June 2024

Macroeconomic aspects of climate change

Main results from the latest NGFS climate scenarios and initial perspectives on the monetary policy implications of climate change

Note for the G20 Framework Working Group, to be included in the report "Macroeconomic impact of climate change and transition pathways"[1]

[1] Prepared by Agnieszka Trzcinska and Senne Aerts from the Chair's team of the NGFS Workstream Scenario Design and Analysis and Michelle van der Merwe from the Chair's team of NGFS Workstream on Monetary Policy. This report leverages extensive work by the members of both NGFS Workstreams.

Executive summary

The Network on Greening the Financial System (NGFS) is a group of over 130 Central banks and Supervisors willing to improve the climate risk management in the financial sector and to mobilize mainstream finance to support the transition toward a sustainable economy. This report provides the NGFS' latest insights into the macroeconomic impacts of climate change and the transition across the horizon for central banks and finance ministries.

The NGFS released the most recent iteration of its long-term climate scenariosin November 2023[2]. They explore seven possible transition pathways, with varying physical and transition impacts depending on global policy choices. The results demonstrate that a substantial economic transformation is required to achieve net zero and the nature of the transition will vary across countries and regions. In all scenarios, negative impacts of physical risk rapidly outweighs the impact of transition efforts. This report examines these effects in more detail highlighting that (i) early and coordinated policy action will yield the highest long-run returns, as delayed action disproportionately grows the scale of the adjustment required; (ii) while economic impacts differ significantly across countries and regions, almost all countries will benefit from keeping global warming levels close to the 1.5 °C threshold; (iii) physical risk impacts are not evenly distributed across the world, with potential losses in the Global South being disproportionately large in the absence of further policy action; and (iv) an immediate and coordinated transition under Net Zero 2050 leads to a increase in inflation over the next five years.

In addition to the long-term scenarios, the NGFS developed a framework for assessing the macroeconomic effects from the physical impacts of climate change and the transition over the 2-3 year horizon that monetary policy typically has in view. In particular, the NGFS sets out the key channels and transmission mechanisms through which the macroeconomy can be affected, highlighting differences across emerging market and developing economies and advanced economies.

Extreme weather events are the near-term effects of climate risk. Considering the three dimensions that determine their impact – the type of hazard, exposure, and vulnerability – it is quite unlikely that any two events will have the same macroeconomic effect. This report sets out in greater detail the role of supply, demand and financial channels in propagating the impacts. Complementary, this report also considers the near-term macroeconomic effects stemming from efforts to transition towards net zero. They depend on a range of factors, including the policy instrument(s) deployed, how any revenues generated are recycled and the credibility of policy. As climate mitigation policies will vary in stringency and coverage across countries, this can generate competitiveness impacts and potentially give rise to changes in trade patterns and domestic production, generating international spillover and cross-border effects.

The NGFS will continue this analyticial work and build on the framework presented in this report in greater depth to consider implications for monetary policy makers. However, initial observations suggest that if climate hazards and mitigation policies persistently reduce output while increasing inflation, monetary policy makers will have a difficult trade off to manage.

[2] As of the moment of writing, Phase IV, released in November 2023, is the most recent. An updated version, Phase V, will be released in October 2024.

Introduction

The Network on Greening the Financial System (NGFS) consists of 138 central banks and supervisors and 21 observers across all continents of the world. The Network is 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.'[3]

While the NGFS started predominantly with a supervisory focus, understanding the macro-financial impacts from climate change and the transition towards net zero has received increasing focus to support members in the delivery of their financial and price stability objectives. The work of the NGFS has clear synergies with the objectives and mandate of the G20 Framework Working Group (FWG), which includes discussing global economic risks, spillovers and uncertainties, as well as understanding the macroeconomic effects of different policy scenarios.

Drawing on the work conduted in the NGFS' Workstream on Scenario Design and Analysis and the Workstream on Monetary Policy, this report provides further insights into the macroeconomic impacts of climate change and the transition across the horizon for central bank and finance ministry members of the G20 FWG.

Work in the NGFS on understanding the longer term macro-financial impacts is most advanced, which is unsurprising given the long horizon over which the worst of the impacts of climate change – if left unmitigated – are expected to play out. In addition, many economies have committed to reaching net zero by around mid-century which will require significant economic and structural changes within and across economies. To support our understanding of these effects and their potential financial system implications, the NGFS developed, together with a consortium of climate scientists and academics, a set of reference scenarios that were first published in 2020. The scenarios show what long-term macro-financial and climate outcomes could look like under different possible states of the world depending on the policy path chosen, with each scenario embodying varying degrees of physical and transition impacts. These reference scenarios are now in their fifth iteration as the NGFS and consortium look to make continual improvements, updates and refinements to support their usefulness for policymakers and other users alike in their decision making and risk management practices. As part of this ongoing process, additional country-level detail has been added as well as better representation of the impacts from physical risks.

However, the impacts stemming from climate change and the transition are not just going to manifest in the long term, there can also be material impacts over the short-to-medium term horizon, which both central banks and finance ministries will need to understand in order to achieve their respective objectives. Indeed, in a survey conducted by the NGFS in 2022, many central banks reported that their economies had already been affected by physical and transition impacts, with the vast majority expecting these effects to become increasingly prominent over the monetary policy horizon going forward. Understanding the impacts arising from climate change and the transition over the 2-3 year horizon has been a key area of focus for the Workstream on Monetary Policy since its establishment in mid 2022. The initial phase of work has been qualitative rather than quantitative, aimed at

[3] See https://www.ngfs.net/en/about-us/membership

developing a common macroeconomic foundation that central bank members from a range of jurisdictions can leverage to help inform their assessments when formulating monetary policy decisions.

This report brings together some of the key quantitative findings from the long-term scenario work, highlighting relevant cross-country and regional differences, alongside the key transmission channels through which these impacts affect the macroeconomy in the near-term, together with the challenges and trade-offs that policy makers may be faced with. Quantiative work to assess short-term impacts is underway within the NGFS, with outputs expected in fthe first quarter of 2025.

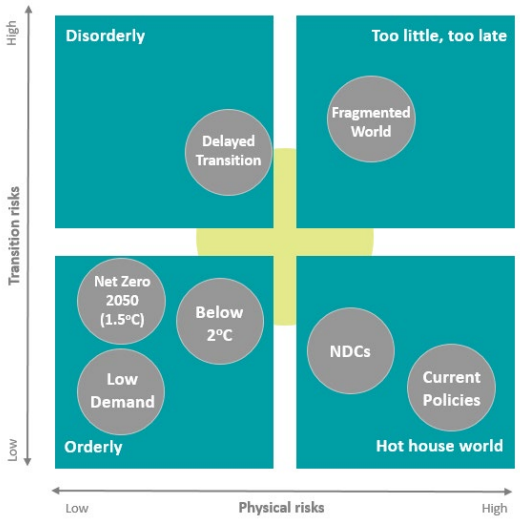
NGFS Scenarios framework

The most recent iteration of the NGFS scenarios – i.e. Phase IV – explores seven possible transition pathways, with varying degrees of physical and transition impacts embedded depending on the policy approach[4]. These scenarios provide a useful starting point for forward-looking analysis, which can help policymakers explore the inherent uncertainty and path-dependency characterising climate-related physical and transition impacts over the coming decades. In this regard, it is important to bear in mind that the sceanrios are not forecasts, but rather a device to help policymakers (and users more broadly) conceptualise various possible future outcomes and the range of risks they pose.

