Network for Greening the Financial System

NGFS Scenarios for central banks and supervisors

September 2022

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Joint foreword

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We are delighted to present the third vintage of the NGFS' climate scenarios.

Climate change poses significant and unprecedented financial risks, the effects of which are difficult to assess. The NGFS climate scenarios are helping an increasing number of public and private sector players to carry out detailed analysis of the financial risks posed by climate change. They produce results that are comparable against a consistent set of variables, and applicable at the global level. These scenarios are playing a foundational role in exploratory exercises around the world, and are increasingly driving decisions in business strategy and risk management.

Developing scenarios that reflect the impact of future green policies and extreme climate phenomena is a highly complex endeavour. The NGFS scenarios have evolved to become deeper, broader and richer with each new iteration, and this third release represents a further marked enhancement. Beyond updating the scenario variables to reflect the latest GDP and population pathways, this third iteration also reflects the most recent country-level climate commitments made at COP26 in November 2021. Furthermore, for the first time, the scenarios include projections of the potential losses from extreme weather events (in particular, cyclones and river floods), to complement the specific impacts of chronic climate changes on the macroeconomy in the previous iteration.

We are excited to release this third vintage of the NGFS scenarios, a further milestone to improving our understanding of the impacts of climate change. Enriching the NGFS scenarios is part of the commitment we made in the "NGFS Glasgow Declaration: Committed to Action" at COP26. As this work continues, the NGFS scenarios will help to shed further light on the financial risks from a changing climate and the opportunities from a green transition, guiding stakeholders in their decision-making and risk management.

Acknowledgements

The Network for Greening the Financial System (NGFS) is a group of 116 central banks and supervisors and 19 observers committed to sharing best practices, contributing to the development of climate – and environment – related risk management in the financial sector and mobilising mainstream finance to support the transition toward a sustainable economy.

The NGFS Workstream 2 has been working on updating the NGFS Scenarios in partnership with an academic consortium from the Potsdam Institute for Climate Impact Research (PIK), International Institute for Applied Systems Analysis (IIASA), University of Maryland (UMD), Climate Analytics (CA) and the National Institute of Economic and Social Research (NIESR). This work was made possible by grants from Bloomberg Philanthropies and ClimateWorks Foundation.

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Overview

Key messages

Scenarios differ markedly in their physical and transition impacts, with significant uncertainty in the size of the estimates and variation across regions.

- The NGFS scenarios have been developed to provide a **common starting point** for analysing climate risks to the economy and financial system. They have been created as a tool to shed light on potential future risks, and to prepare the financial system for the shocks that may arise. Importantly, the **NGFS scenarios are not forecasts:** instead, they aim at exploring the bookends of plausible futures (neither the most probable nor desirable) for financial risk assessment.

- To reflect the uncertainty inherent to modeling climate related macroeconomic and financial risks, the NGFS scenarios use different models, and explore a wide range of scenarios across regions and sectors.

- In this third iteration, the NGFS scenarios have been brought up to date, including by incorporating countries' commitments to reach net-zero emissions, and have been enriched with more sectoral granularity and a finer representation of physical risk, including acute risks.

- Reaching global net zero CO_2 emissions by 2050 will require an ambitious transition across all sectors of the economy. The NGFS Scenarios show that immediate coordinated transition will nevertheless be less costly than inaction or disorderly transition in the long run.

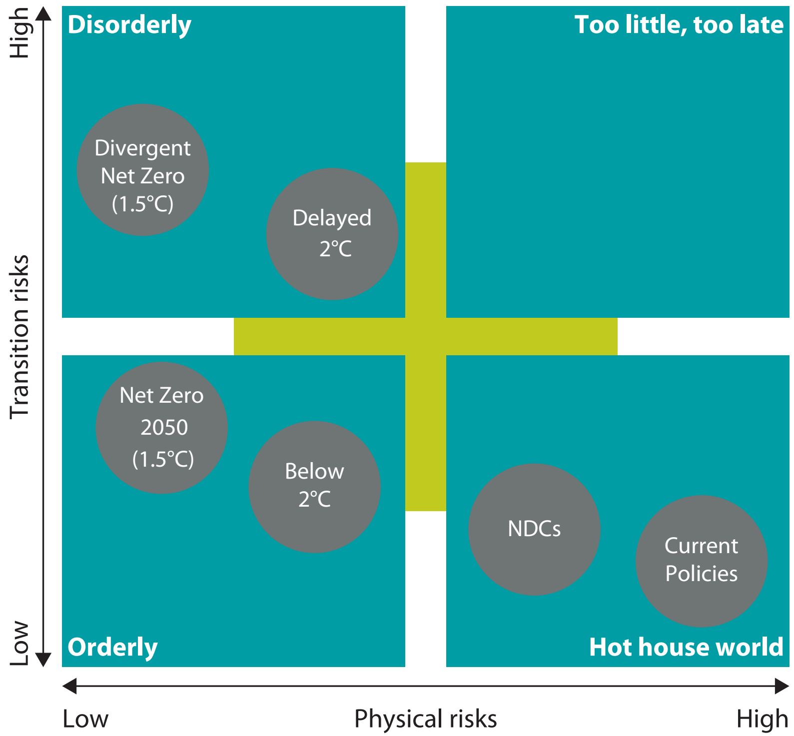
- More precisely, physical risks in hot house world scenarios (Current Policies or Nationally Determined Contributions scenarios) will lead to the strongest negative impacts on GDP with economic cost diverging significantly after 2040.

Objectives and framework

The NGFS scenarios explore the impacts of climate change and climate policy with the aim of providing a common reference framework.

- The NGFS scenarios explore a set of **six scenarios** which are consistent with the NGFS framework (see figure) published in the First NGFS Comprehensive Report covering the following dimensions:
  - **Orderly** scenarios assume climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued.
  - **Disorderly** scenarios explore higher transition risk due to policies being delayed or divergent across countries and sectors. For example, carbon prices are typically higher for a given temperature outcome.
  - **Hot house world** scenarios assume that some climate policies are implemented in some jurisdictions, but globally efforts are insufficient to halt significant global warming. The scenarios result in severe physical risk including irreversible impacts like sea-level rise.

NGFS scenarios framework



Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100.

Scenarios at a glance

Scenarios are characterised by their overall level of physical and transition risk. This is driven by the level of policy ambition, policy timing, coordination and technology levers.

		Physical risk	Transition risk			
Category	**Scenario**	**Policy ambition**	**Policy reaction**	**Technology change**	**Carbon dioxide removal -**	**Regional policy variation +**
Orderly	Net Zero 2050	1.4°C	Immediate and smooth	Fast change	Medium-high use	Medium variation
	Below 2°C	1.6°C	Immediate and smooth	Moderate change	Medium-high use	Low variation
Disorderly	Divergent Net Zero	1.4°C	Immediate but divergent across sectors	Fast change	Low-medium use	Medium variation
	Delayed Transition	1.6 °C	Delayed	Slow / Fast change	Low-medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.6°C	NDCs	Slow change	Low-medium use	Medium variation
	Current Policies	3°C +	Non-currente policies	Slow change	Low use	Low variation

Colour coding indicates whether the characteristic makes the scenario more or less severe from a macro-financial risk perspective^

- Lower risk
- Moderate risk
- Higher risk

Colour coding in the table:

Scenario	Policy ambition	Policy reaction	Technology change	Carbon dioxide removal	Regional policy variation
Net Zero 2050	Lower risk	Moderate risk	Higher risk	Moderate risk	Moderate risk
Below 2°C	Moderate risk	Moderate risk	Moderate risk	Moderate risk	Lower risk
Divergent Net Zero	Lower risk	Higher risk	Higher risk	Lower risk	Moderate risk
Delayed Transition	Moderate risk	Higher risk	Higher risk	Lower risk	Higher risk
Nationally Determined Contributions (NDCs)	Higher risk	Lower risk	Lower risk	Lower risk	Moderate risk
Current Policies	Higher risk	Lower risk	Lower risk	Lower risk	Lower risk

* See slide 18 for more details.
- The impact of CDR on transition risk is twofold: on the one hand, low levels of CDR imply an increase in transition costs, as reductions in gross emissions should be obtained in a different way; on the other hand, high reliance on CDR is also a risk if the technology does not become more widely available in the coming years.
+ Risks will be higher in the countries and regions that have stronger policy. For example in Net Zero 2050, various countries and regions reach net zero GHG by 2050, while many others have emission of several Gt of CO_2eq .
^ This assessment is based on expert judgment based on how changing this assumption affects key drivers of physical and transition risk. For example, higher temperatures are correlated with higher impacts on physical assets and the economy. On the transition side economic and financial impacts increase with: a) strong, sudden and/or divergent policy, b) fast technological change even if carbon price changes are modest, c) limited availability of carbon dioxide removal meaning the transition must be more abrupt in other parts of the economy, d) stronger policy in those particular countries and/or regions.

Scenario narratives

Each NGFS scenario explores a different set of assumptions for how climate policy, emissions, and temperatures evolve.

Orderly

Net Zero 2050 limits global warming to 1.5°C through stringent climate policies and innovation, reaching global net zero CO_2 emissions around 2050. Some jurisdictions such as the US, EU, UK, Canada, Australia and Japan reach net zero for all GHGs.

Below 2°C gradually increases the stringency of climate policies, giving a 67% chance of limiting global warming to below 2°C.

Disorderly

Divergent Net Zero reaches net zero around 2050 but with higher costs due to divergent policies introduced across sectors* leading to a quicker phase out of oil use.

Delayed transition assumes annual emissions do not decrease until 2030. Strong policies are needed to limit warming to below 2°C. Negative emissions are limited.

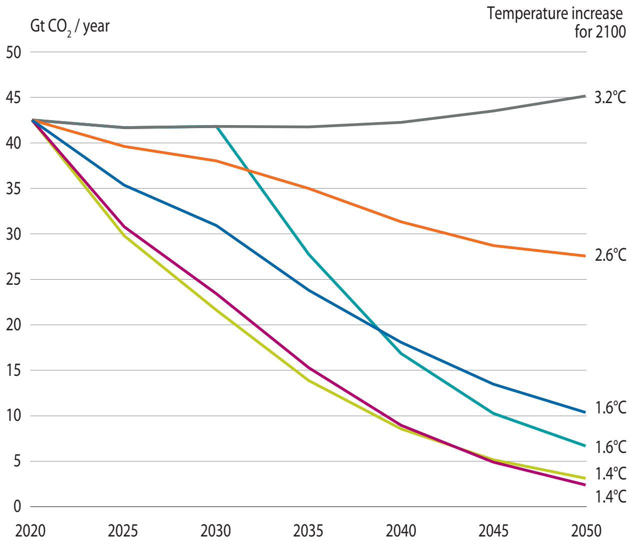
Hot house world

Nationally Determined Contributions (NDCs) includes all pledged targets even if not yet backed up by implemented effective policies.

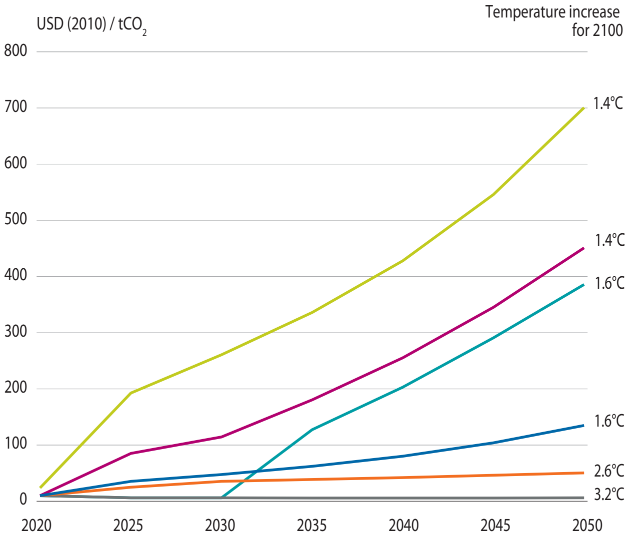
Current Policies assumes that only currently implemented policies are preserved, leading to high physical risks.

* Therefore, carbon prices vary across sectors.

CO_2 emissions by scenario



Carbon price development



Delayed Transition — Divergent Net Zero — Current Policies — NDCs — Net Zero 2050 — Below 2°C

World aggregates mask strong differences across sectors and jurisdictions. Regionally and sectorally granular information is available on the IIASA database. End of century warming outcomes shown. 5-year time step data.
Source: IIASA NGFS Climate Scenarios Database, REMIND model.

The chart represents shadow carbon prices, which is a measure of policy intensity. Carbon prices are weighted global. Regionally and sectorally granular information is available on the IIASA database.
Source: IIASA NGFS Climate Scenarios Database, REMIND model.

