would negatively impact human productivity during hot days in summer. On the other hand, Japan is well-equipped with robust infrastructure to counter the multiple natural perils, such as resilient buildings and clean energy. It ranks relatively high in terms of adaptive capacity.
Australia	20.4	**14**	The economy is subject to multiple impact channels from gradual temperature rise induced by climate change, with sea-level rise along the long coastal lines, and negatively impacted productivity in different sectors including agriculture, mining and tourism. On the acute risk front, our approach to take the average CRS values at national level may underestimate the true impact from severe weather events, as the intense dry and wet conditions only exist in some sub-regions of the country.
UK	21.1	**15**	Sea level rise with associated flooding along the coast constitutes the biggest climate risk to the UK economy. This is exacerbated by the likelihood that overall wetter weather conditions are set to increase, raising the potential for more river and flash flooding across the British Isles. Within the same year, longer periods of high temperature could also stress crop yields. .
China	32.7	**41**	With a wide distribution/spread of productive resources on account of the sheer size of the country, China's economy is vulnerable to both extreme dry and heavy precipitation weather events. For example, agriculture accounts for about 7% of national output, and production in this sector can be severely impaired by weather extremes. Meanwhile, heat stress could impact health conditions, which in turn could weigh on labour productivity. The large negative GDP impact indicated by our scenario analysis is accentuated by China, as of today, still having relatively low adaptive ability to manage climate change effects, especially as it undergoes rapid urbanisation and economic assets accumulate. However, with rising risk awareness on climate change and rapidly increasing spending on associated R&D and technology (such as carbon capture), China's overall adaptive capabilities will likely strengthen considerably in the coming years. This is even more so as green transformation was emphasized in China's newest 14th five-year plan.
Indonesia	39.2	**48**	**Most vulnerable:** Indonesia is exposed to the full gamut of physical risks emanating from climate change effects, including sea level rise. Both dry and wet weather extremes could impact agriculture yields, and heat stress may weigh on labour productivity. More extreme weather conditions will also take their toll on the tourism sector. The level of adaptive capacity is among the lowest of the sample countries, adding to Indonesia's vulnerability to climate change.

Source: Swiss Re Institute

Transition risks: the potential financial implications of moving to a low-carbon economy

Utilities, material and energy sectors most exposed

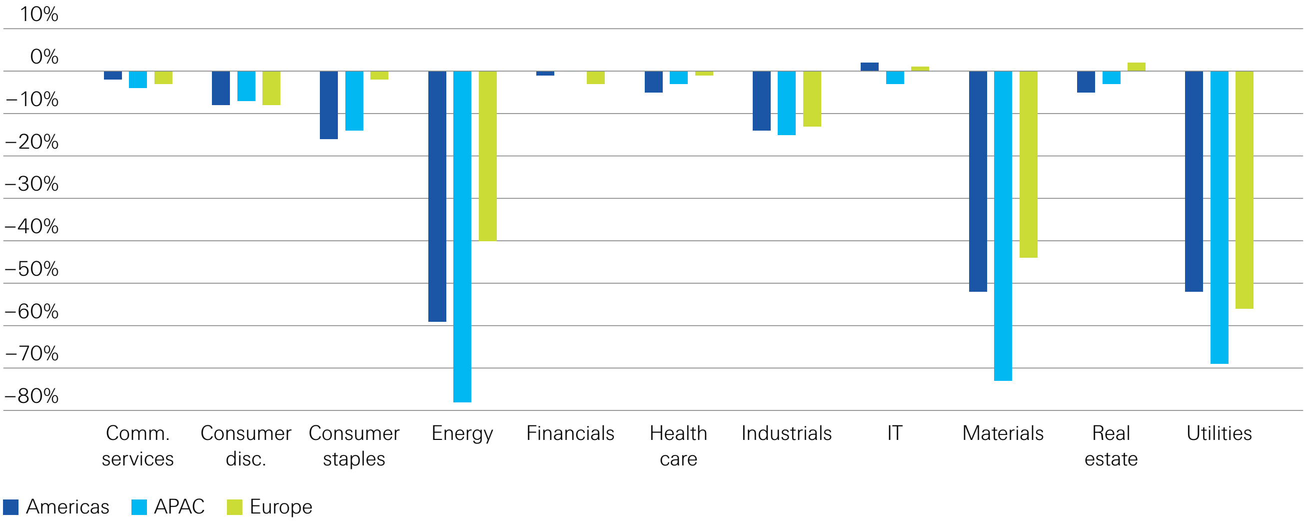
The transition risks of climate change can lead to asset devaluation.

The transition risks from climate change result from the adjustment to a low-carbon economy, such as changes to how society deploys resources, uses technology and rolls out regulation. Transition risks have implications for the global financial markets. The main impact channel is potential for asset devaluation as a result of the desired move to a low-carbon economy, with generation of "stranded" assets such as fossil fuel deposits or coal reserves. What's key in the design of potential carbon tax pricing is that it is meaningful, clearly communicated and phased-in over time, so that companies can adapt. A gradual path would include a firm or country slowly transitioning over a period of time to a more carbon neutral footprint. A sudden and rapid transition could be brought about by government policy, a technological revolution, or a sharp shift in consumer preferences or market sentiment.