The scenarios can be grouped into four categories (quadrants): (i) orderly transition, (ii) disorderly transition, (iii) hot house world, and (iv) too little, too late, which showcase the trade-offs between higher transition and physical impacts. The three orderly transition scenarios ('Low Demand', 'Net Zero 2050' and 'Below 2°C') assume that ambitious climate policies are introduced early and become gradually more stringent to effectively mitigate climate change and meet the Paris targets (either 1.5°C or below 2°C temperature increase) by 2100. The disorderly transition scenario ('Delayed Transition') assumes that climate policies are delayed or divergent across countries and sectors, but the Paris targets are met by the end of the century at higher economic costs. The two hot house world scenarios ('Current Policies' and 'Nationally Determined Contributions') assume that global warming cannot be limited because of insufficient global policy efforts. As a result, critical temperature thresholds are exceeded, leading to severe physical risks and irreversible impacts. Lastly, the too little, too late scenario ('Fragmented World') assumes that a late and uncoordinated transition fails to limit physical risks. The scenario mapping is displayed in Chart 1.

[4] For further information see https://www.ngfs.net/sites/default/files/medias/documents/ngfs_climate_scenarios_for_central_banks_and_supervisors_phase_iv.pdf

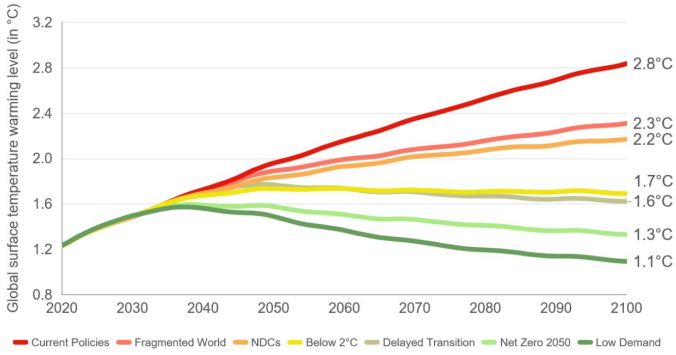
Chart 1: NGFS scenario framework



Notes: Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100
Source: NGFS Scenarios, 2023.

Each scenario is associated with different temperature pathways and carbon emission trajectories, with the differences determined by the degree of policy action taken. The 'Current policies' scenario continues to be inconsistent with achieving the goals of the Paris Agreement, with a 2.8°C increase in temperature expected by the end of the century relative to the pre-industrial period, with only the 'Low Demand' and 'Net Zero 2050' keeping temperature increases below 1.5°C of warming. Chart 2 shows temperature projections across the different scenarios.

Chart 2: Temperature rise



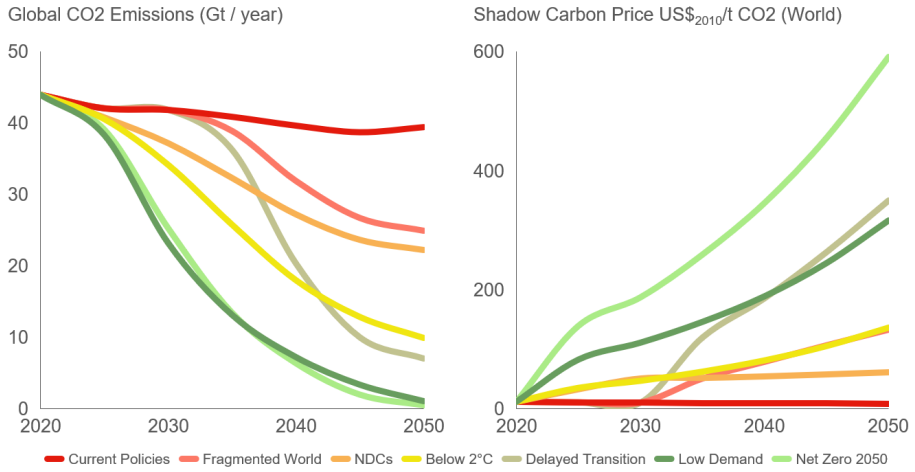
Source: NGFS Scenarios, 2023, REMIND model

In the scenarios, policy action is summarised through the shadow carbon price. The 'shadow' carbon price is used in the scenarios as a proxy for the intensity of climate policies, which can encompass all types of climate mitigation actions including taxation and regulation. An increase in the shadow carbon price reflects more stringent climate change mitigation efforts, which creates transition impacts in economies, with the effects most acute in high-emitting sectors.

The effects associated with transition depend, among others, on the structure of the economy, the dependence on fossil fuels and the trade composition. The scenarios highlight that the economic impacts associated with transitioning are exacerbated by delayed action and/or insufficient

coordination between countries. The scenarios suggest that a shadow carbon price of around $250/tCO2 globally is needed by 2035 to secure an orderly transition towards net zero by 2050. Chart 3 shows the projected evolution of CO2 emissions and carbon prices across the seven reference scenarios.

Chart 3: CO_2 emissions and carbon price developments

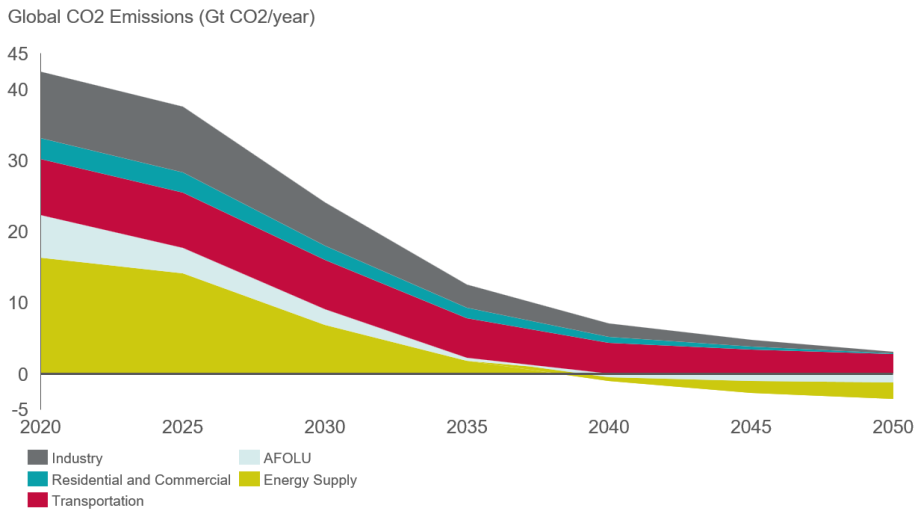


Source: NGFS Scenarios, 2023, REMIND model

The scenarios highlight that a substantial economic transformation is required to achieve net zero and the nature of the transition will vary across countries and regions.