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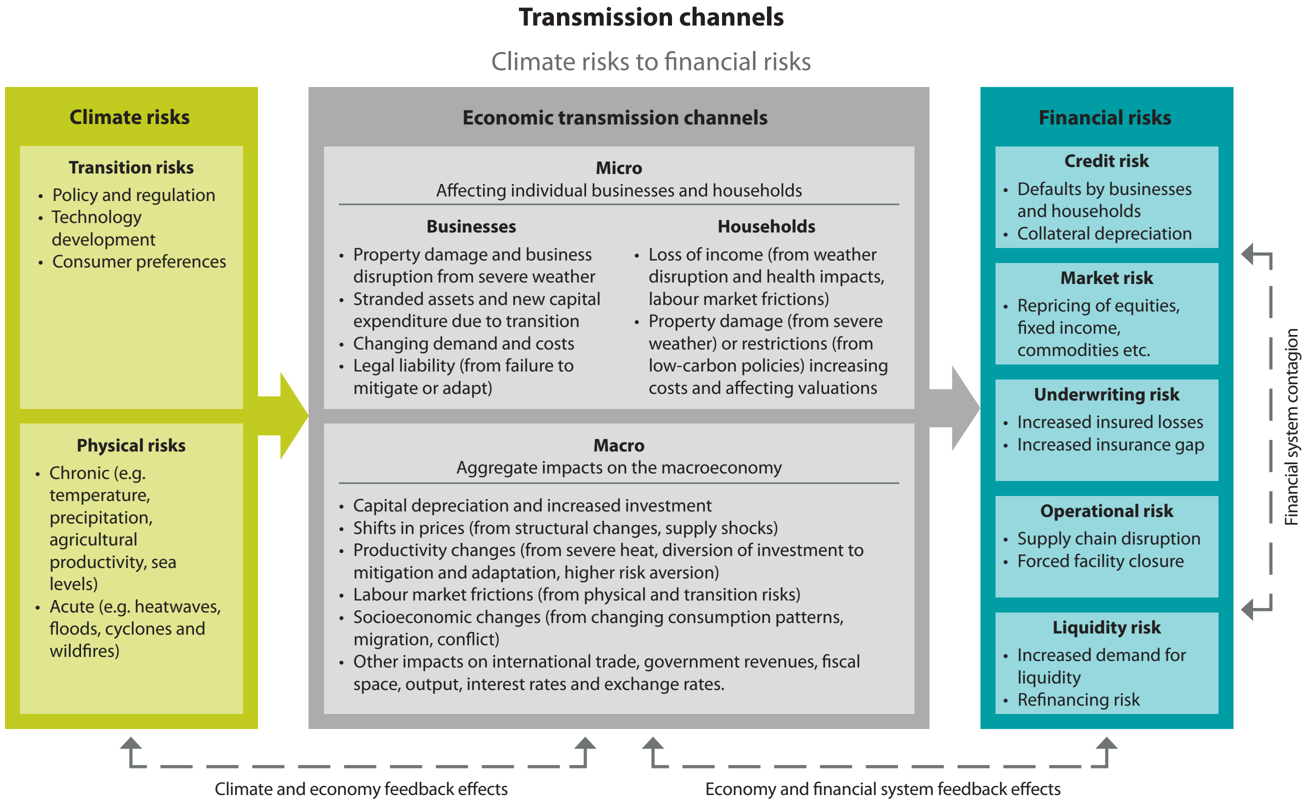
Transmission channels

Climate risks could affect the economy and financial system through a range of different transmission channels.

- **Transition risks** will affect the profitability of businesses and wealth of households, creating financial risks for lenders and investors. They will also affect the broader economy through investment, productivity and relative price channels, particularly if the transition leads to stranded assets.

- **Physical risks** affect the economy in two ways.
  - **Acute impacts** from extreme weather events can lead to business disruption and damages to property. There is some evidence that with increased warming they could also lead to persistent longer term impacts on the economy. These events can increase underwriting risks for insurers, possibly leading to lower insurance coverage in some regions, and impair asset values.
  - **Chronic impacts**, particularly from increased temperatures, sea levels rise and precipitation, may affect labour, capital, land and natural capital in specific areas. These changes will require a significant level of investment and adaptation from companies, households and governments.

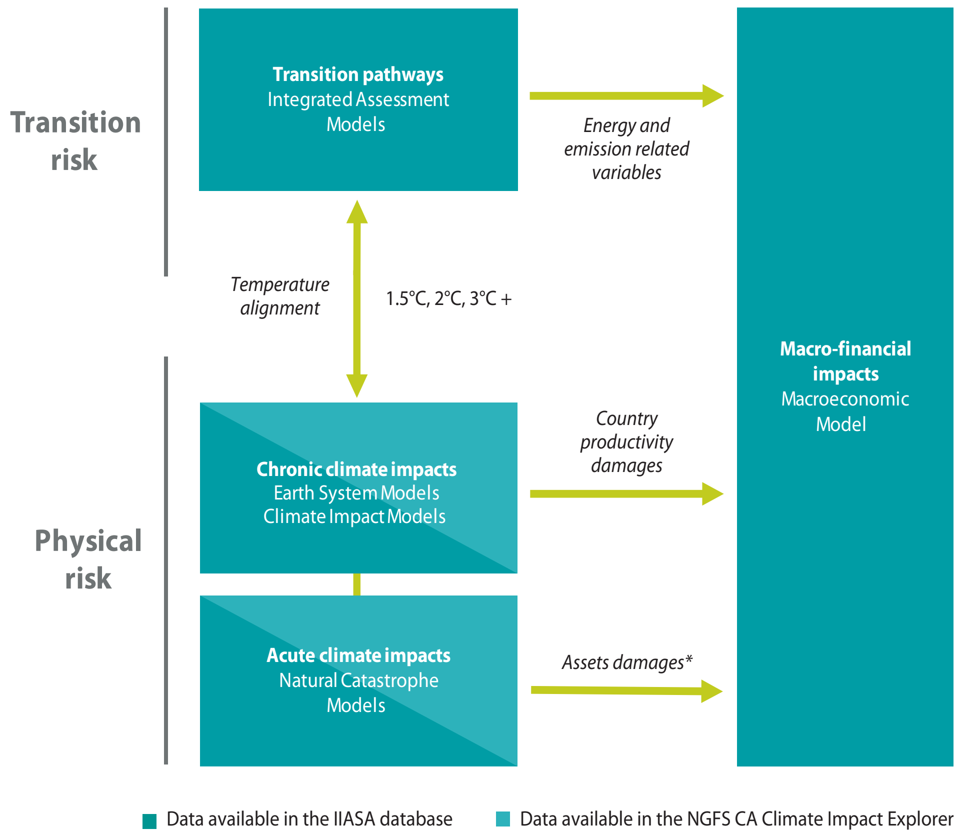


Models, data and navigation tools (1/2)

The NGFS scenarios provide a range of data on transition risks, physical risks and economic impacts. This is produced by a suite of models aligned in a coherent way.

- Transition and economic variables are made available in the NGFS Scenarios Database hosted by IIASA. The transition pathways were produced by three IAM teams: PIK (REMIND-MAgPIE model), IIASA (MESSAGEix-GLOBIOM model) and UMD (GCAM model). Economic variables were produced by the National Institute for Economic and Social Research (NIESR) (NiGEM model).
- Climate variables can be explored through the NGFS Climate Impact Explorer hosted by Climate Analytics. More granular data are available via the ISIMIP project. Physical risk analysis was supported by Climate Analytics, ETH Zurich and PIK.
- Key data and resources can be explored interactively on the NGFS Scenarios Portal.

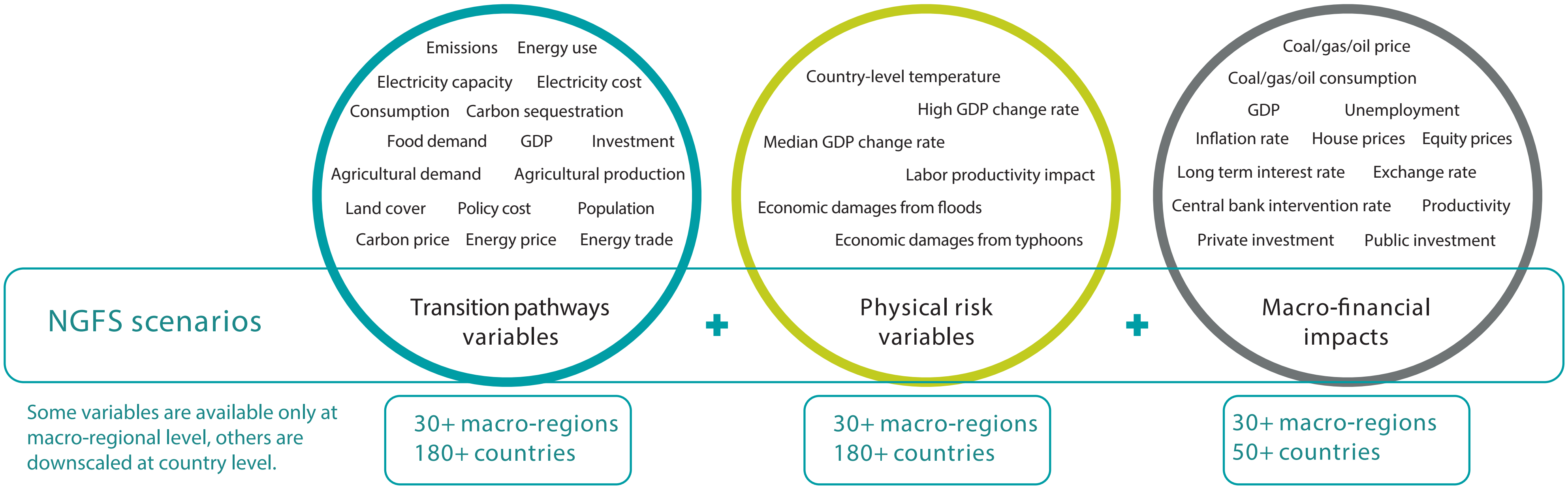
NGFS suite of models approach



The current acute physical impacts include GDP effects from extreme events, but exclude capital stock effects.

Models, data and navigation tools (2/2)

The NGFS scenarios consist of a set of climate-related and macro-financial variables available for each model, scenario and geography.



This slide does not contain the full list of variables and is for illustrative purposes only. The names of the variables do not necessarily correspond to the ones used in the IIASA Portal. The number of countries/regions available varies significantly depending on the variable. Downscaled climate-related and macro-financial variables are available for 180+ and 50+ countries, respectively. Physical risk variables such as labour productivity impact can be accessed on the Climate Impact Explorer.

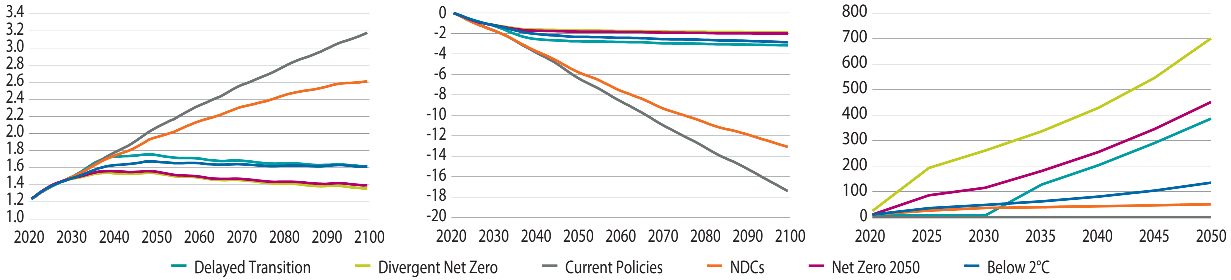
Key results

Integrated Assessment Models (IAMs) and damage function

Temperature evolution
Median, °C

Chronic physical risk impact
Asset & productivity damages (% of GDP) due to high global mean temperature

Transition risk impact
Carbon price increase (USD/tCO_2)



Other transition risk variables: energy investment, emissions and energy mix, etc.

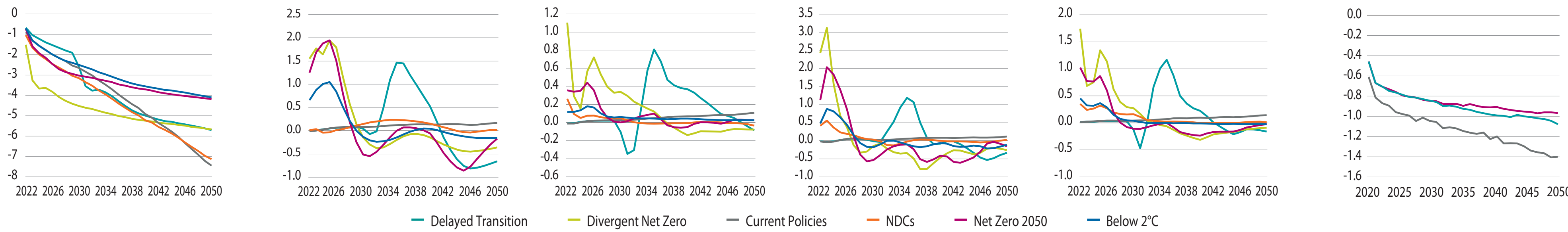
Source: IIASA NGFS Climate Scenarios Database, REMIND model.