Sectors most exposed to imposition of a carbon tax include utilities, materials and energy. By region, Asia is most exposed.

In this chapter we use a carbon tax approach, which proxies the immediate costs of transition risk, to gauge the impact of a sudden transition across industries and regions,[26] and market risk within insurer portfolios. Swiss Re itself charges an internal levy of USD 100 per ton on its own carbon emissions. Based on modelling by Blackrock, we find that earnings in the utilities, materials and energy sectors would be the most impacted by immediate imposition of a USD 100 per metric ton global carbon tax (see Figure 11).[27] By region, the revenue weighted earnings impact would be roughly -20% in Asia Pacific (APAC), and about -15% in the Americas and Europe.

Figure 11
Estimated impact of an immediate global USD 100 per ton carbon tax on company earnings, by sector and region



Source: Blackrock *Carbon Tax Impact Model*, Swiss Re Institute

In addition to equity valuations, credit risk can also increase.

Besides the earnings impacts, many companies could also see heightened credit risk, as a change in their projected earnings and costs could affect their debt repayment capacity and/or devalue existing collateral.[28] Global credit losses from power and oil & gas industries alone could amount to between USD 50–300 billion

[26] While different carbon pricing options exist, a taxation approach is the relatively easier one to model. Alternatively, carbon pricing could for instance be enacted via a cap-and-trade program instead of direct carbon taxes. Other transition risks, which are typically less appreciated and not yet adequately quantified, are for example emerging water scarcity which can influence regions, sectors and individual businesses. See also *Values at risk? Sustainability risks and goals in the Dutch financial sector*, De Nederlandsche Bank, 2019.

[27] BlackRock's *Carbon Tax Impact model*. Assumes a global carbon tax that impacts all companies equally, in relation to their Scope 1 and Scope 2 emissions, and potential for new green revenue capture. The data universe includes the MSCI All Countries World Index, comprised of 2757 publicly listed firms.

[28] M. Molico, "Researching the Economic Impacts of Climate Change", *Bank of Canada*, 19 Nov 2019.

on outstanding debt. While the impact varies dramatically across companies within the sector, the probability of default could rise by two or three times for the most impacted firms.

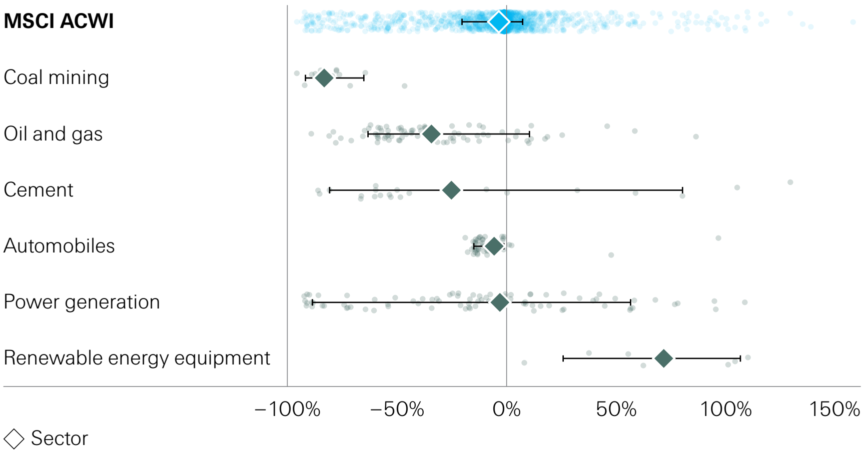
The timing of policy decisions in driving transition will influence the severity of loss of asset value.

The degree of transition risks (and associated uncertainties) depend on the choices adopted by policymakers and their timing, and the pace and breath of technological advancements. For example, average value losses for auto manufacturers range from 5–20%, depending on whether the transition is precipitated by a revolution in renewables costs (making them much cheaper) versus costs in carbon capture and storage, or an overall economy-wide increase in energy efficiency. [29] By contrast, for concrete and cement producers, the average value losses could amount to 10–25% depending on the timing of policy measures in driving the transition.

Decarbonisation requires substantial investment. It also presents opportunity for many companies across sectors.

Decarbonisation will require large investment while also presenting opportunities across many sectors. Rapid decarbonisation would put some existing assets and investments at risk, but would also catalyse investments in new and non-traditional sectors.[30] For example, to meet the target of well below 2°C of warming, the IPCC estimates that annual investment of about USD 2.4 trillion up to 2035 will be needed to transform the world's energy system.[31] This suggests a USD 500 billion annual increase from global energy investment rates over the past three years.[32] It would also entail a shift in demand across and within sectors. Some companies, even in the most negatively impacted sectors, could benefit (see Figure 12).[33] For instance, in many countries solar photovoltaic is now less costly than new coal- or gas-fired plants for electricity power generation. Solar power is a key component of renewable energy. Given that the International Energy Agency estimates renewable energies together will cater to 80% of the growth in global electricity demand to 2030, main beneficiaries will likely be businesses in the solar photovoltaic segment.[34]

Figure 12
Expected change in the net present value of profits in a scenario targeting no more than 2°C warming with action starting in 2020, relative to no policy action



Note: Bars show the range between the 10th and 90th percentiles of company performance within each sector of the MSCI All Countries World Index. Sectors represent a subset of those analysed, which covered all sectors in which there are companies listed on the MSCI ACWI..
Source: *Low-carbon transition scenarios: Exploring scenario analysis for equity valuations*, HSBC Global Asset Management, October 2018.