Most of the global emissions reduction under the Net Zero 2050 scenario is driven by large decreases in the energy supply sector and industrial sectors. By 2050, the largest emitter of CO_2 is the transportation sector where, based on current technologies, moving away from fossil fuels is most challenging (Chart 4).

Chart 4: Net Zero 2050 global emissions



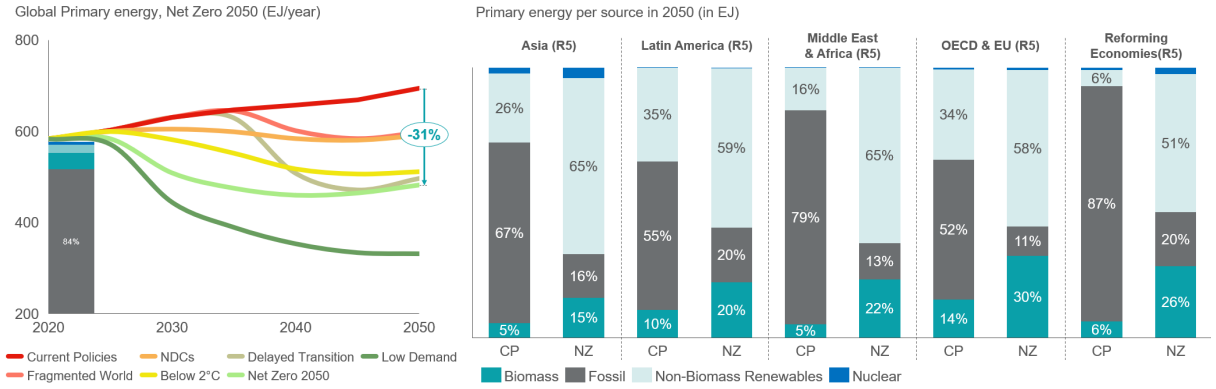
Notes: AFOLU stands for Agriculture, Forestry, and Other Land Uses.

Source: NGFS Scenarios, 2023, REMIND model

Substantial changes in the global supply of primary energy are key to achieving net zero by 2050, both in terms of overall production levels as well as the composition of the energy source. Compared with 2020 levels, global primary energy supply needs to decline by around 20 per cent by 2050 (which is roughly 30 per cent below the level embodied by current policies in 2050). The decline in primary energy supply does not necessarily result from lower energy demand. Many improvements can be

found via increasing energy efficiency, satisfying similar levels of global energy demand at lower requirements of primary energy supply. By 2050, renewables and biomass would deliver more than 80% of global primary energy needs (Chart 5). While reliance on fossil fuels declines only slightly by 2050 under Current Policies, in an ambitious Net Zero scenario, the share of energy production from fossil fuels would need to drop drastically to around 10-20% in all regions in 2050 (Chart 6).

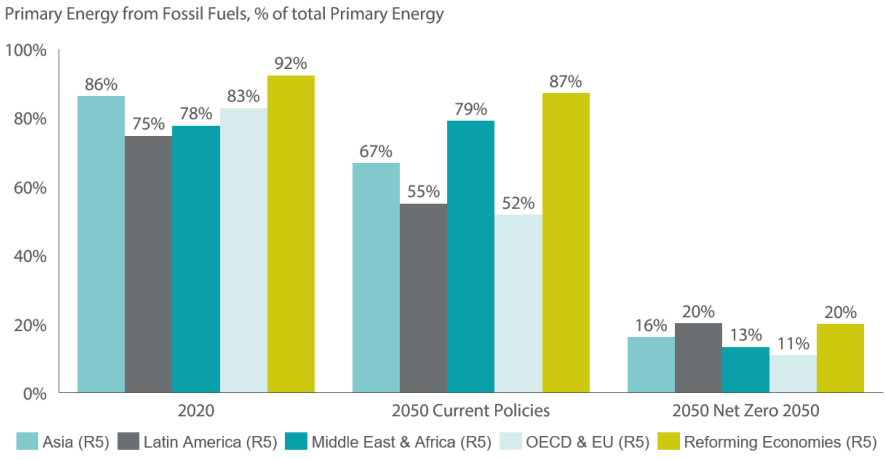
Chart 5: Global energy production



Notes: CP stands for Current Policies scenario; NZ stands for Net Zero 2050 scenario

Source: NGFS Scenarios, 2023, REMIND model

Chart 6: Use of fossil fuels



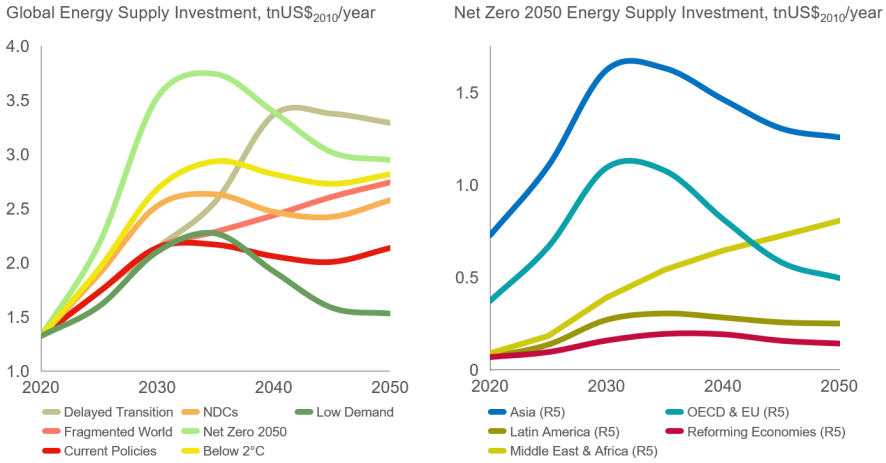
Notes: OECD & EU (R5) includes the OECD 90, EU Member States and candidate 7chieving. Reforming Economies (R5) includes countries from the Reforming Economies of Eastern Europe and the Former Soviet Union. Asia (R5) includes most Asian countries with the exception of the Middle East, Japan and Former Soviet Union states. Middle East & Africa (R5) includes the countries of the Middle East and Africa. Latin America (R5) includes the countries of Latin America and the Caribbean. See more: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10.