NiGEM

GDP impact
Per cent change from baseline*

Inflation impact
pp change from baseline*
China | Europe | Latin America | United States

Acute physical risk
GDP impact as % change from baseline



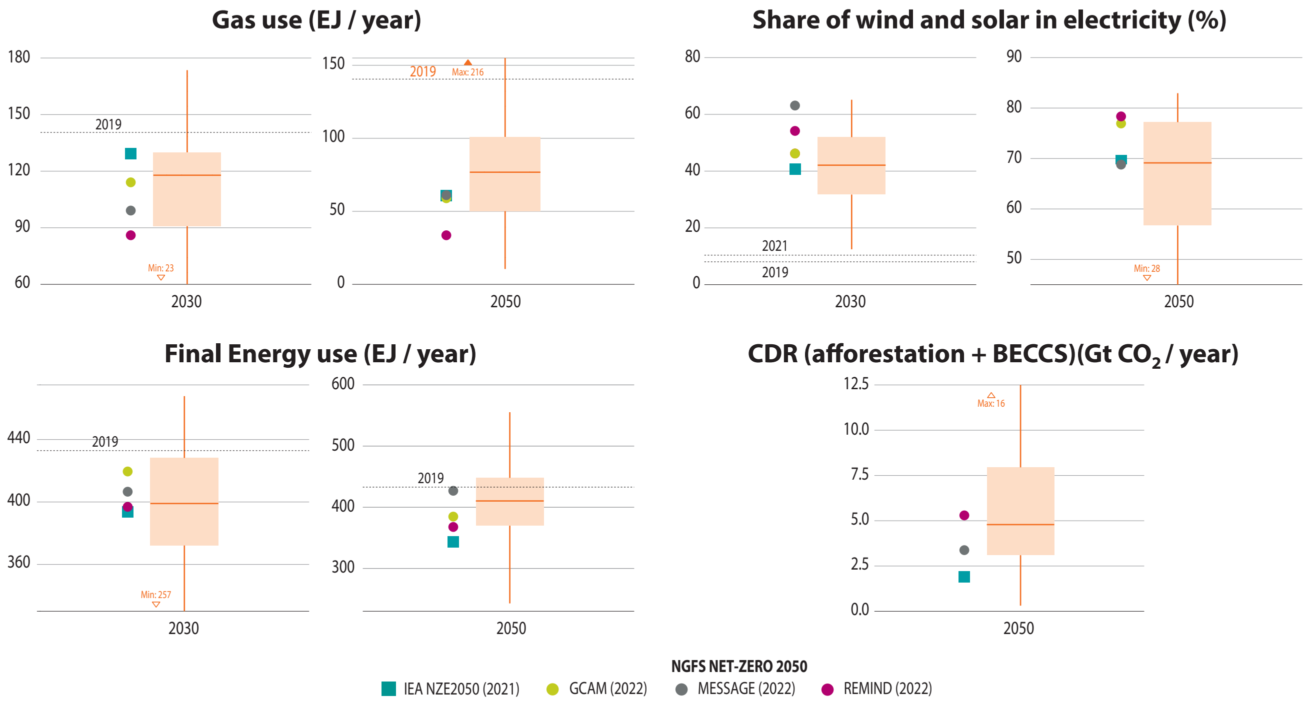
Other macro-financial variables: unemployment, equity prices, trade, interest rates, etc.

* The baseline is a hypothetical scenario with no transition nor physical risk.
Source: IIASA NGFS Climate Scenarios Database, NiGEM with REMIND inputs.

Comparison with IPCC and IEA scenarios

The IPCC, the IEA and the NGFS all use Integrated Assessment Models (IAMs) to provide transition pathways for various narratives, with different but consistent results.

- The NGFS Phase II scenarios were assessed in AR6 of IPCC WG III and were integrated in its final report. They cover a small range of input and model assumptions but have on average higher sectoral and regional granularity than the rest of emission scenarios assessed by WG III.
- The NGFS Phase II GCAM Current Policies scenario was selected as a *Reference pathway* by the WG III as a comparison to the Illustrative Mitigation Pathways.
- As they were developed for risk assessment purposes, the NGFS Scenarios do not always have equivalents in the IEA or IPCC realms because the latter focus on exploring transition pathways. However, Net Zero 2050 scenarios are well aligned on a number of dimensions (graphs on the right).
- The latest vintage of NGFS scenarios (Phase III), published after the release of AR6 reports, are here compared to AR6 and IEA scenarios.



* The boxplots show the values for 25th, 50th and 75th percentiles (orange boxes) and min/max values (whiskers) across C1 scenarios in the AR6 database.

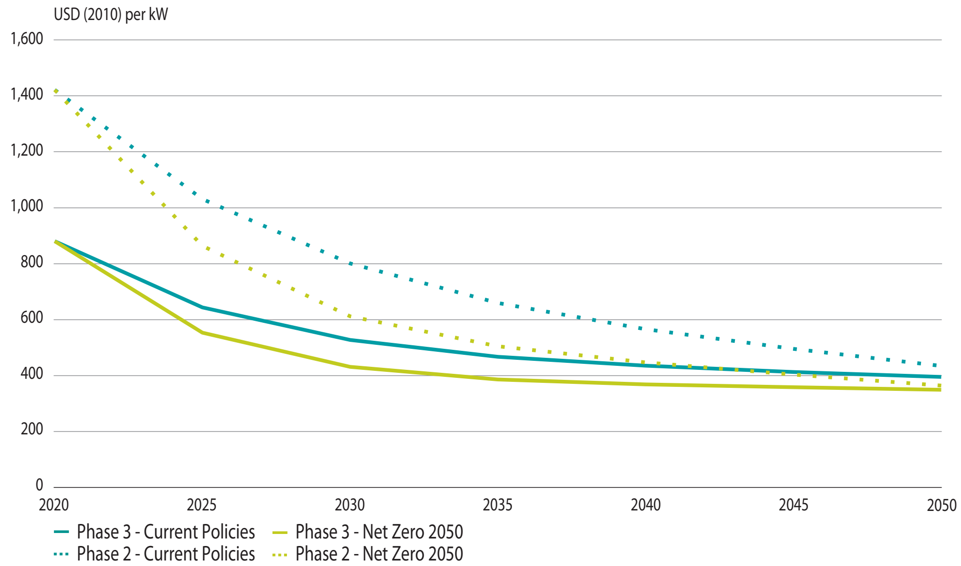
What's new in the NGFS Scenarios

Update Overview

The NGFS scenarios have been brought up-to-date with new economic and climate data, policy commitments and model versions.

- Phase III of the NGFS scenarios reflect the new country-level commitments to reach net-zero emissions made at COP26 in November 2021, as well as all commitments made until March 2022.
- The scenarios also include data to reflect the latest trends in renewable energy technologies (e.g. solar and wind), and key mitigation technologies.
- Similarly, data for GDP and population in the scenarios have been updated using the latest snapshot from the IMF World Economic Outlook 2021, including COVID-19.
- The current data do not yet account for the war in Ukraine as the situation and its aftermath are still unclear and therefore difficult to model. See the document Not too late – Confronting the growing odds of a late and disorderly transition.

Capital cost of Solar PV



Source : IIASA NGFS Climate Scenarios Database, REMIND model.

Improved modelling of physical risks (1/2)

Estimates of GDP losses from chronic risks now more fully account for model uncertainty.

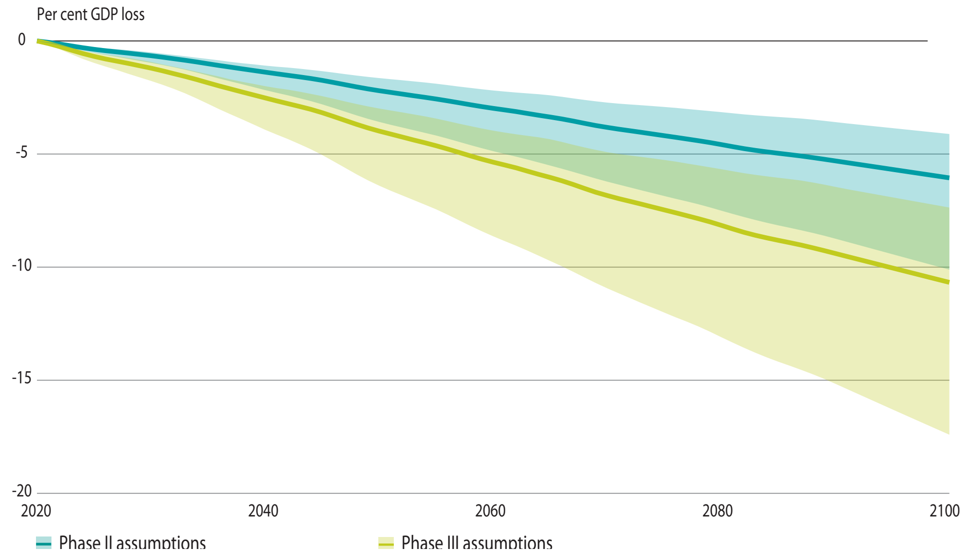
- GDP losses arising from an increase in global mean temperature are based on the damage function methodology set out in Kalkuhl & Wenz (2020), which can be used to extrapolate observed damages from year-to-year variations in chronic climate hazards due to climate change in the future.

- The application of this damage function within the Phase III scenarios (in green in the chart) now show a stronger impact and a wider range of uncertainty arising from increases in global mean temperature.

- The 95th percentile of the impact distribution given by the damage function is now used, instead of the median, to reflect the uncertainty inherent in the modelling of the macroeconomic effects of chronic physical risks.

- The new damage function estimates have been inputted into NiGEM, the macroeconomic model in the NGFS scenarios, to derive a set of impacts on GDP. GDP losses from chronic physical risks reaches more than 6% in 2050, and up to 18% by the end of the century in the Current Policies scenario.

Model uncertainty on chronic physical risk GDP losses (Current policies)



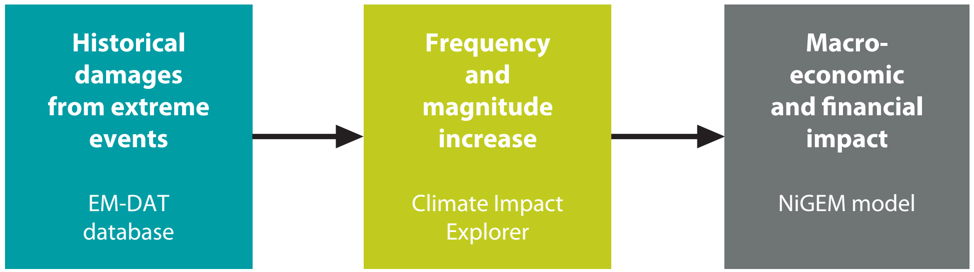
Source: IIASA NGFS Climate Scenario Database – Kalkuhl and Wenz (2020) damage function with temperature trajectory resulting from REMIND model emissions. The baseline is scenario (from IAM outputs) with no transition nor physical risk.

Improved modelling of physical risks (2/2)

Acute physical risks were included for the first time via the integration of stochastic shocks.

- For the first time since their launch, the NGFS scenarios provide an indicative illustration of the impacts of acute physical risks for different scenarios.
- Using historical shock data from the Emergency Events Database (EM-DAT) historic economic damages from weather-related natural disasters have been derived to model stochastic shocks for acute risks in NiGEM.
- "Multipliers" were then computed using selected Climate Impact Explorer indicators^ to derive the future trends for acute risks, providing damage pathways for 3 NGFS scenarios. They were used as input to NiGEM for approximating future changes in damages to GDP* related to acute risks from climate change.

Modelling of acute physical risk



^ focusing on cyclones and river flood damage estimates from the CLIMADA model.
* The impact of acute physical risk on macrofinancial variables other than GDP is not available in this iteration of the NGFS Scenarios.