[29] *The roads to a low-carbon transition: What it means for investors*, HSBC, March 2020.
[30] J.F. Mercure et al, "Modelling innovation and the macroeconomics of low-carbon transitions: theory, perspectives and practical use," *Climate Policy*, vol. 19, No. 8, 2019.
[31] *Special Report: Global Warming of 1.5°C*, Intergovernmental Panel on Climate Change, October 2018.
[32] *Total global energy investments 2017–2020*, International Energy Agency, available *here*.
[33] *Low-carbon transition scenarios: Exploring scenario analysis for equity valuations*, HSBC, January 2019.
[34] "How the IEA sees the future of energy", *Financial Times*, October 2020.

Mitigating climate change risks

Shaping mitigation policies

Financial services companies are incorporating climate change into risk management practices.

The financial sector is increasingly incorporating climate risk into prudential regulation, in part as a response to warnings such as from BIS in its *Green Swan* report.[35] There, the BIS says that "climate-related risks will remain largely uninsurable or unhedgeable as long as system-wide action is not taken", and therefore "only a structural transformation of our global socioeconomic system can really shield the financial system against 'green swan' events".

We believe natural peril risks remain insurable.

Implications for, and the role of, insurance business

Importantly, weather-related risks remains insurable. This is due to the short-term nature of most property re/insurance business, which allows for continuous adjustment of risk views. The main effect of climate change on insurers is rising loss costs. The effects of rising temperatures are already feeding through to higher insured claims (eg, for property damage, crop shortfall, business interruption) from some secondary perils, including heat waves, wildfires, droughts and torrential rainfall. These are hazards for which confidence of a direct link with rising temperatures is medium/high. For other hazards like hurricanes (so-called "primary" perils), there is still much uncertainty around cause and effect with respect to climate change. This is in large part due to the relative infrequent occurrence of primary perils, and the complexity of their formation. Nevertheless, there are signals that climate change is impacting hurricane risk. For instance, there have been signs of increased scale of flooding as a result of the extreme precipitation and storm surges inflicted by major hurricane events (so-called secondary effects of primary perils).[36]

Insurers need to continue to build and update understanding of the current-day risks that climate and socio-economic changes present.

There has been a rising trend of the economic cost of natural perils, both primary and secondary, over many years. This resulted from more people moving to high-risk areas including coastal regions and wildland-urban interface areas, and as economic assets in exposed areas accumulate. Given the rising loss potential, both from hazard intensification and rising exposure, and to ensure that natural peril risks remain insurable, the industry needs to consider increasing confidence through additional research, and by quantifying modelling uncertainties in areas where confidence remains low. In addition, insurers should actively track socio-economic developments and the status of local risk mitigation measures for continual assessment updates, so that risk models represent present-day climate and socio-economic circumstances.

By closing protection gaps, insurers can help households and businesses strengthen their resilience against natural catastrophe risks.

Insurance is an important tool by which households and businesses can strengthen their resilience to better manage rising natural catastrophe risks. Based on *sigma* data, we estimate that today's global protection gap for weather-related losses is at around 70%. At the macroeconomic level, uninsured losses from physical risks may affect resource availability and economic productivity across sectors with cascading impacts on the financial system. Re/insurers should use their understanding of risk to help households, private companies and societies mitigate and adapt, the aim being to protect a greater share of the global assets. Insurance is a central component of building resilience at the macro- and micro levels. This is acknowledged in the United Nations' (UN) 17 Sustainable Development Goals (SDGs), which include insurance as a main tool to strengthen the resilience of societies. The 2030 Agenda for Sustainable Development makes explicit references to disaster risk reduction and includes numerous targets that capture various aspects of resilience.[37]

As long-term investors, insurers can support the transition to a low-carbon economy.

Insurers' commitment to a "net zero" asset and underwriting portfolio and PPPs with sustainability criteria at their core would all support the climate transition. Insurers can also contribute to and capture opportunities from the transition to a low-carbon economy, in their function as institutional investors and risk capacity providers.[38] For some industries, climate change will result in a decrease of insured asset values and/

[35] *The Green Swan*, BIS, January 2020.
[36] *sigma* 2/2020, op. cit.
[37] *Transforming Our World: The 2030 Agenda for Sustainable Development*, United Nations, 2015,
[38] *Turning up the heat – climate risk assessment in the insurance sector*, Bank for International Settlements, FSI Insights on policy implementation No 20, November 2019.

or loss in the valuation of related securities (stranded assets).[39] Industries that focus on green technology, renewable energy, carbon capture and storage also provide new insurance and investment opportunities. Re/insurers have started to work with their clients supporting their transition to a low-carbon economy through underwriting activities and investment strategies. They can also encourage behavioural change by setting appropriate risk prices and work on new products and underwriting solutions as new hazards emerge. Similar to developments in cyber and other emerging risk lines, insuring green technologies may initially be challenging due to limited loss history and/or inadequate understanding of environmental and policy feedback loops. Parametric solutions can provide alternatives where traditional indemnity products face limitations to insurability. To facilitate the transition to a net zero economy, Swiss Re's underwriting will also tighten its coal policy by 2023 through coal-exposure thresholds. These will be lowered gradually and will lead to a complete phase out of underwriting of thermal coal exposures in OECD countries by 2030, and in the rest of the world by 2040.