Source: NGFS Scenarios, 2023, REMIND model

To support the structural transformation, significant investment flows need to be directed towards greener sources of energy production in the coming decades to achieve net zero. In most scenarios, global energy investments per annum need to be above US$2 trillion, with more than one-third going to renewables mostly for the generation and storage of renewable electricity (Chart 7). In the Net Zero 2050 scenario, energy supply investment equates to more than 2% of global GDP by 2030, doubling from 2020 levels. There is also substantial variation across countries, with annual energy supply

investments under the Net Zero 2050 scenario peaking around 2030 in the OECD & EU and in Asia, but remaining at an elevated level in Asia until 2050. In contrast, investment in the Middle East and Africa continuously increases each year until 2050, while in Latin America and and Reforming Economies, annual investments increase initially but remain relatively stable and at a much lower level than in other regions.

Chart 7: Investments in Energy



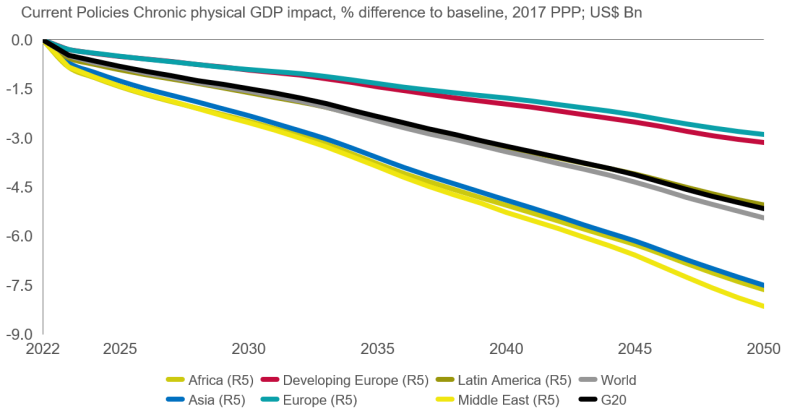
Source: NGFS Scenarios, 2023, REMIND model

In all scenarios, the impact of physical risk rapidly outweighs the impact of transition efforts.

Without the structural transformation to lower greenhouse gas emissions, the impacts from chronic physical risks will impose larger economic costs every year for all countries and regions. Chronic risk becomes gradually more important over time, particularly if no further policy action by governments occurs. The scenarios show that the GDP cost of chronic physical impacts on economic output are almost double under the 'Current Policies' scenario compared with 'Net Zero 2050'.[5] Estimates suggest the GDP losses from chronic physical risks vary substantially across regions, and by much more than what just looking at G20 and global aggregates would suggest, with the most substantive effects in the Middle East, Africa and Asia – more than double the magnitude of the impacts on European economies (Chart 8).

[5] GDP losses caused by chronic impacts are calculated in each scenario using country-level damage functions as set out in Kalkuhl and Wenz (2020). The methodology does not include damage impacts related to extreme weather events, sea-level rise or wider societal impacts from migration or conflict and therefore should be considered a lower bound estimate.

Chart 8: Chronic physical risk impact

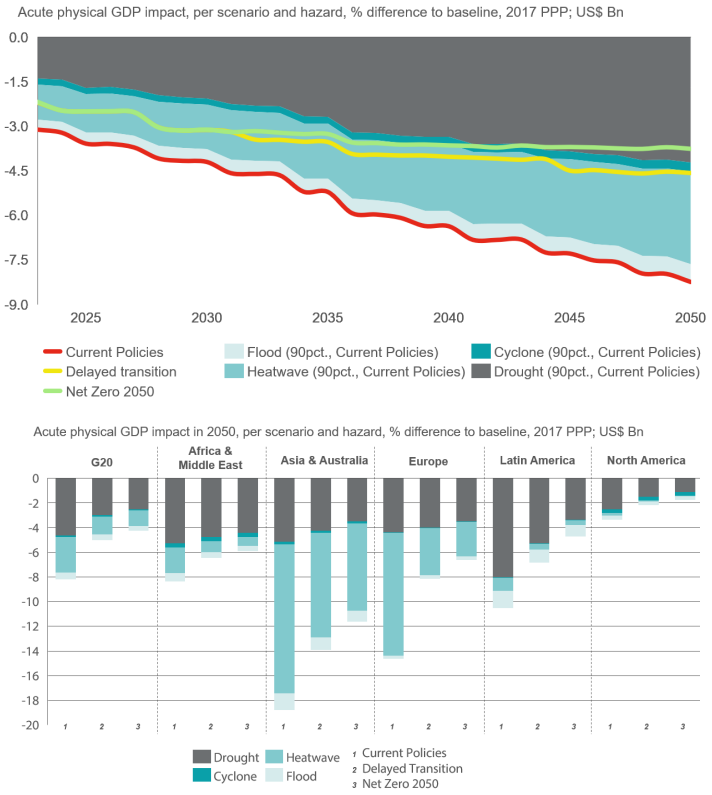


Notes: GDP impacts are modelled for NiGEM regions. For regions composition see the NGFS Climate Scenarios Technical Documentation, pp. 176-177. Baseline constitutes a fictional scenario in which climate change does not occur, i.e., there are no physical or transition risks. G20 region corresponds to GDP-weigthed average of G20 members natively available in NiGEM.

Source: NGFS Scenarios, 2023, NiGEM model based on REMIND inputs

Extreme weather events will also become increasingly frequent and severe, generating economic losses and adding to macroeconomic volatility. Breaking down the global economic costs across different scenarios by the types of climate hazard, droughts and heatwaves pose the largest overall risk to GDP, with impacts varying considerably across different regions. For example, Europe and Asia are most exposed to heatwaves, while Africa and North America are primarily exposed to drought (Chart 9).

Chart 9: Acute physical risk impact



Notes: Simple averages across countries available for that region. Latin America is composed of Chile, Mexico and Argentina. Data on flood impacts are only available for Mexico, the US and South Africa. G20 region corresponds to GDP-weigthed average of G20 members natively available in NiGEM.

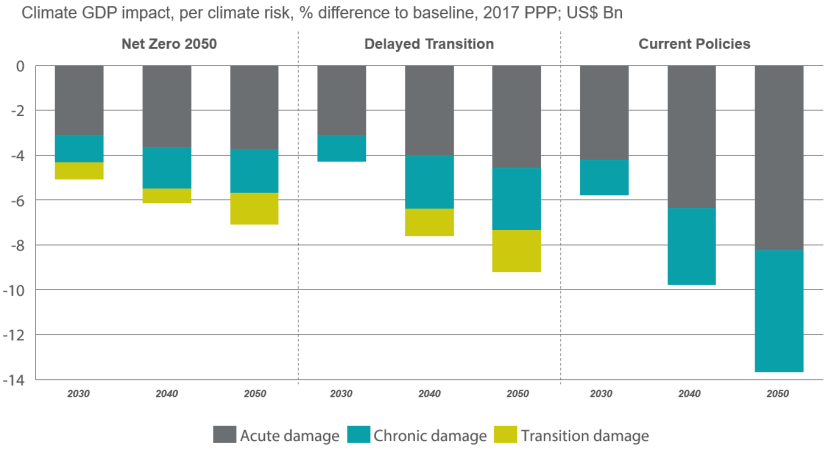
Source: NGFS Scenarios, 2023, Climate Analytics model based on REMIND inputs

Aggregate macro-financial takeaways

The NGFS scenarios provide policymakers with a range of possible future pathways to explore that can be used to inform decision making. While the scenarios are not forecasts and do not capture all the potential macro-financial impacts associated with climate change, there are a series of key messages that can be gleaned from them.