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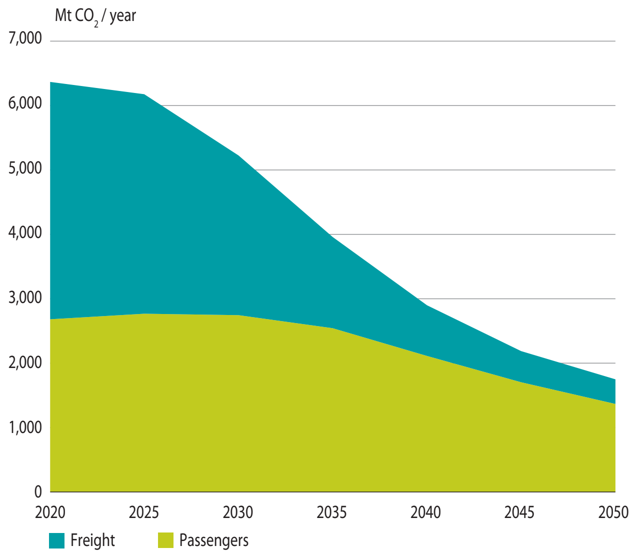
Increased sectoral breakdown

Transition risks are represented with increased granularity in certain sectors.

- The reflection of the **transport and industry sectors** has been improved across all six scenarios within REMIND and GCAM.
- Within the MESSAGE model, the industry sector has been updated with increased granularity.
- Separately to the sectoral updates appearing in the Phase III package, the NGFS has conducted a pilot project with the G-Cubed model, exploring the feasibility of this model for improving the sectoral breakdown of the scenarios. While the G-Cubed model has not been integrated into the Phase III package, the results of the pilot exercise and accompanying data are available for download here.

Emissions of road transportation

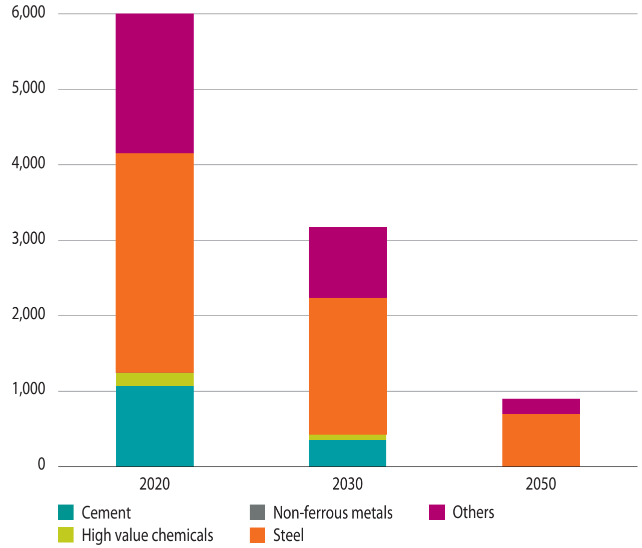
Net-Zero 2050



Source: IIASA NGFS Scenario Database, REMIND model.

Industrial CO_2 emissions due to energy consumption

Net-Zero 2050



Source: IIASA NGFS Scenario Database, MESSAGE model.

Main results of the NGFS Scenarios

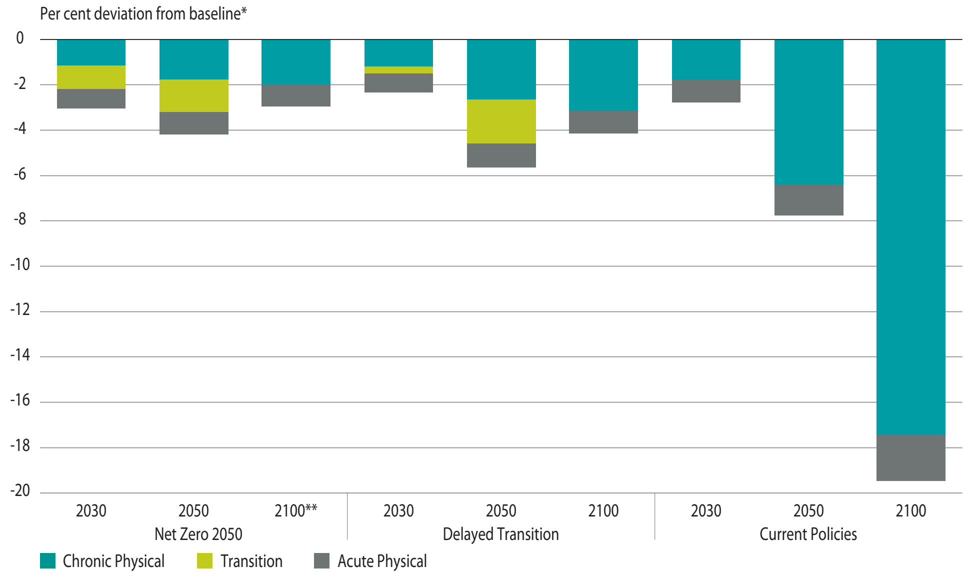
Key macrofinancial results

Gross domestic product (1/2)

Scenarios differ markedly in their economic impact, with significant uncertainty in the size of the estimates and variation across regions.

- Impacts on GDP (right chart) are specified relative to a forecast representing prior trends but also incorporating some of the near-term impacts from COVID-19.
- **Transition risks** have a moderately negative impact on world GDP in Net Zero 2050 as negative impacts on demand from higher carbon prices and energy costs are only partially offset by the recycling of carbon revenues into government investment and lower employment taxes. GDP impacts from transition risk are more markedly negative in the disorderly scenarios as the speed of the transition combined with investment uncertainty affects consumption and investment.
- GDP losses from **physical risk** vary in line with different temperatures projected for each scenario. In the first half of the century impacts are similar, however they start strongly diverging thereafter. By 2100 impacts are by far highest in the Current Policies scenario (up to 20 % of GDP relative to prior trend) as temperature targets and the corresponding decarbonisation are missed.
- For all scenarios and time scales, physical risks outweigh transition risks. Stringent mitigation in line with the Net Zero 2050 scenario will already be beneficial by 2050 and strongly reduces risks towards the end of the century. This also underlines the need to add investments on **adaptation**.

GDP deviation due to transition, chronic and acute risks - REMIND model



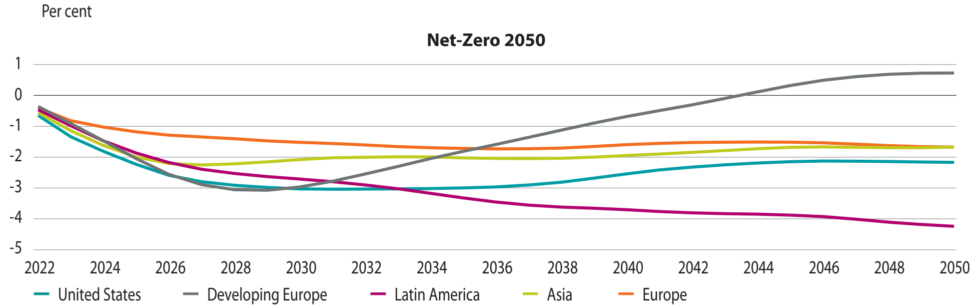
* The NiGEM baseline is a hypothetical scenario with no transition nor physical risk.
** Economic impacts are modelled out to 2050. To obtain an estimate of impacts in 2100, we took the estimate of chronic physical risk impacts based on the damage function, extrapolated acute physical risk increase (based on the period 2022-2050) up to 2100, and assumed no transition risk impacts at this point (ie. the GDP loss is solely due to physical risk).
Source: IIASA NGFS Climate Scenarios Database, NiGEM model (REMIND inputs).

Gross domestic product (2/2)

The NiGEM model provides economic impacts per country and region, giving estimates of country's exposure to transition and physical risks.

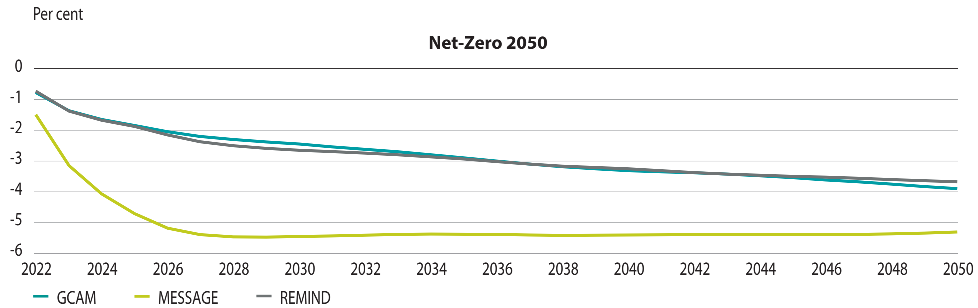
- In the NGFS Scenarios, both transition and physical risk impacts vary across countries according to various factors.
- Transition risk depends, among others, on the structure of the economy, the dependence on fossil fuels and trade composition. Physical risk depends on the exposure and vulnerability to temperature increase and extreme weather events, with tropical and subtropical regions facing larger risk increases.
- NiGEM provides country and regional pathways for GDP. Impacts are higher for countries and regions that face higher emissions reduction, higher carbon prices, lower fossil fuel exports or higher physical risk damages (upper chart).
- Impacts also vary across models, depending on model structure and assumptions. The lower chart shows GDP impacts in NiGEM, where NiGEM is calibrated based on inputs from the three IAMs (REMIND, MESSAGE, GCAM).
- Results from MESSAGE are more adverse because of lower CDR use, more ambitious temperature outcomes and stronger decarbonisation needed due to structurally higher energy demand in MESSAGE, therefore inducing higher carbon price.

GDP deviation relative to Baseline*,**



Source: IIASA NGFS Climate Scenarios Database, NiGEM model (REMIND inputs).

Global GDP deviation relative to Baseline



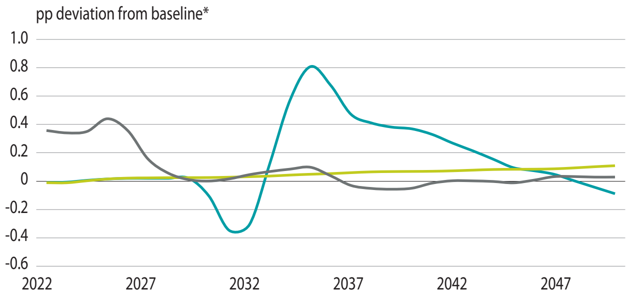
* The NiGEM baseline is a hypothetical scenario without transition nor physical risk.
** Country-level GDP includes transition and chronic physical risk only.
Source: IIASA NGFS Climate Scenarios Database, NiGEM model (REMIND inputs).

Inflation and unemployment

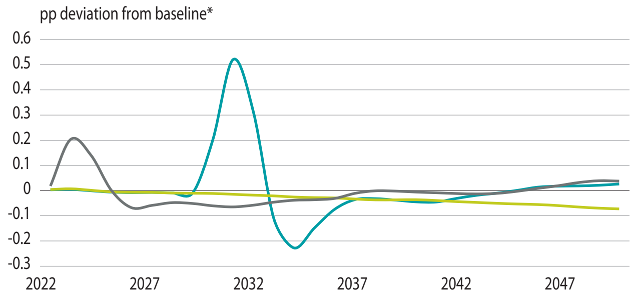
The scenarios include a wide range of macroeconomic variables, capturing structural relationships between key aggregates such as unemployment and inflation.

- In many countries, the implementation of carbon prices in the transition scenarios tends to raise energy costs in the short-term, initially weighing down on prices (as lower demand and financial market losses hit outputs). Rising carbon prices subsequently feed through to modest increases in **inflation** and **unemployment** before returning to prior trends. In some countries and time periods the offsetting positive growth effects from carbon revenue recycling leads to a reduction in unemployment.
- In some scenarios this leads to a potential **monetary policy tradeoff.** The NGFS modelling framework assumed a 'two-pillar' strategy, targeting a combination of inflation and nominal GDP as a default. This can be adjusted in the NiGEM model alongside fiscal policy assumptions (see slide 36).
- The negligible impacts in the Current Policies scenario reflect not only limited transition risk, but also the fact that only one potential physical risk transmission channel (productivity) has been modelled. More research is needed on the potential for climate impacts to raise inflation (e.g. through supply-side shortages) and/or unemployment (e.g. due to displacement).

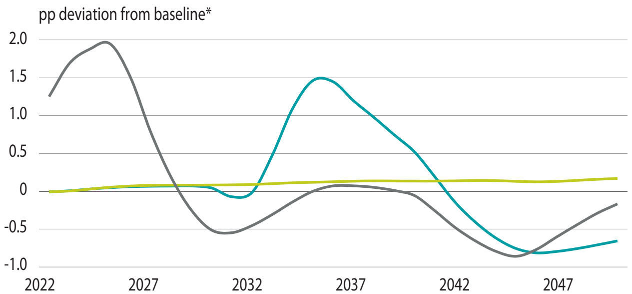
Inflation rate in Europe



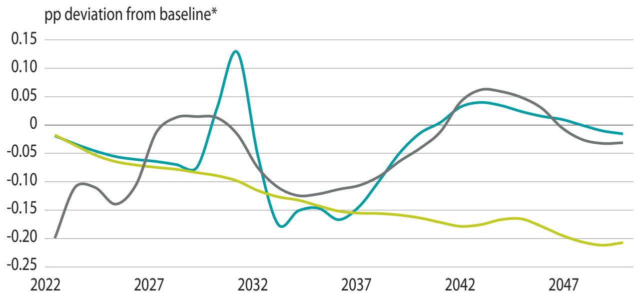
Unemployment rate in Europe



Inflation rate in China



Unemployment rate in China



— Delayed Transition — Current Policies — Net-Zero 2050

* The baseline is a hypothetical scenario with no transition nor physical risk.
Sources: NiGEM based on REMIND-MAgPIE IAM data and damage estimates from Kalkuhl & Wenz (2020).