Global initiatives

The Financial Stability Board is pushing for international adoption of harmonised climate-risk related financial disclosure.

The Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) has developed a set of recommendations to ensure consistent climate-related financial risk disclosures by companies. It continues to push for international (voluntary) adoption of the standards across all financial services.[40] More recently, a global group of central banks established the Network for Greening the Financial System (NGFS) which aims to redirect capital to green and low-carbon investments and integrate climate-related risks into financial stability monitoring and micro-supervision.

National supervisory bodies are also taking action.

At national level, regulators across Europe (eg, the UK, the Netherlands, France, Germany), Asia Pacific (eg. Australia, Singapore) and in the US have conducted reviews of how financial institutions are managing the transition risks from climate change.[41] The results show that very few firms are taking a strategic approach. In light of these findings, the Prudential Regulation Authority of the UK was the first regulator globally to issue specific guidance on how firms should strategically manage climate risk. And in December 2019, the Bank of England issued the discussion paper to use its 2021 biennial exploratory scenario (BES) on the financial risks from climate change. It plans to run climate-related stress tests for the largest banks, insurers and the financial system in 2021, based on the NGFS scenario framework.[42]

However, much more is needed to strengthen financial system resilience to the transition risks of climate change.

Despite these initiatives, more is needed to achieve the net-zero target set by the Paris Agreement. For example, in the response to COVID-19 pandemic, governments around the world have committed more than USD 12 trillion of fiscal stimulus globally, but very few of these measures are for green, sustainable or climate objectives.[43] In the EU, member states are required to demonstrate that 25% of their spending should be in line with climate goals in order to access the newly created recovery fund, but actions from the US and Asian countries are largely muted.[44] Meanwhile, most central banks have not factored climate risks into their regulatory capital frameworks. The underlying reason is that climate risk analysis is inherently

39 Stranded assets are assets that have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities which can be caused by a range of environment-related and/or policy risks.

40 *Recommendations of the Task Force on Climate-related Financial Disclosures*, TCFD, 2017.

41 Including Swiss Re, which has embedded the consideration of financial risks from climate change into its governance framework. See *Swiss Re Group Sustainability Strategy*.

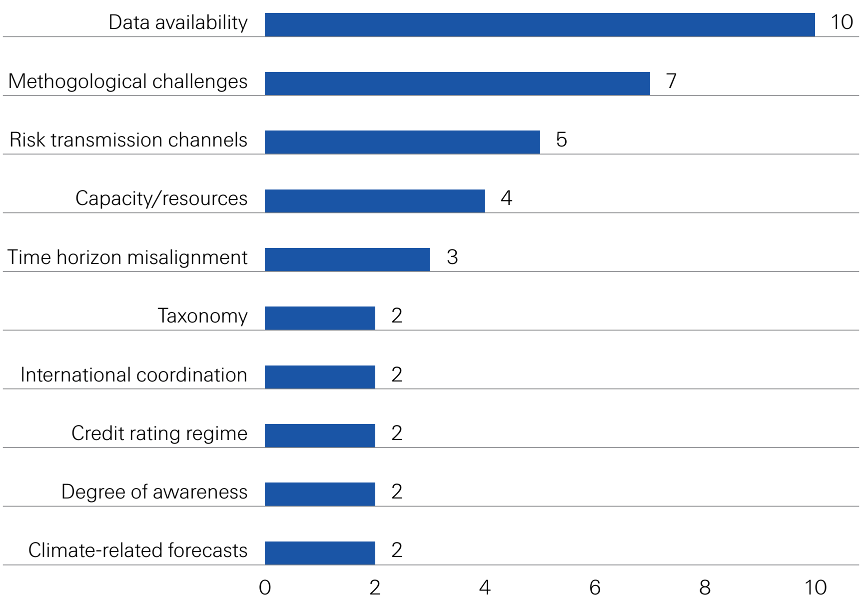
42 See *The 2021 biennial exploratory scenario on the financial risks from climate change*, Bank of England PRA, 2019; *The Implications of Climate Change for Financial Stability*, Financial Stability Board, November 2020.

43 The WEF estimates that a share of around 10% of stimulus packages – invested every year over the 2020–24 period – would be sufficient to fund the transition to achieve the goal of Paris Agreement. See *How the global coronavirus stimulus could put Paris Agreement on track*, World Economic Forum, October 2020.