First, early and coordinated policy action will yield the highest long-run returns, as the scale of the adjustment required grows disproportionately if action is delayed. Indeed, the projected costs of inaction are a lower bound as the implications of potential tipping points and increased conflict and migration are not captured. Moreover, in the longer term even a delayed transition gives rise to better macroeconomic outcomes than no further policy action (Chart 10).

Chart 10: GDP deviation due to transition, chronic and acute risks



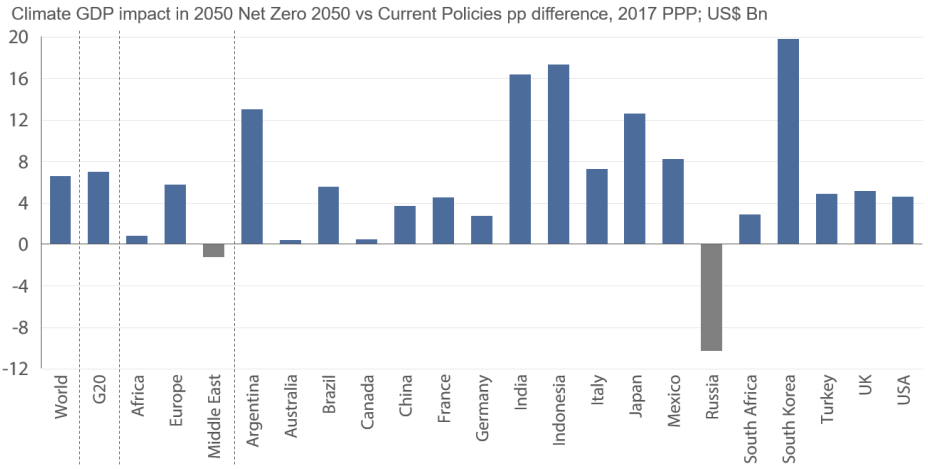
Notes: The above figure shows how GDP is impacted across scenarios compared with a hypothetical (and impossible) baseline scenario in which no transition or physical risks occur. This baseline scenario represents a world in which climate change does not occur. Thus, climate change has a negative impact on GDP in every plausible scenario, but the magnitude of the losses differs across them.
For chronic physical risk Current Policies and Fragmented World scenarios uses damages corresponding to the 95th percentile of the temperature profile to account for tail physical risks, while other scenarios use the 50th percentile.

Source: NGFS Scenarios, 2023, NiGEM model based on REMIND inputs

Second, while economic impacts differ significantly across countries and regions, almost all countries will benefit from keeping global warming levels close to the 1.5 °C threshold. Impacts on GDP vary based on the extent to which greenhouse gas emissions need to decline, the path for (shadow) carbon prices, industry composition, including if they have larger fossil fuel (export) industry, as well as their susceptibility to physical risk damages from increased temperatures and extreme weather events. The initial negative GDP impacts from introducing transition policies can be partially mitigated by the recycling of carbon revenues, which in the scenario framework deployed, the shadow price of carbon acts like a tax and a revenue stream is generated. The default assumption in NGFS scenarios is that carbon revenues are recycled through lower labour taxes. However, the orderly scenarios assume 50% of revenue is used to fund government investment, while the other 50% is used to pay off government debt.

Compared with the unrealistic 'no climate change' baseline, in Net Zero 2050 transition impacts have a moderately negative impact on world GDP as the 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. Yet, the potentiall losses incurred from transition efforts rapidly appear insignificant compared to losses that would be incurred due to physical risks in a scenario of unmitigated climate change. That said, in the Net Zero 2050 scenario output is higher for almost all economies by 2050 compared with a scenario of Current Policies (Chart 11).

Chart 11: GDP deviation of Net Zero 2050 versus Current Policies across regions/countries in 2050

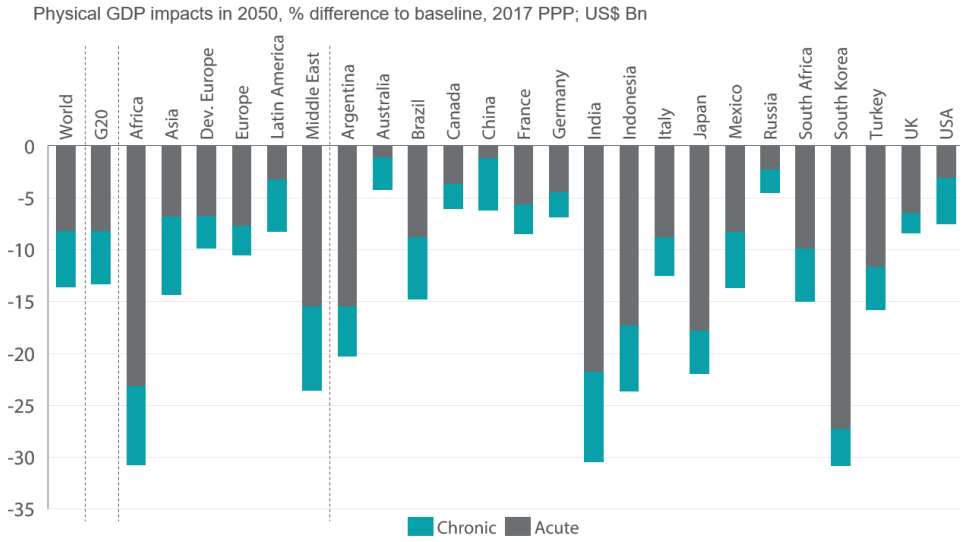


Notes: G20 region corresponds to GDP-weigthed average of G20 members natively available in NiGEM.

Source: NGFS Scenarios, 2023, NiGEM model based on REMIND inputs, sum of acute physical, chronic physical, and transition risks

Third, physical risk impacts are not evenly distributed across the world, with potential losses in the Global South being disproportionately large in the absence of further policy action. By 2050, acute and chronic physical risk could lead to GDP losses of more than 30% in certain regions and economies relative to the hypothetical no climate change baseline. This is because missed temperature targets will cause irreversible changes in climate. The largest impacts arise from increased frequency and severity of acute or extreme weather events, with Africa the most impacted region, and India and South Korea two of the most affected economies in the G20 (Chart 12).