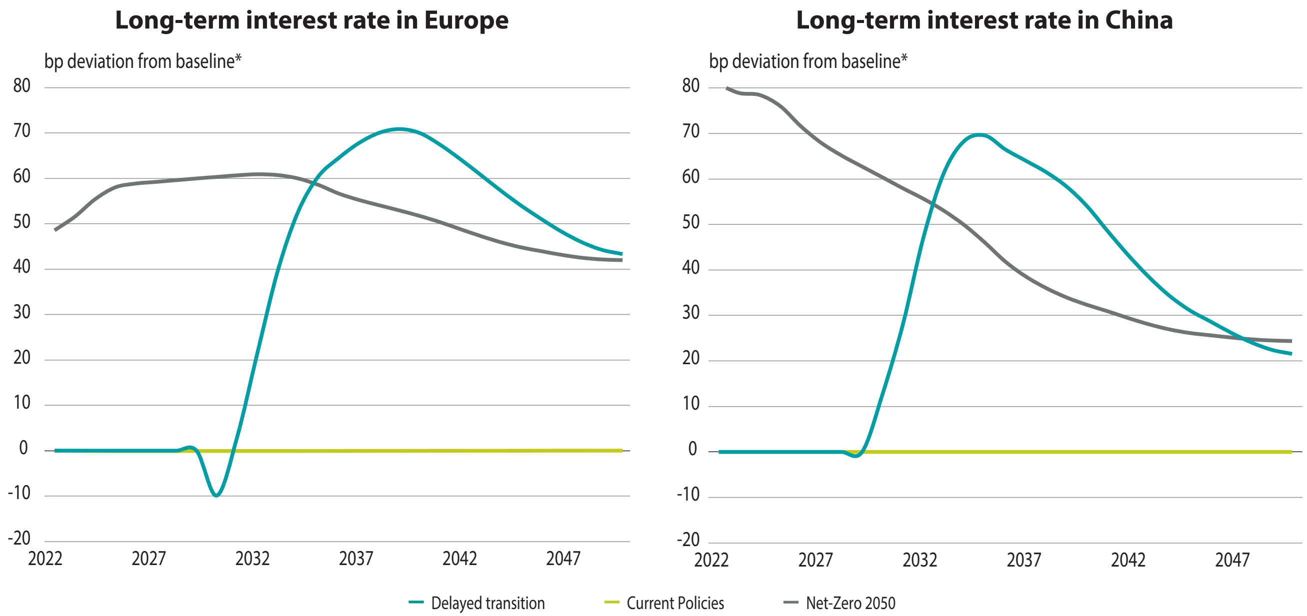
Financial markets

Climate change and transition policies create significant financial fluctuations. The macrofinancial results reflect both risks and opportunities.

- **Long-term interest rates** tend to increase in the transition scenarios, reflecting the inflationary pressure created by carbon prices, as well as the increased investment demand that the transition spurs on.

- Disorderly transitions can affect **real financial asset valuations** significantly, with considerable regional differences. Although the NiGEM results cannot be disaggregated into individual sectors, it is likely that sectors that can decarbonise less easily will be affected more than other sectors. The NGFS will work to further develop sectoral impacts going forward.

- In the disorderly scenarios we assumed that policy uncertainty leads to a higher investment premium. This lasts for two years, with the premium gradually returning to baseline thereafter. This occurs in the period 2021-2022 in the Divergent Net Zero policies scenario and 2030-2031 in the Delayed Transition scenario.



* The baseline is a hypothetical scenario with no transition nor physical risk.
Sources: NiGEM based on REMIND-MAgPIE IAM data and damage estimates from Kalkuhl & Wenz (2020).

Main results of the NGFS Scenarios

Transition risk

Understanding transition risk

Eliminating most greenhouse gas emissions will affect all sectors of the economy, and gives rise to transition risks for the economy and financial system.

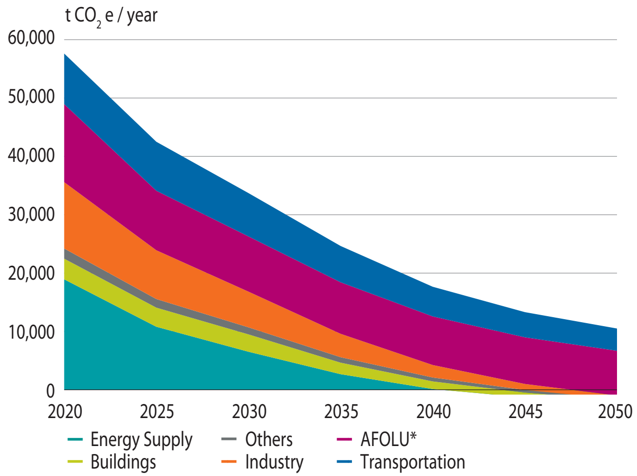
- Transitioning away from fossil fuels and carbon-intensive production and consumption requires a significant shift towards emissions-neutral alternatives in all sectors (left chart). Policy-makers can induce this transition by increasing the implicit cost of emissions. As it takes time to develop and deploy alternative technologies, climate policies may lead to higher costs in the interim.

- The transition pathways have been modelled using three detailed **Integrated Assessment Models** (IAMs)*. They can be used to assess the changes in energy, land-use and policy needed to meet a particular temperature outcome or carbon budget (right figure). The shadow carbon price underpinning those changes has been derived for each model. This price is distinct of, and may differ, from the social cost of carbon, which depends on an assessment of avoided damages and valuing impacts on present vs. future generations.

* These models have been used extensively to inform policy and decision makers and feature in several climate assessment reports, c.f. IPCC, 2018, IPCC, 2022, UNEP, 2018.

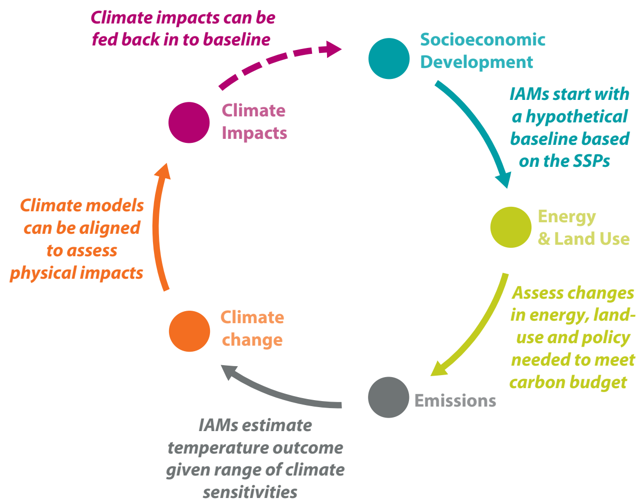
Sectoral GHG emissions

Net Zero 2050



* AFOLU: Agriculture, Forestry and Other Land Use.

Modelling climate policy and climate change



Source: SENSES project.

Emissions prices

A key indicator of the level of transition risk is the shadow emissions price, a proxy for government policy intensity and changes in technology and consumer preferences.

- In the IAMs used to produce the NGFS scenarios, a higher emissions price* implies more stringent policy. Models suggest that a carbon price of around $(2010)200/ton would be needed in the next decade to incentivise a transition towards net zero by 2050 (lower chart).

- This shadow price is a measure of overall policy intensity. In reality, governments are pursuing a range of fiscal and regulatory policies, which have varying costs and benefits.

- Shadow emission prices are sensitive to:

  – The level of ambition to mitigate climate change. Higher ambition translates into higher emissions prices.

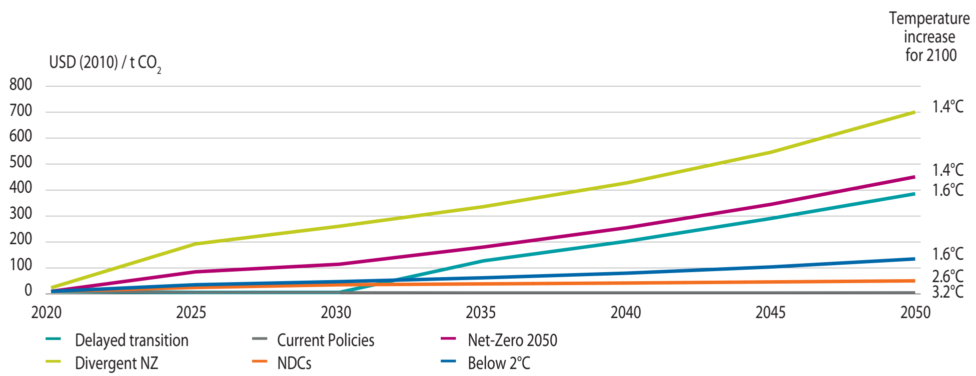
  – The timing of policy implementation. Higher emissions prices are needed in the medium to long-term if action is delayed.

  – The distribution of policy measures across sectors and regions, which are assumed to be differentiated in the Divergent Net Zero scenario.

  – Technology assumptions such as the availability and viability of carbon dioxide removal.

* Emissions prices are defined as the marginal abatement cost of an incremental tonne of greenhouse gas emissions. Prices are influenced by the stringency of policy as well as how technology costs will evolve. Prices tend to be lower in emerging economies as there tends to be a greater number of low-cost abatement options still available.

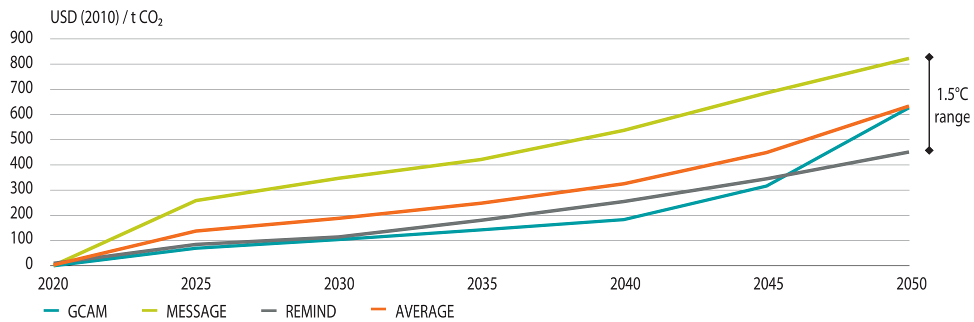
Carbon price development



The chart represents shadow carbon prices, which is a measure of policy intensity. Carbon prices are weighted global. Regionally and sectorally granular information is available on the IIASA database.
Source: IIASA NGFS Climate Scenarios Database, REMIND model.

Carbon Price across models

Net Zero 2050



Source : IIASA NGFS Climate Scenarios Database.

NGFS Central Banks and Supervisors Network for Greening the Financial System

Carbon dioxide removal

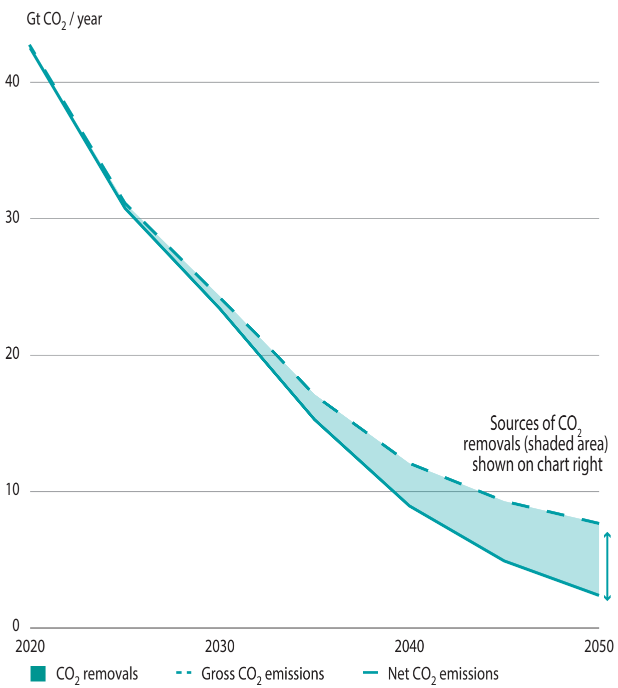
The speed and timing of the transition depends on the availability and deployment of various forms of carbon dioxide removal, i.e. the long-term storage of carbon in soils, plants and rocks.