44 *Greener future post-COVID-19? Green policies & global stimulus*, Citi Research, September 2020.

complex, while data gaps and methodological challenges are viewed as major barriers to assess climate financial risks (Figure 13).[45]

Figure 13
Challenges to assess climate financial risks, identified by number of jurisdictions



Source: Basel Committee survey, 2020

Avoiding worst-case climate outcomes: call to action

The public and private sectors need to accelerate globally coordinated climate-related policy actions.

Climate change is a systemic risk that requires a globally coordinated response. To combat climate change and ease the transition to a low-carbon economy, the public and private sectors need to accelerate climate-related policy action and collaborate. We see the following as key areas to mitigate the worst-case climate outcomes:

Public sector

- **Accelerate and amplify the effectiveness of public policy.**[46] A global carbon tax that supports long-term decision making also supports the net zero transition. A carbon tax would, with increased familiarity and understanding, help promote more transparent pricing of climate-related risks, reflected in financial markets.

- **Central banks to include sustainability criteria in collateral frameworks** to extend liquidity provisions to institutions. This would be a powerful tool to steer pledged collateral towards greener and more sustainable assets in a market-consistent manner.

- **Fiscal incentives for carbon capture and reduction and climate resilient development.** Tax incentives could encourage business to invest in carbon capture and GHG-emission reduction technologies. This could also lead to more research in and development of these areas, and enable more finance flows towards climate resilient development.

- **Governments' fiscal envelope should consider contingent climate costs.** Governments should use a full balance sheet approach to show their "net wealth". By doing so, they should also account for contingent climate costs as this may severely impact their fiscal budgets.

[45] *Climate-related financial risks: a survey on current initiatives*, Basel Committee on Banking Supervision, Bank for International Settlements, April 2020.
[46] Some of these points are outlined by the G30 report Mainstreaming the transition to a net-zero economy, available *here*.

- **Globally-harmonised regulatory approaches, including climate scenario approaches.** Regulators and industry should jointly develop climate risk modelling that can be flexible across jurisdictions, while aligning with a common set of assumptions, scenarios and guidelines. Climate-related financial regulation should be risk and principles-based, and internationally harmonised.

- **Transparency and standardisation around definitions, data, standards and metrics is needed.** For example, the definition around what is "green" and "sustainable" should be universal. Shared standards, allowing for some regional variation, are key for carbon price discovery and would strengthen comparability of corporate reporting.

Private sector

- **Actively support transition to a low-carbon economy:** by joining the United Nation's Net Zero Asset Owner Alliance, institutional investors, including insurers, can deliver a bold commitment to transition their portfolios to net-zero GHG emissions by 2050. Insurers should consider deploying sustainable underwriting practices.

- **Rating agencies should more explicitly take climate change into account.** Climate change is a systemic risk, which rating agencies should take into account when assessing corporate balance sheets in their rating methodology. They can play a key role in shaping best practices of what constitutes a "good climate" rating and what doesn't, to avoid "greenwashing" of capital flows.

Public-Private-Partnerships (PPPs) and multilateral development banks

- **Establish PPPs with climate goals and sustainability criteria at their core.** PPPs should be leveraged to design, de-risk and provide financing for climate-positive projects. This could have social and economic benefits, too: investing USD 1 trillion annually in green energy between 2021–23 could add 1.1 percentage points to global economic growth and create new jobs.[47] Meanwhile, GHG emissions could be reduced by 15% over that timeframe. The IMF estimates that economic multipliers of green spending are 2 to 7 larger than those associated with non-eco friendly expenditure.[48]

- **Support market-scale sustainable investments by adequate risk sharing mechanisms through the public and private sectors.** Having transparent and standardised risk sharing approaches would facilitate scaling of environmental sustainability-related projects. Insurers could support this drive by providing risk coverage and expertise to further support the channelling of capital flows from the balance sheets of multilateral developments banks and private institutions to climate-positive projects.

- **Share risk knowledge and expertise.** The private sector, and in particular re/insurance companies, should share their expertise around risk models and new technologies so that the effects of climate change and natural catastrophes can be better understood and mitigated.

[47] *Sustainable Recovery*, International Energy Agency, 2020

[48] *Building Back Better: How Big Are Green Spending Multipliers?*, IMF, 2021.

Conclusion

Climate risk is a systemic risk. No action is not an option.

Climate risk is a systemic risk requiring coordinated action. With our scenario analysis, we estimate that in a severe, unmitigated climate-change scenario, global GDP could be 18% less by mid-century compared to a no-climate change world. Our motivation is not to be alarmist, but to profile to the severity of potential risks, including of tail exposures, if society does nothing about climate change. No country is immune to the effects of climate change, and no action is not an option. Many major economies would lose roughly 10% of their GDP in about 30 years' time, while some in southeast Asia could lose roughly half of their GDP in that timeframe.

Countries most negatively impacted by climate change are least able to afford adaptation measures.