Chart 12: Acute and chronic physical impacts under Current Policies in 2050



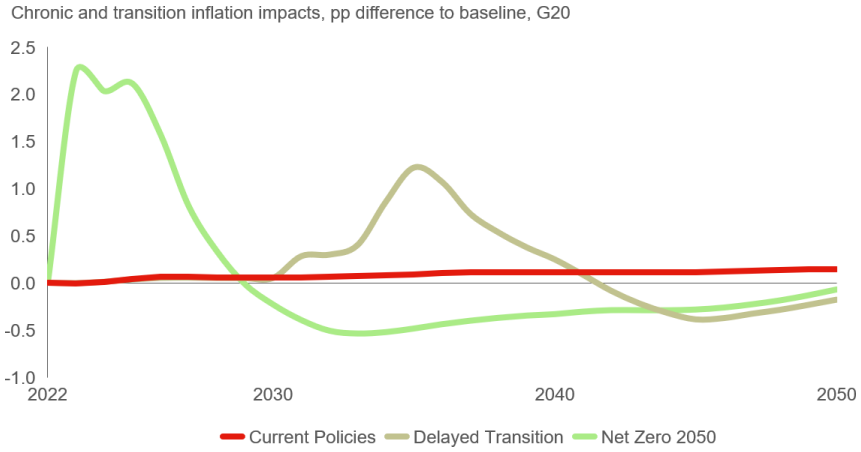
Notes: For chronic physical risk Current Policies and Fragmented World scenarios uses damages corresponding to the 95th percentile of the temperature profile to account for tail physical risks, while other scenarios use the 50th percentile. G20 region corresponds to GDP-weigthed average of G20 members natively available in NiGEM.

Source: NGFS Scenarios, 2023, NiGEM model based on REMIND inputs

Lastly, an immediate and coordinated transition under Net Zero 2050 leads to a increase in inflation over five years. In many countries, the implementation of (shadow) carbon pricing in transition

scenarios tends to raise energy costs in the short term. Inflation is pushed upwards initially as the direct impact from higher carbon prices more than outweigh the decrease in aggregate demand (which in turn puts some downward pressure on primary energy prices). Inflation gradually returns to the baseline as the market slowly shifts away from high-carbon to low-carbon energy sources, with the latter being unaffected by the higher carbon prices (Chart 12). In the NGFS modelling framework, the monetary policy maker had a dual mandate to target inflation and nominal GDP, which means that it manages the trade-off between bringing inflation back to target and closing the output gap. In reality central banks may decide to manage the trade-off in this scenario differently, particularly in the context of recent inflation overshoots and risks to inflation expectations. For example, an inflation-targeting central bank might decide to tighten policy by more, returning inflation to target sooner, resulting in a more negative short-run impact on GDP.

Chart 12: Inflation impacts under Net Zero 2050, Delayed Transition and Current Policies for G20 economies



Notes: G20 region corresponds to GDP-weigthed average of G20 members natively available in NiGEM. Impacts on inflation stemming from acute events not available.

Source: NGFS Scenarios, 2023, NiGEM model based on REMIND inputs

Assessing the near term macroeconomic impacts of climate change and the transition – a framework for economic policymakers

Macroeconomic effects of transition depend on the policy instruments chosen

The long-term NGFS scenarios have been an important tool to explore a wide range of climate policy scenarios and help policymakers navigate and manage potential risks as well as the uncertainty inherent with climate change. To simplify what is already a very complex modelling task, as outlined in the earlier section, the scenarios rely on a shadow price of carbon to proxy for the intensity of government policy. In reality, however, governments will deploy a wide range of policy instruments to deliver their respective climate objectives, with the chosen policy mix dependent on a range of jurisdiction-specific factors, such as economic structure, stage of development, political acceptability etc. And while the focus of the NGFS scenarios to date has been on the longer term, governments have already been putting policies into place, including, in some instances, to meet substantive emissions reductions by 2030. And these policies and/or the anticipation of their introduction are having macroeconomic consequences now and in the immediate horizon over which policy is set.

For both finance ministries and central banks, it is important therefore to develop a clear understanding of the macroeconomic effects of different policy levers and mixes, and this requires

more indepth analysis than the proxy for policy instensity provided by the shadow price of carbon in the scenarios. The economic literature exploring the macroeconomic effects of different policy levers over the short-to-medium term has rapidly expanded over recent years and provides a useful starting point on which insights can be formed. This has also been the starting point for the analytical agenda of the NGFS Workstream on Monetary Policy, which has been focused on the 2-3 year horizon over which monetary policy is typically set.

First, the economic literature makes clear that different mitigation policies will have different macroeconomic consequences across the horizon.[6] Variations in the design, pace, stringency and implementation of such policies, including their transparency, predictability, and degree of coordination across countries will be important determinants of their net impact on the supply and demand side of an economy and in turn their impacts on output and inflation. Furthermore, uncertainty about the future path of climate policy can impact the macroeconomy through household and firm behaviour as well as through the financial markets channel. Whether a policy lever generates a revenue stream and how any revenues are used by governments can also have a sizeable macroeconomic impact.

The three main types of climate policies widely in use globally are: carbon pricing policies, including carbon taxes and Emissions Trading Schemes (ETS), subsidies, and non-market-based climate policies such as regulations and standards:

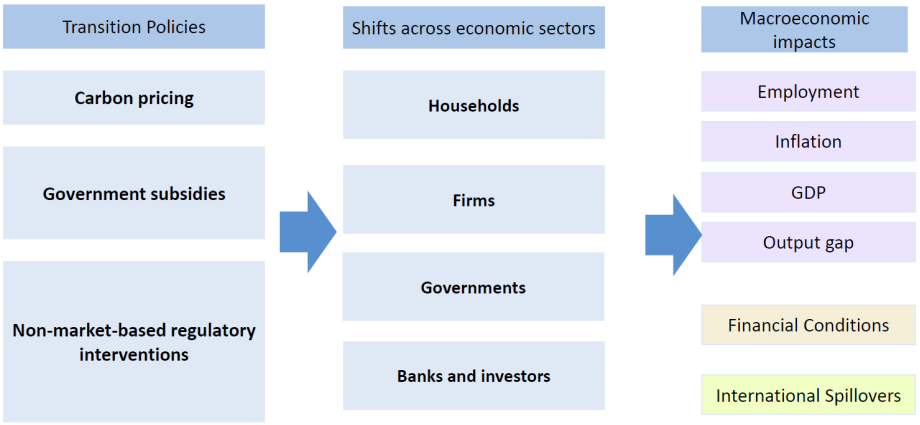
- Carbon pricing policies increase the price of carbon intensive goods or emissions over the period for which they apply, in order to incentivise households and firms to shift to alternatives with less carbon content and to promote energy efficiency. This can be done via increasing taxes levied on carbon instensive goods or via emissions trading systems, such as a 'cap and trade' system. Importantly, direct forms of carbon pricing also generate a revenue stream that governments can use utilise in a range of different ways depending on their preferences. For example, to pay down debt, fund public investment, address distributional considerations etc. How any revenues are recycled back into the economy are a key determinant of the overall impact on output and inflation.
- Government subsidies can be deployed to encourage investment in low carbon-intensive activities. This will generally create new jobs and generate investment but may also result in stranding of some of the existing capital stock as it is phased out. However, subsidies tend to be regarded as less efficient in reducing emissions compared with carbon pricing policies and also need to be financed by governments.
- Non-market-based regulatory interventions can be used to discourage investment in carbon-intensive industries and/or shift investment towards greener sectors and can be particularly effective in less price sensitive sectors.