- **Carbon Dioxide Removal** (CDR) involves removing carbon from the atmosphere through increasing forest cover and soil sequestration (land use) or growing crops for bioenergy (bioenergy with carbon capture and storage, BECCS).

- CDR assumptions play an important role in IAMs. If deployed effectively lower warming outcomes could be achieved, or targets could be reached sooner given the practical difficulty of eliminating all emissions in the near term. However, they only currently take place on a limited scale and face their own challenges.

- The NGFS scenarios assume **low to medium availability of these technologies**. However patterns vary strongly across models (right chart) depending on cost assumptions. They also vary substantially across countries depending on the costs and availability of CDR options.

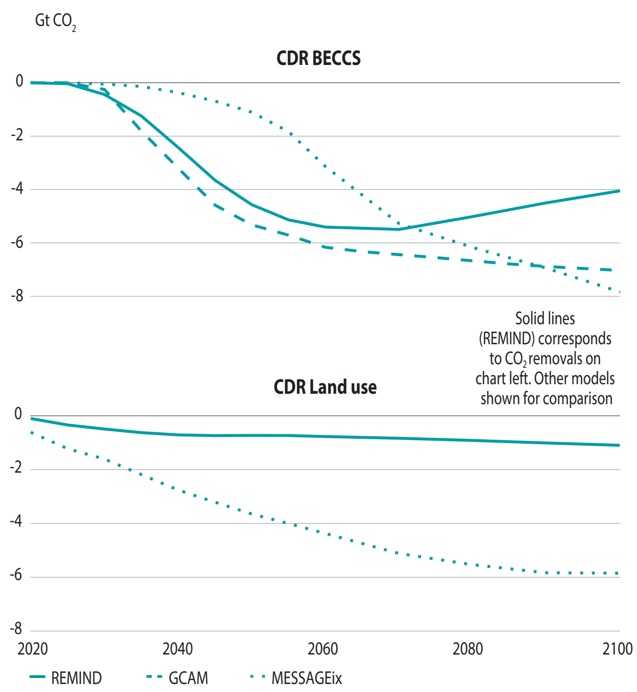
CO_2 removals in Net Zero 2050



Source: IIASA NGFS Climate Scenarios Database , REMIND model.

CO_2 removals across models

Net Zero 2050



Source: IIASA NGFS Climate Scenarios Database.

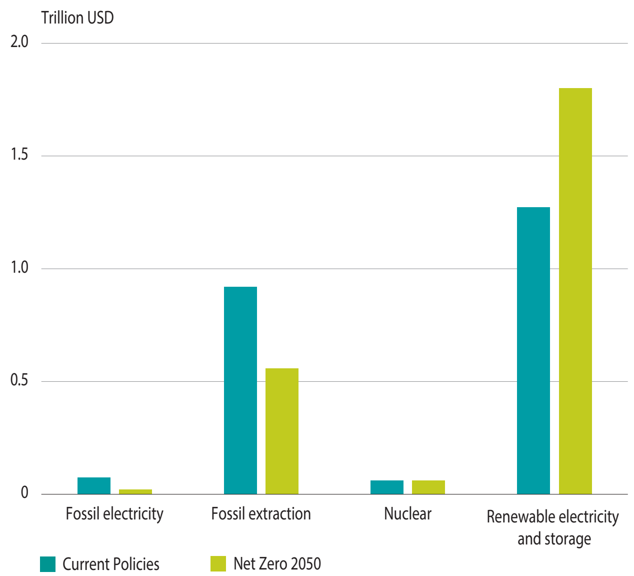
Energy investment

Significant investment flows would need to be directed towards green energy in the coming decades to achieve net zero.

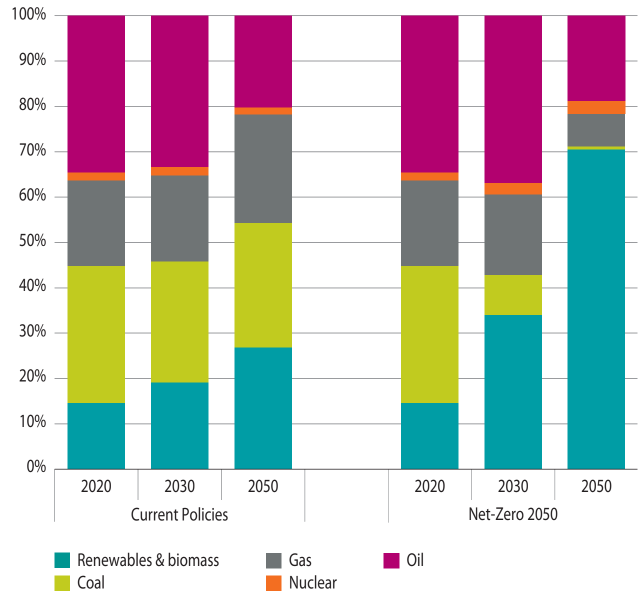
- Transitioning to a net zero economy would require investment flows to be geared towards mass deployment of green electricity and electricity storage (left chart). There is some legacy capital investment in fossil fuel extraction, which is a measure of all investments in mining, shipping and ports for fossil fuels, transmission and distribution for gas as well as the transport and refining for oil to maintain the infrastructure while phasing down the overall capacity. Given its high CO2 emissions relative to other fossil fuel alternative, the share of coal is rapidly phased out in the energy mix from 28% in 2020 to 7% in 2030 and close to 0% in 2050.

- By 2050, renewables and biomass would deliver 70% of global primary energy needs in the Net Zero 2050 scenario (right chart). This is a marked contrast to the Current Policies scenario where fossil fuels continue to be the dominant source of primary energy, even after accounting for current technology trends.

Average annual energy investment to 2050



Primary energy mix per scenario



Direct equivalent accounting method used, which is predominant in publications on long-term transition pathways.
See Technical Documentation for further details.
Source : IIASA NGFS Climate Scenarios Database, REMIND model.

Main results of the NGFS Scenarios

Physical risk

Temperature rise

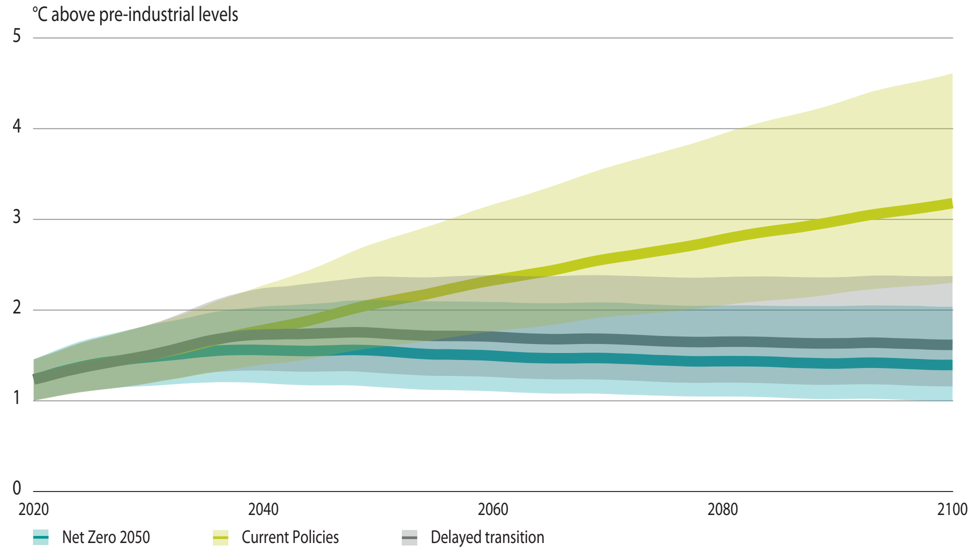
Mean temperatures rise in all scenarios, exceeding 3°C in Current Policies. Changing climate conditions affect physical labour productivity and lead to severe and irreversible impacts.

- Global mean temperatures have increased by around 1.1°C from pre-industrial levels. Temperatures to date are very likely higher than at any time in the last 12,000 years, the period in which human civilisation has developed* and the speed of the current increase is unmatched over the past 2,000 years**.

- In scenarios where climate goals are met deep reductions in emissions are needed to limit the rise in global mean temperatures to below 1.5°C or 2°C by the end of the century. This does not occur in the Current policies scenario, leading to a temperature rise exceeding 3°C and severe and irreversible impacts. Temperatures are increasing unevenly across the world with land warming faster than oceans and high latitudes experiencing higher warming.

- Temperature changes lead to chronic changes in living conditions affecting health, labour productivity, agriculture, ecosystems and sea-level rise. It is also changing the frequency and severity of severe weather events such as heatwaves, droughts, wildfires, tropical cyclones and flooding.

Global mean temperature rise



Source: IIASA NGFS Climate Scenarios Database, REMIND model.

* See Kaufman, D, et al. (2020).
** See IPCC (2021).

GDP loss estimates from chronic risks

Global warming, and the associated changes in climate, will have significant impacts on the economy by the end of the century in a Hot house world scenario.

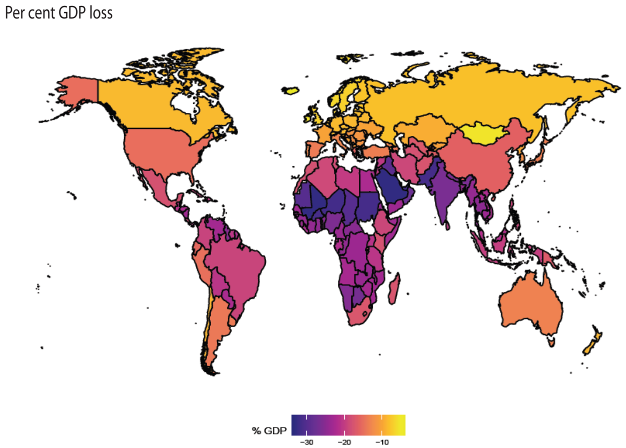
- Estimates of GDP losses from chronic risks vary considerably depending on assumptions about climate sensitivity and the method used to estimate the damages. The NGFS estimates have been updated to take into account model uncertainty and now include higher damages.

- GDP losses were calculated based on the methodology set out in Kalkuhl and Wenz (2020) at the country level for the change in average temperature in each scenario compared to the previous year. Estimates suggest a global GDP impact of up to 18% relative to a prior trends baseline in the current policies scenario. Losses are much higher in tropical regions (left chart).

- The methodology does not include impacts related to extreme weather, sea-level rise or wider societal impacts from migration or conflict. For given countries these would likely strongly increase the physical risk. These estimates also do not fully capture adaptation, which would reduce impacts but require significant investment.

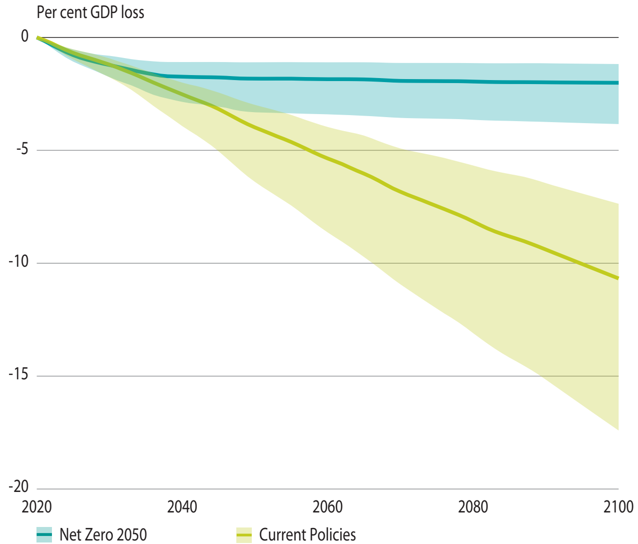
Physical risk GDP losses by country

Current policies (95th percentile damages)



Source: Calculations by PIK based on scenario temperature outcomes and damage estimates from Kalkuhl and Wenz (2020). Base year for warming is 2005.