The countries most negatively impacted are often the ones with fewest resources to adapt to and mitigate the effect of rising global temperatures. Our climate economics index incorporates the economic impact of gradual climate change, countries' vulnerability to extreme wet and dry weather events, and their adaptive capacity. The index rankings show advanced markets such as Germany benefiting from both lower exposures to and greatest resources to counter the effects of climate change. In contrast, many emerging markets, which will also make an increasing contribution to global growth in the future, are both heavily exposed and poorly resourced to adapt. Global policy action is needed to ensure equitable progress in greening economies, both for local benefit and to make the world economy more resilient in the long term.

In some sectors, a USD 100 global carbon tax could hit company earnings dramatically.

The transition towards a low carbon economy is non-negotiable but has repercussions for asset valuations. It is clear that climate transition risks can have a substantial impact on equity and credit valuations. The sectors most exposed to a global carbon tax include utilities, materials and energy. Introducing a global carbon levy at USD 100 per ton could hit company earnings in those three sectors by 40–80%. Regionally, Asia is again most exposed. The timing and scope of policy decisions will influence the severity of asset value changes.

A low-carbon future demands a coordinated public- and private-sector response.

Climate change will have economic costs even if the Paris Agreement goals are met, but the costs could be significantly more severe in alternative scenarios. Hence, the Paris targets remain the best achievable outcome. To get back to and reach those targets will require coordinated global policy action. The public and private sectors, including insurers as providers of risk transfer capacity, risk knowledge and long-term investment, can facilitate transition to a low-carbon economy. Increasing transparency, data and disclosure to price and transfer risks is needed. To this end we should see more policy action on carbon pricing coupled with incentivising nature based and carbon-offsetting solutions. International convergence on the definition of what counts as green and sustainable investments is also needed. As part of corporate reporting, institutions should also disclose their roadmaps on how they intend to reach the Paris and 2050 net-zero targets.

Appendix 1: traditional modelling approaches

Approaches to assess economic damage from climate change typically fall into one of three categories described here. All have limitations due to the complexity of multiple nonlinear dynamics, uncertainty around the distribution of parameters and omission of fat tails/tipping points in climate impact scenarios.

Integrated Assessment Models (IAMs): these were the first to explore the relationship between climate change and economic damage, which laid the foundation for the IPCC's climate risk assessment. These models start with an emissions pathway and link it to macroeconomic impact via use of a damage function, a function for the utility or welfare of society, and a function representing emissions abatement costs. While IAMs generally produce estimates of a negative GDP impact in the range of 2%–10% by 2100, they are sometimes criticized for the damage function, which links temperature to the effect on GDP as well as the discount rate used in modelling. For tractability, IAMs omit a number of relevant pieces of the climate change puzzle, such as changes to the frequency and severity of natural catastrophes, migration and conflict, natural capital and financial markets. This inevitably leads to an under-estimation of economic impact.

"Newer" panel data models: the next generation of models is designed to address shortcomings in IAMs. In an initial attempt to gauge the damage functions embedded in IAMs, researchers employ a cross-sectional regression approach to estimate the parameters. However, this approach assumes a costless adaptation process to mitigate climate risk and ignores agent expectations of a future climate change path. In light of this, the "newer" panel data model uses reduced-form time-series panel data to estimate GDP growth as a function of annual temperature variations, which is a next step up from the IAMs and finds impacts an order of magnitude higher than IAMs. For example, Burke et al (2018)[49] projects 15%–25% reduction in per capita output by 2100 for the 2.5–3°C of global warming, and reduction of more than 30% for 4 °C warming.

Bottom-up or case-study based approaches: a number of economists have recently used these, and they typically show much more economic activity at risk from climate change than either IAMs or panel data methods. The Stern Review (see page 6) was one of the first compilations in this area, reviewing the impact from climate change on several growth and development avenues. Other sector- and region-based case studies also paint an alarming picture, implying substantial socioeconomic impact.[50]

It is likely that the estimated impacts of GDP damages from climate change will rise as existing modelling develops to incorporate economic linkages in trade, migration and other channels, and to generalise the results to multiple countries. For example, the climate scenario document[51] issued by the Network for Greening the Financial System (NGFS) in June 2020 outlines three transition and physical representative scenarios as the start point to include range estimates from multiple models.[52]

[49] Burke, Davis & Diffenbaugh, "Large potential reduction in economic damages under UN mitigation targets", *Nature*, 2018.
[50] See for example *Climate risk and response. Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020; *American climate prospectus. Economic risks in the US*, Rhodium Group, 2014.
[51] *NGFS Climate Scenarios for central banks and supervisors*, June 2020,
[52] The NGFS framework is built upon IPCC RCP scenarios but takes more transition risk analysis into consideration. Our research approach differs from NGFS methods by focusing more on tail-risk analysis and addressing the omitted-factors problem.

Appendix 2: GDP-impact scenario analysis set-up

Starting point: quantifiable impact channels

To assess the effect of climate change, we start with looking at the quantification of six widely used “impact channels”. For those, Roson and Sartori synthesised primary academic research and linked temperature changes to economic impacts in all regions.[53] The channels and associated impacts are as follows:

- Agricultural productivity effects: higher temperatures and carbon concentration levels, and changing precipitation patterns impact crop yields and agricultural productivity. Typically, cold regions see longer, and warm regions shorter growing seasons. Higher GHG concentration levels initially act as fertilizer but over time, the effect of warmer temperatures weighs more heavily and crop yields diminish.