These transition policies will affect the behaviour of households, firms and investors in the economy and will have implications for government spending and revenues too (Chart 13). Shifts in consumer

[6] The initial work in Workstream Monetary Policy has focused on the impacts associated with mitigation policies only, and therefore the impacts associated with adaptation measures are not discussed here.

prices, wages, and asset prices associated with the impact of transition policies will affect household income, wealth and saving patterns. These effects will vary according to the policy deployed.

Chart 13: Propagation of effects from transition drivers to the macroeconomy



For firms, transition policies aim to incentivise a shift in production and investment towards green production. Furthermore, investment decisions at the firm level will also be influenced by changes to costs, productivity and profits as well as the nature of the financing conditions they face.

The green transition also impacts governments' fiscal balances. For example, carbon pricing will generate revenue whereas subsidising green technology will need to be financed by debt issuance or taxes. How governments decide to recycle revenues and/or finance subsidies will impact macroeconomic outcomes. For countries that rely on fossil-fuel revenues, managing the green transition will likely be more challenging. On the other hand, those endowed with critical minerals needed for the green transition may benefit from new opportunities.

The necessary reallocation of capital creates challenges and opportunities for banks and other investors. Carbon-intensive firms may see negative impacts on their future profitability, asset valuation and credit conditions. On the other hand, low-carbon firms are likely to see the opposite effect as banks and investors reallocate capital away from carbon-intensive industries. Financial feedback effects can amplify effects and changes in investment flows can cause volatility in financial markets and affect the valuation of a wide range of assets.

Moreover, expectations regarding the impact of future policy changes can influence consumer and investor behaviour, possibly driving precautionary savings or speculative investments which may magnify economic fluctuations, particularly in sectors directly impacted by climate policies.

Climate mitigation policies also have the potential to generate significant international spillovers. As these policies will vary in stringency and coverage across countries, this can generate competitiveness impacts and potentially give rise to changes in trade patterns and domestic production.

For many economies, some combination of these policies have been or plan to be deployed. To help illustrate the varied impacts on output and inflation in the short-to-medium term, Table 1 highlights the different channels associated with two stylised revenue neutral policy examples. It also outlines broader considerations that governments might have in mind when selecting their domestic policy mix. Relevant longer-term impacts via productivity, technological change and open economy effects

are not captured. The stylised examples show that different policy levers can, despite having common objectives to incentivise green activities and discourage emissions intensive ones, have opposite macroeconomic impacts in the near term; for example, with output falling and inflation rising under a carbon tax scenario, while under a subsidy scenario, output rises and inflation falls.

Table 1: Illustrative transition policy examples

Policy option	Channels that affect short-to-medium term inflation					Other considerations
	Output		Direct price effect	Indirect price effect	Inflation expectations	
	Aggregate demand	Aggregate supply				
Carbon tax, with revenues recycled as transfers to low-income households	Lower fossil fuel demand. More income to households with a high marginal propensity to consume.	Higher costs of production. Policy uncertainty affects capital accumulation.	Higher fossil fuel-based energy prices.	Higher cost of inputs likely to be passed on to consumer prices.	Raise firms' and households' inflation expectations.	More cost effective. Efficient at lowering GHG emissions. Can address distributional concerns.
Green energy technology subsidies, financed by carbon taxes or ETS revenues	Lowers overall energy prices and increases demand for green technology.	Lower marginal costs can support higher supply due to increase in production	Lower energy prices due to increased green energy supply.	Lower energy prices may reduce the costs of other related goods	Lowers inflation expectations from falling energy and related goods prices.	Higher public acceptability than a carbon tax. May be more effective in non-price sensitive sectors.

Note: The table describes changes in relative prices. The overall impact on CPI inflation will be determined by the monetary policy response.
Source: NGFS (forthcoming, 2024)

Capturing the macroeconomic impact of an exreme weather events requires a close investigation of various transmission channels

Over the 2-3 year horizon, acute physical hazards – or extreme weather events – are expected to generate most of the economic damages associated with physical impacts relative to chronic impacts, and as such have been the focus on the physical impacts side in the first phase of work by Workstream Monetary Policy. As policymakers look to assess the macroeconomic impacts from these extreme events, the literature distinguishes between three dimensions that determine the impact, emphasising that it is quite unlikely that any two events will have the same macroeconomic effect:

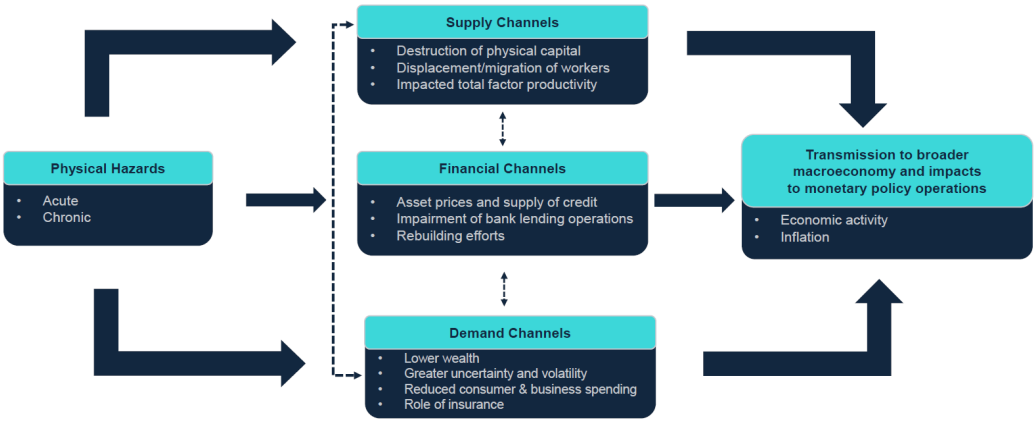
- **Type**: the nature of the hazard itself (heatwave, wildfire, flood, drought etc)

- **Exposure**: whether it impacts a location with significant economic activity; and
- **Vulnerability**: reflecting issues such as construction quality, disaster preparedness and response capacity.