Physical risk GDP losses



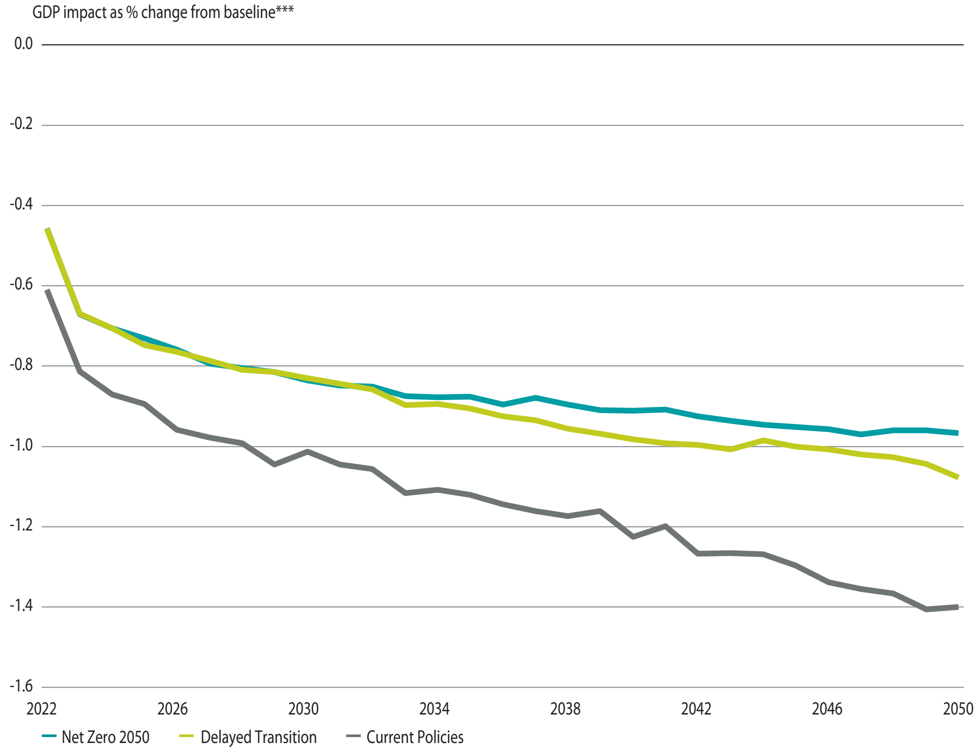
Source: IIASA NGFS Climate Scenarios Database, REMIND model.

GDP loss estimates from acute risks

For the first time, NGFS scenarios include estimates of macroeconomic impact of acute physical risks.

- Observed climate change of 1.1°C has already more than doubled both the global land area and the global population annually exposed to river flood, crop failure, tropical cyclones, wildfire, drought and heatwaves (Lange et al., 2020)
- Global warming of 2°C relative to preindustrial conditions is projected to lead to a fivefold increase in exposure to all types of natural hazards globally. The most pronounced increases are projected for droughts and heatwaves.
- Changes in exposure are unevenly distributed, with tropical and subtropical regions facing larger increases than higher latitudes.
- The NGFS scenarios now include estimates of global GDP impacts from acute physical risks* for 3 NGFS scenarios.
- Information from the international disaster database EM-DAT is used to approximate historic damages from weather-related extreme events to derive stochastic shocks as inputs to the NiGEM model.
- Projections for selected CIE indicators** are used to derive changes to projected damages for the future for the 3 NGFS scenarios in the CIE.

Acute physical risk



Source: NiGEM model, based EM-DAT data and CIE-based multipliers for acute risks.

* The impact of acute physical risk on macrofinancial variables other than GDP is not available in this iteration of the NGFS Scenarios.
** Acute risks taken into account for these projected damages include cyclones and river floods based on the CLIMADA model.
*** The baseline is a hypothetical scenario with no transition nor physical risk.

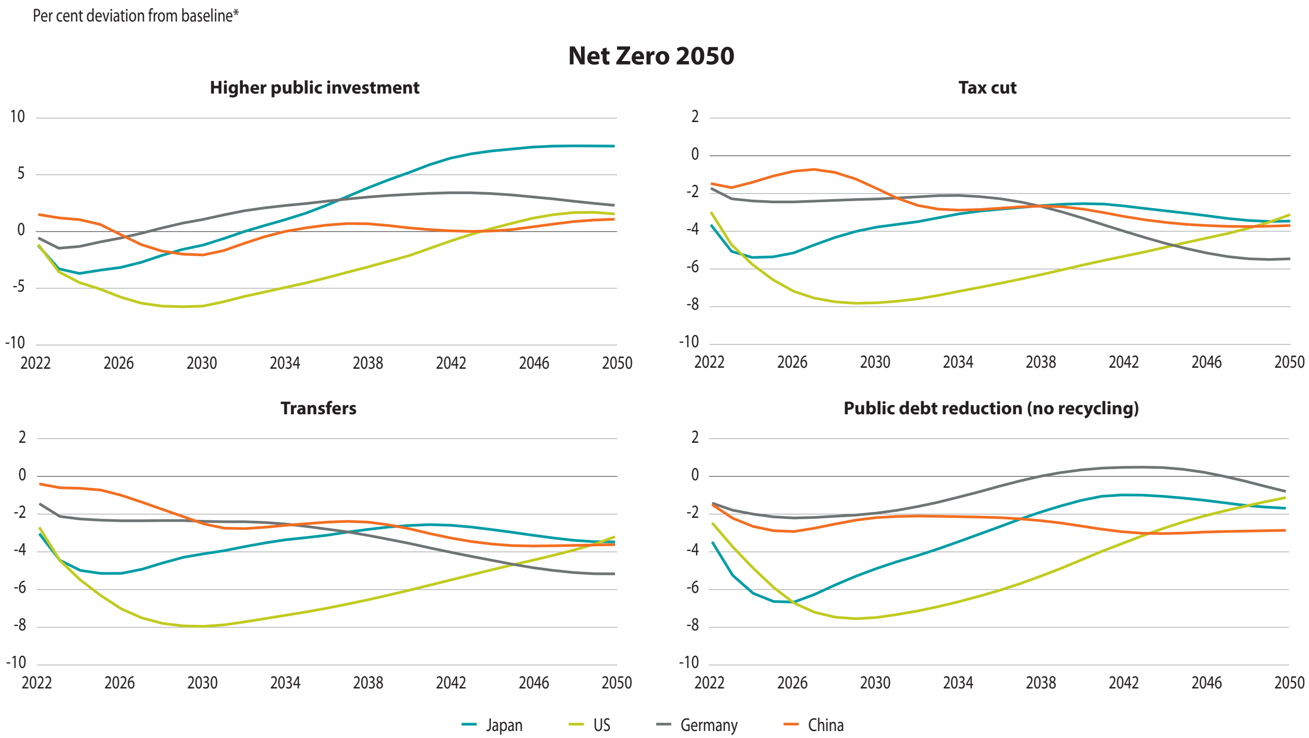
Scenarios applications

Sensitivity around macroeconomic policy assumptions (1/2)

Fiscal and monetary policy assumptions affect the NGFS scenarios pathways.

- Alternative macroeconomic policy assumptions have been explored to understand the **sensitivity of the NGFS scenarios to differing narratives about the future state of the policy landscape.** The macroeconomic implications of these pathways have been explored using NiGEM (with REMIND inputs) and using Phase II data.
- Regarding **fiscal policy assumptions**, four different options are considered to recycle carbon tax revenues: an increase in public investment, a cut in taxes applied to private sector agents, an increase in transfers to households and the reimbursement of public debt.
- **Recycling through public investment brings the strongest stimulus to economic activity** (see Charts). Despite different short- to medium-term dynamics, **the long-term impact in the cases of tax cuts or transfers is rather similar across countries** with a permanent decline in GDP compared to baseline. Finally, **using carbon tax revenues to reduce public debt yields to broadly neutral impacts in the long-term.**

GDP impact of various fiscal revenue recycling options for selected economies



* The baseline is a hypothetical scenario with no transition nor physical risk.
Source : NGFS work, based on Phase II data.

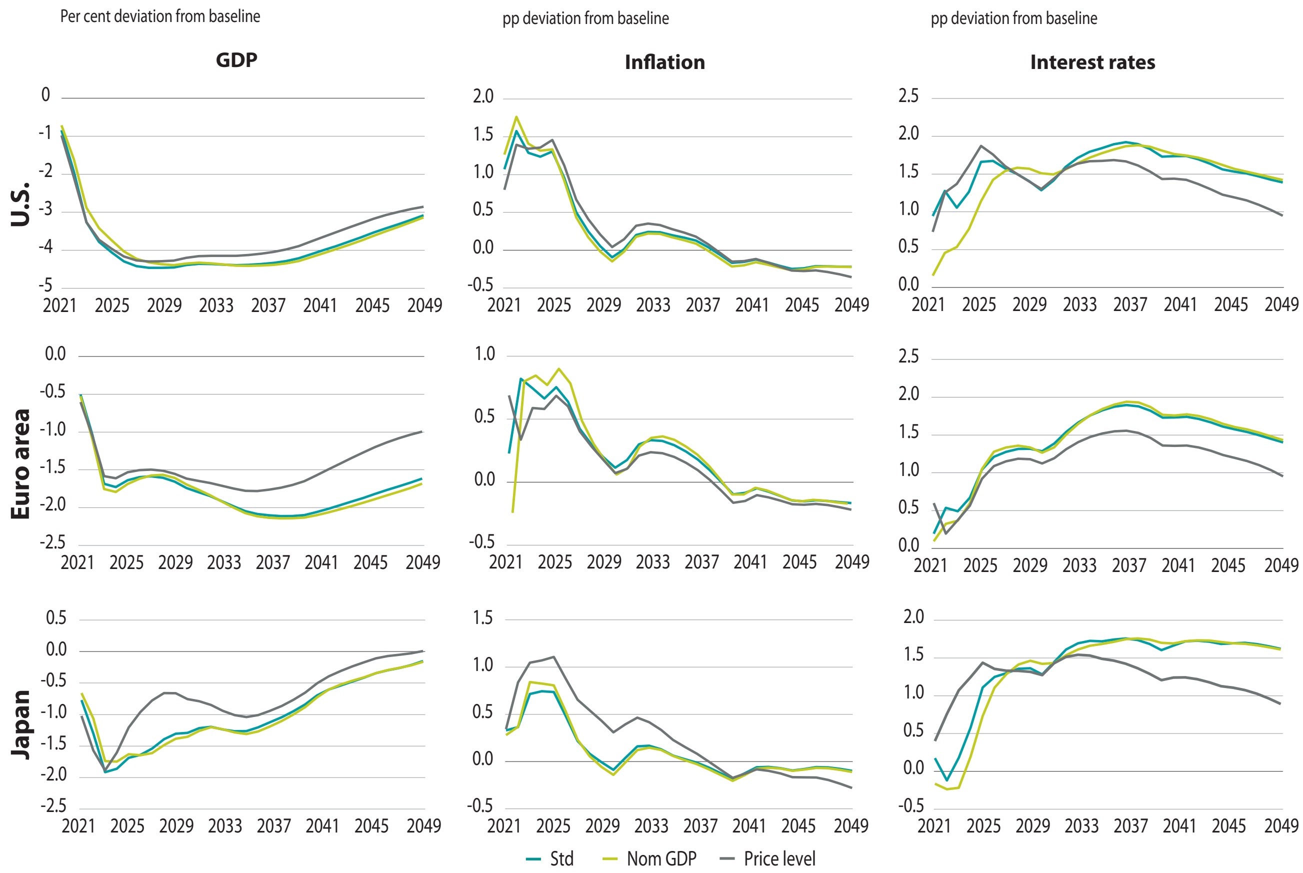
Sensitivity around macroeconomic policy assumptions (2/2)

- Regarding the **sensitivity to monetary policy rules**, the price-level targeting option leads to slightly less negative impacts on GDP while being slightly more inflationary over the first half of the simulation horizon. With the standard and the nominal targeting rules, short-term interest rates tend to increase more gradually but reach higher levels in the long term.

- Overall, the **main findings** of the exercise are:
  - **Policy environment plays an important role in scenario setup** and interpretation of the impact of climate change shocks on the economies.
  - There is always a **trade-off between inflation and GDP from any carbon tax recycling program** and the recycling option chosen should reflect the narrative for the climate scenario under consideration.
  - The **type of monetary policy environment chosen can mitigate as well as amplify the effects of fiscal policy**.

- The full results of this sensitivity analysis are available here.