- Human-health effects: rising temperatures will likely lead to higher mortality and morbidity of certain diseases. Roson & Sartori combine the quantitative impacts of climate-induced changes in vector-borne diseases (eg, malaria, dengue), heat and cold related diseases, and diarrhoea.

- Labour productivity/heat stress effects: higher temperature and humidity lead to more frequent pauses, interruptions, lower speed and higher probability of injury. More exposed industries, such as agriculture, will suffer more than services.

- Sea level rise: rising temperatures lead to thermal expansion of oceans and melting glaciers that drive sea-level rise, leading to land loss through erosion, inundation and salt intrusion. This can lead to economic losses for owners of coastal land that is used for productive purposes.

- Tourism flows: warm regions will become less (eg, due to heat, erosion of beaches) and cold regions more attractive as tourist destinations. This will have distributional implications in exports for tourism-dependent countries.

- Household energy demand: rising temperatures will reduce demand for heating oil, but there will be more demand for electric cooling. This will impact energy prices and investments, especially for and in oil.

Modelling approach

The research on climate impacts on economic outcomes is still in its early days and data remains scarce. Out of the many possible channels through which climate change can affect economic variables (impact channels) only a handful have at least some quantitative backing allowing to estimate parameters for modelling purposes. Relying on a subset of impact channels will necessarily produce results that underestimate the true impact of climate change on economic outcomes. Acknowledging this implication, we challenge and stress the input factors to illustrate the impact from omitted variables and inform about sensitivities of input factors and the various sources of uncertainty in a scenario setting.

As a starting point to analyse economic impacts from unmitigated climate change, we take a large structural macroeconomic model by Moody’s Analytics that incorporates the elasticity of productivity and other variables to rising temperatures with respect to above outlined climate change “impact channels”, as identified by Roson and Sartori (see pointer 1 in Figure 14).[54] [55] The country-specific elasticities vary, depending on characteristics such as industrial composition, reliance on tourism and current climatic environment.

[53] Roson and Satori, op. cit. The number of studies per impact channels varies and the analytical transformations needed to derive temperature-productivity impacts link varies. Roson and Satori processed many diverse studies based on different approaches and methodologies. The robustness of the parameters relies on the original information in those studies.

[54] Moody’s Analytics incorporated the said impact channels in its global and US models. See *The Economic Implications of Climate Change*, Moody’s Analytics, 2019.

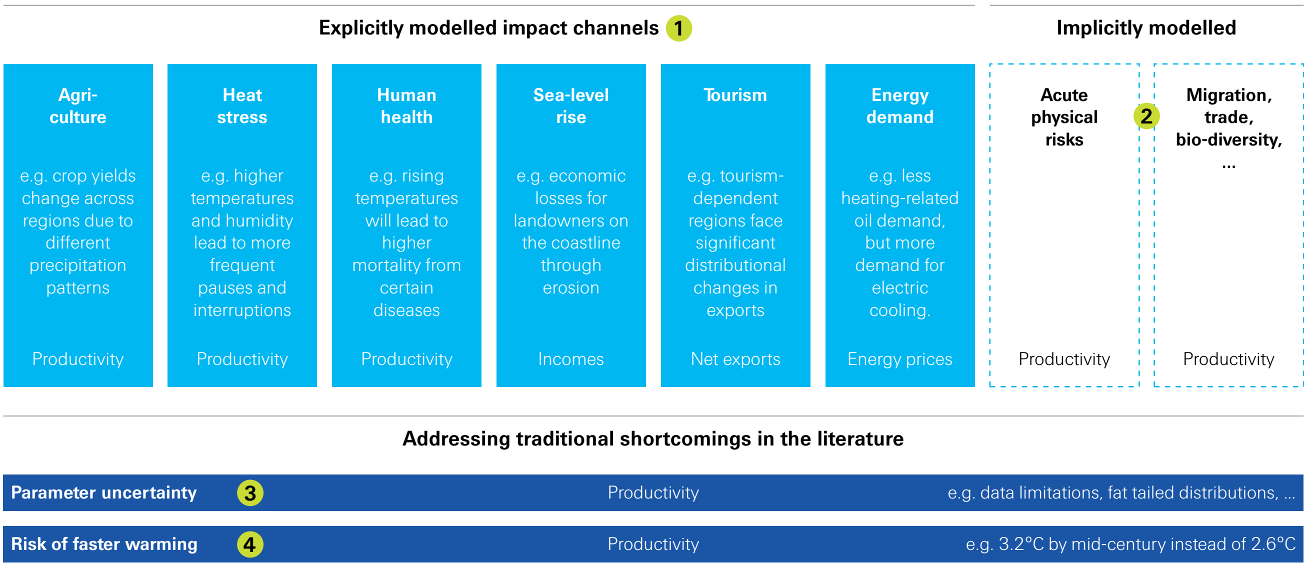
[55] R. Roson and M. Sartori, op. cit.