Implications of alternative monetary policy rules for selected economies



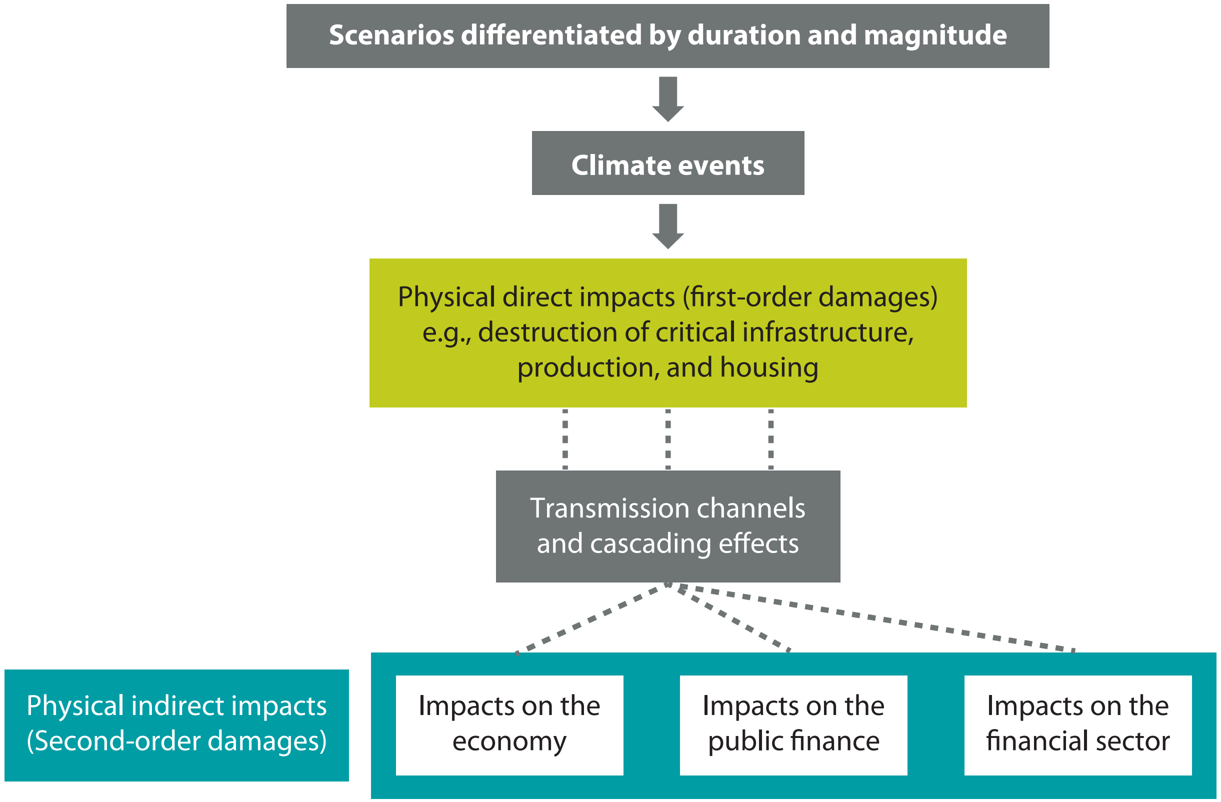
Note: **Std:** 2-pillar monetary policy interest rate rule; **Nom GDP:** monetary policy interest rate rule targeting nominal GDP; **Price level:** monetary policy interest rate rule targeting the price level.
Source: NGFS.

Guidance on physical risk assessment (1/2)

Physical risk assessment necessitates an approach combining climate science, catastrophe risk modeling, macroeconomic modeling and financial modeling.

- The NGFS has been working on a methodological guidance note on physical climate risk assessment (available here) supported with case-studies from select EMDEs (e.g., Morocco, Indonesia, Philippines, Tunisia, Western Africa), and references and links to data sources and tools.
- Several key factors contribute to acute physical climate risks: (i) the hazard associated with each peril that a region is exposed to, and the growing influence of climate change on the hazard; (ii) the exposure to these perils, which is highly dependent on the specific geographic location of assets and systems, and which varies based on a range of dynamics, including population and economic growth and migration; (iii) the vulnerability of exposed assets and systems; and (iv) the mechanisms through which the risks manifest at a financial or macroeconomic level. Finally, early adaptation can contribute to mitigate these impacts.

Direct and indirect impacts of extreme events



Source: World Bank.

Guidance on physical risk assessment (2/2)

- **EMDEs face specific needs and challenges,** including limited data and modeling tools. Methodologies used in developed countries should and can be adapted to such constraints.
- The guidance note presents a **practical six steps methodological framework** for extreme physical climate risk assessment and highlights **lessons learned** from recent physical climate risk assessments in EMDEs.

Proposed methodological framework	**1. Define needs and objectives** ⬌	**2. Identify available data and resources** ⬌	**3. Define the scope and approach** ➡	**4. Generate the scenarios** ➡	**5. Estimate the impacts** ➡	**6. Present and interpret the results**
Key lessons	A country-specific modelling approach should be tailored to the needs, objectives, data availability, risks, and sectors identified by the stakeholders.	There is a wide range of existing datasets and resources, both at global and regional/ national levels. It is important to identify which ones can be used to best support the assessment.	A phased approach – from qualitative to quantitative analysis, can support sound climate risk assessment through an iterative process, and can be refined as data and tools become available.	Scenarios should (i) be plausible but disruptive; (ii) explore a range of different events; (iii) propagate shocks through economic sectors and agents; and (iv) reveal critical vulnerabilities and non-linearities.	Both direct and indirect economic impacts should be considered for various geographies, sub-sectors, and financial sector exposed, whenever possible.	The interpretation of results should focus on the order of magnitude and trends, and clearly discuss uncertainties, assumptions, and limitations.

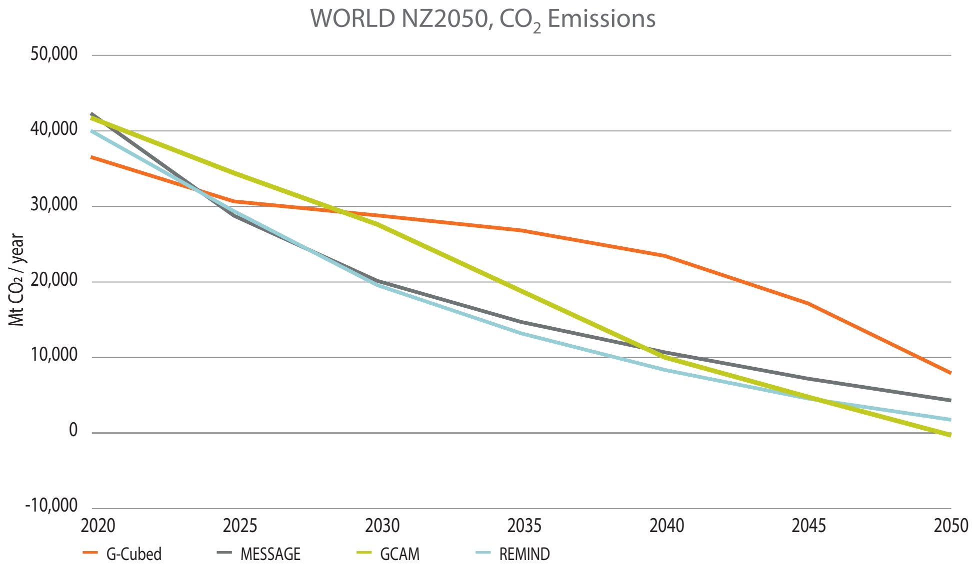
Source: World Bank.

G-Cubed pilot project

The NGFS undertook a project to explore the running of the scenarios in the G-Cubed model.

- The NGFS ran a pilot project to understand how the G-Cubed, a general equilibrium model with rich sectoral detail, could be utilised to increase the sectoral granularity of the NGFS scenarios and to complement the results derived from the IAMs.
- Three of the NGFS Phase II scenarios were run within the G-Cubed model: Current Policies, Net-Zero 2050 and Delayed Transition. Outputs from the model for these three scenarios were compared with those of the IAMs.
- Model intercomparison exercises such as the G-Cubed pilot project are relatively unique within the field, and the richness of the conclusions from the project reflects the value of open academic discourse between those with differing perspectives.
- The conclusions and learnings results arising from the pilot project are summarised in an NGFS Occasional Paper. The quantitative data from the G-Cubed model are available to explore online and for download.

Model intercomparison of world CO_2 emission in the Net Zero 2050 scenario



Source: NGFS.

Scenario

Development pipeline

Next objectives for the NGFS Scenarios

Phase IV objective: improve the design of the NGFS Scenarios and promote their wide use by a broad range of stakeholders.

Technical objectives

Improve scenarios

- Increase **sectoral granularity** and **geographical coverage**, especially in emerging economies
- Manage the trade off between **usability and complexity** of scenarios
- Introduce **short-term scenarios** (including higher-frequency data) that could be best used for scenario analysis and stress-tests

Update scenarios

- Better represent acute **physical risk**
- Update based on latest data and models

Strategic objectives

Make NGFS scenarios a common standard

- **Improve usability** and limit complexity of the scenarios ("off-the-shelf")
- Improve transparency and provide users with **methodological guidance**
- **Broaden the user base** of scenarios (beyond central banks/ supervisors to also private institutions, academics), and **increase range** of usage of NGFS scenarios

Vision on the use of NGFS Scenarios

The NGFS will continue to develop the scenarios to make them more comprehensive and relevant for an increasing range of applications.

- **Reference point for transition plans:** to calibrate transition plans of private and public institutions, and disclose performance with respect to Paris-aligned targets
- **Tool for impact assessment:** used not only by regulators/supervisors but also by private entities for climate stress test/scenario analysis, and to improve internal risk management tools and practices
- **Tool for macroeconomic and policy analysis:** to inform fiscal and monetary policymakers to calibrate policies (e.g. on carbon pricing)

Annex

Central Banks and Supervisors
Network for Greening the Financial System

Summary of models

The NGFS scenarios have been developed with the participation of the following research institutions and models.

Comparison	Climate impacts	Transition pathways	Economic impacts
External research partners	Climate Analytics PIK	PIK UMD IIASA	NIESR
Models	Climate models participating in the ISIMIP project CLIMADA	REMIND-MAgPIE 3.0-4.4 GCAM 5.3+ MESSAGEix-GLOBIOM 1.1-M-R12	NiGEM v1.22 NGFS version IAMs (only GDP provided as an output in the database)
Inputs	Atmospheric concentrations of emissions and associated radiative forcing Economic exposure data for assessment of economic impacts	Constraints from an emissions budget and other climate policies at the global and regional level	Carbon tax prices and revenues, energy consumption, "useful energy", physical risk damage functions
Key assumptions and uncertainties	Physical relationships between various aspects of the climate system Changes in climate at the local scale	Technology costs. Inter-temporal optimisation (for REMIND-MAgPIE and MESSAGEix-GLOBIOM); dynamic recursive (for GCAM). Optimal government policy design and capital reallocation	Econometric relationships between variables hold. Rational expectations and perfect foresight
Outputs	**Climate indicators** (e.g. temperature, precipitation, river flow, agricultural yields, soil moisture) **Economic indicators** (e.g. direct losses from flooding and cyclones, area and population exposed to extreme weather)	Energy demand, energy capacity, investment in energy, energy prices, carbon prices, emissions trajectories, temperature trajectories, agricultural variables, water variables, GDP	GDP (and components), unemployment, inflation, productivity, personal disposable income, house prices, interest rates, exchange rates, equity prices, etc.
Time horizon	Time steps of 5 years, up to 2100 in Explorer Up to daily time steps for underlying ISIMIP data	Time steps of 5 years up to 2100 (10 years from 2060 onwards for REMIND-MAgPIE & MESSAGEix-GLOBOM)	Annual steps, up to 2050 (NiGEM)

References

References

IIASA 2022 : NGFS Scenario Explorer hosted by IIASA
https://data.ene.iiasa.ac.at/ngfs/

IMF (2021)
World Economic Outlook, October 2021: "Recovery During a Pandemic". International Monetary Fund, Washington, DC. https://www.imf.org/en/Publications/WEO/Issues/2021/10/12/world-economic-outlook-october-2021

IPCC (2018)
Global Warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

IPCC (2021)
Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi: "https://dx.doi.org/10.1017/9781009157896"10.1017/9781009157896.

IPCC (2022)
Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.

Kalkuhl, M., & Wenz, L. (2020)
The impact of climate conditions on economic production. Evidence from a global panel of regions. Journal of Environmental Economics and Management, 103, 102360.

Kaufman, D., McKay, N., Routson, C., Erb, M., Dätwyler, C., Sommer, P. S., ... & Davis, B. (2020)
Holocene global mean surface temperature, a multi-method reconstruction approach. Scientific data, 7(1), 1-13.

Lange, S., Volkholz, J., Geiger, T., Zhao, F., Vega, I., Veldkamp, T., ... & Frieler, K. (2020).
Projecting exposure to extreme climate impact events across six event categories and three spatial scales. Earth's Future, 8(12), e2020EF001616.

References

NGFS (2019a)
A call for action: Climate change as a source of financial risk. First Comprehensive report, Network for Greening the Financial System, Paris, France.

NGFS (2019b)
Macroeconomic and financial stability: Implications of climate change. Technical supplement to the First NGFS Comprehensive Report, Network for Greening the Financial System, Paris, France.

NGFS (2022a)
Occasional Paper, Running the NGFS Scenarios in G-Cubed: A Tale of Two Modelling Frameworks, Network for Greening the Financial System, Paris, France.

NGFS (2022b)
Technical documentation to the NGFS Scenario. Network for Greening the Financial System, Paris, France.

UNEP (2018a)
Emissions Gap Report. UNEP, Nairobi.

UNEP (2018b)
Extending our horizons: Assessing Credit Risk and Opportunity in a Changing Climate. UNEP, Nairobi.

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