The Moody's Analytics macroeconomic model simulates the interdependencies and intertemporal dynamics of country-specific variables.[56] It accounts for many cross-border demand, price and financial market variables to yield a more holistic assessment of the economic impact of higher temperatures than analysis on a country-stand-alone basis would allow. With 73 countries, the model covers more than 95% of global GDP. Note that for comparability reasons, we only show the 48 common countries across our analysis.

Figure 14
Our model set-up

Modelling approach

The modelling approach builds on a set of explicitly modelled impact channels (1), implicitly models missing channels (2), stresses the impact elasticities (3) and allows for alternative temperature paths (4). The affected variables in the model environment are illustrated in grey.



Source: Swiss Re Institute

Accounting for uncertainties

However, relying on a set of six channels underestimates the full economic impact of unmitigated climate change. This is because of still large uncertainties around the understanding of climate change, its impacts on the economy, and as many other impact channels are omitted. Omitted channels include but are not limited to extreme weather events, disruption of global supply chains and trade, climate migration and biodiversity. Most point to negative economic outcomes such that clearly the combined impact of all possible channels will be much more than that of the six alone.

For this reason, we extend the model set up by implicitly modelling for the omitted channels. We focus on changes in productivity, being a main factor driving long-term economic growth, as the main lever to stress the impact elasticities of economic outcomes to rising temperatures. Absent quantifiable data and acknowledging the presence of *known unknowns* and *unknown unknowns*, we take the cross-country median of the combined elasticity of productivity-linked channels (agricultural, heat stress and human health impacts) as a proxy for the omitted channels, and correct country-specific parameters by adding that composite proxy to the estimated productivity elasticity of a given country (see pointer 2 in Figure 14).

[56] The equations and parameters in Moody's Analytics model are empirically and theoretically calibrated to provide high out-of-sample forecasting and scenario-analysis capabilities.

A shortcoming of our model build so far is that some economic impacts are linearly estimated: non-linearities are not adequately captured.[57] We use multiplicative factors of 5 and 10 to simulate the increasing severity of outcomes from non-linearities (pointer 3 in Figure 14). Importantly, the framework does *not* consider tipping points, events such as the partial disintegration of ice sheets, biosphere collapses or permafrost loss, that pose a threat of abrupt and irreversible climate change. This is because it is thought that tipping points will materialise well after our model horizon of mid-century only. That said, while tipping points were previously thought to occur at higher degrees of warming, there is new evidence that they could be exceeded already between 1°C and 2°C.[58] Other research suggests a similar amount of CO_2 ppm as in the RCP 8.5 scenario towards the end of the century could lead to warming of roughly 8°C resulting from abrupt break-up of stratocumulus cloud.[59] Yet other research suggests that if tipping points do happen, there could be an x8 increase in climate change associated economic damages.[60]

Lastly, we acknowledge the uncertainty around how temperatures increase as a response to higher emissions, and simulate a temperature path increasing by 3.2°C by 2050 relative to the pre-industrial period to stress test the heavy tails of different climate sensitivities (pointer 4). This figure represents the upper end of the likely warming range in the RCP 8.5 scenario.[61] Since the ceiling of the RCP 4.5 likely warming range coincides with the mid-range of RCP 8.5, there was no need to add another scenario. To represent these uncertainties, using the "current trajectory" and "no-mitigation" emission paths (RCP 4.5 and RCP 8.5, respectively), we present different scenarios to reflect in different shades the omission of impact channels, the inability to properly account for parameter uncertainty ((un)known unknowns)), and the risk of faster warming. We use the same scenario adjustments, but based on the RCP 2.6 emission path, to present outcomes conditional on reaching the Paris Agreement goal of limiting global warming to well below 2°C.[62] As above, we do not cover the issue of tipping points.

57 As can be seen from the primary research by Roson and Sartori, it's not possible to estimate non-linear relationships between temperature increases and economic activity for most channels, especially for temperature increases that have not been observed yet.
58 T.M. Lenton, J. Rockström, O. Gaffney et. al., 2019, op. cit.
59 Schneider, T., Kaul, C. M. & Pressel, K. G. *Nature Geosci.* vol 12, 2019.
60 Cai, Y., Lenton, T. & Lontzek, T. Risk of multiple interacting tipping points should encourage rapid CO_2 emission reduction, *Nature Clim Change*, vol. 6, 2016.
61 The estimated temperature increases are based on the IPCC *AR5* report. The often mentioned reference period 1986–2005 can be easily converted into pre-industrial comparisons by adding 0.6°C.
62 The mean temperature rise to mid-century from RCP 2.6 is 1.61°C according to the IPCC *AR5* report.

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Swiss Re Institute
Mythenquai 50/60
P.O. Box
8022 Zurich
Switzerland

Telephone +41 43 285 2551
Email institute@swissre.com

Authors
Jessie Guo
Daniel Kubli
Patrick Saner

Editor
Paul Ronke

Managing editor
Dr Jerome Jean Haegeli
Swiss Re Group Chief Economist

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Swiss Re Management Ltd.
Swiss Re Institute
Mythenquai 50/60
P.O. Box
8022 Zurich
Switzerland

Telephone +41 43 285 2551
Fax +41 43 282 0075
institute@swissre.com
institute.swissre.com