The empirical literature also suggests the presence of a resilience threshold: events below this threshold are associated with a significantly lower toll on the human and economic activity than events that surpass this threshold. The threshold is country specific and is dependent on a country's wealth, fiscal capacity, and insurance mechanisms, among other factors. It is likely to be lower in lower-income countries than in higher-income ones, and as a result, lower-income countries already experience relatively larger damages and economic repercussions from physical hazards. When severe weather events become more frequent and intense, the resilience threshold will be surpassed more often in a specific country, and larger economic damages will be experienced. Greater damages take an increasing toll on the country's capacity to cope with future hazards as fiscal capacity is diminished and the insurance sector is impaired. Consequently, the resilience threshold could fall and the economic impact of a physical hazard for a given geophysical strength may increase. Adaptation can help mitigate the impact of current and future physical hazards, and in doing so could raise (or at least stabilise) a country's resilience threshold.

To help unpack the impacts of physical hazards on the macroeconomy, Chart 14 sketches out a transmission diagram of the main channels: supply, demand and financial. Supply-side channels encompass the standard factors of production – capital, labour, and total factor productivity (TFP) – where TFP encapsulates the role of technology, financing conditions, infrastructure, supply chain disruptions, etc. Demand-side channels include, among others, wealth and income effects associated with the destruction of assets or imperfect insurance, uncertainty over the future price of selected assets, and lower aggregate spending as consumer and business confidence weaken. Financial channels capture the linkages between physical impacts and the financial sector, where the latter plays an important role in the propagation of shocks through changes in asset prices and the supply of credit.

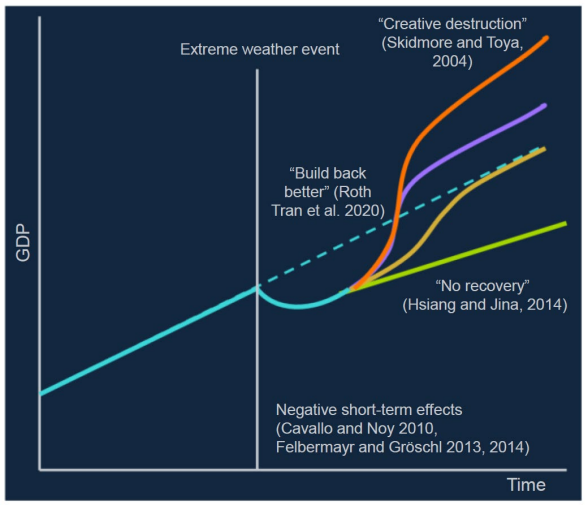
Chart 14: Transmission of physical hazards to the macroeconomy



Source: NGFS forthcoming, 2024

Most of the literature finds that following the impact of an exreme weather event, the level and growth rate of GDP drops in the immediate aftermath. Over time, GDP growth recovers but for severe disasters GDP can remain below its pre-shock level for some time, and there is mixed evidence in the literature as to whether the level of GDP returns to, or surpasses, the trend path it was previously on (Chart 15). The impact on inflation is mixed because there are a range of determinants.

Chart 15: Stylised depiction of GDP impacts following an extreme weather event



Source: Bank of England

Extreme weather events can also give rise to material international spillovers via trade linkages. For example, via global commodities trade and prices, in addition to global supply chains routes where recent drought-like conditions have lowered water levels in key shipping channels in Europe impeding the flow of goods.

Climate hazards and mitigation policies could push output down and inflation up in a persistent way, creating difficult trade offs for monetary policy makers

While a successful transition will improve macroeconomic outcomes in the long run, the adjustment process will add to the complexity faced by policymakers in the near term. Central banks will increasingly confront new challenges for monetary policy that stem from the economic impact of climate change.

Severe weather events are largely unpredictable and thus resemble other shocks that unfold over the business cycle and to which monetary policymakers tend to adjust monetary policy. In the aftermath of a severe weather event, near-term movements in the key variables relevant for monetary policy – inflation and measures of resource utilisation or spare capacity – could indicate a need to adjust financial conditions with the direction depending on the relative balance between the supply and demand effects of the event and their persistence. Communication of monetary policy could be complicated, in particular for inflation-targeting central banks, when greater and persistent inflationary pressures from severe weather events call for policy tightening against the backdrop of an extensive decline in supply. Further out, policymakers have to wrestle with the question of the long-term implications of extreme weather events for potential output and growth and the appropriate longer-run stance of monetary policy. Going beyond the effects of a specific event, the changes in the distribution of severe weather events – an increase in the frequency, intensity, and geographical spread of physical hazards – will alter the investment and savings behaviour of economic actors globally with implications for important policy determinants such as the long-run neutral rate of interest.

At the same time, many governments have set net zero targets, and the economic impact of policies to enable the transition to these targets is increasing. Some policies are more likely to add to inflationary pressures than others. To the extent that transition policies require a large and protracted increase in the relative cost of carbon emissions, whether that is through a carbon price, or a change in regulation/standards, this creates a persistent relative price shift that central banks will also need to factor into their decision making.[7] The transition will also add to the complexity of estimating potential output and the neutral rate of interest, as it will involve large reallocations of resources across sectors, while implications for overall investment will depend on the balance of impacts in low and heavily emitting sectors. Such shifts will affect the productivity of labour and capital, particularly in countries with large energy sectors.

Greater macroeconomic volatility and uncertainty around economic outcomes will also complicate decision making. For instance, uncertainty regarding the size, mix and impact of policy measures could delay investment in renewable technologies. Slower growth in renewable energy sources could support fossil energy prices, putting upward pressure on inflation and slowing the transition.

If climate hazards and mitigation policies push output down and inflation up in a persistent way, monetary policy makers will have a difficult trade off to manage. While several strategies are conceivable, inflation-targeting central banks are likely to tighten policy to offset any persistent upward impetus to inflation. Fully accommodating this higher inflation (or targeting inflation measures that exclude energy costs) would not be consistent with many central banks' current mandates, particularly in the aftermath of substantial recent inflation overshoots. Communicating such tightening to the public could be complicated, but by delivering low and stable inflation, central bank policies can provide a stable economic platform for the climate transition to take place, providing supportive conditions for green investment and capital flows.

NGFS Next steps

The new vintage of the NGFS long-term scenarios (Phase V) will be released in October 2024. They will be updated to incorporate new economic and climate data, policy commitments, and model versions. In addition, the 2024 release will incorporate the impacts from a new damage function, which will have a substantial effect on the impacts from physical risk. The current damage function in the long term scenarios, by Kalkuhl and Wenz (2020), only accounts for the impacts associated with increases in global mean temperature.

The new damage function will also incorporate the impacts on other climate variables, such as precipitation and temperature variability, as well as the persistence of climate impacts. The 2024 release will also be accompanied with technical documentation on how to disaggregate NGFS climate scenarios output at a finer sectoral granularity. The guide will provide a conceptual framework that could be employed to disaggregate Integrated Assessment Model sectoral time series to a finer industrial and geographic level using Multi-Regional Input/Output Tables and other techniques.

Lastly, with a view to complementing the utility of long-term narratives, the NGFS has recently started work on developing short-term climate scenarios. The short-term scenarios will offer a better understanding of the near-term macro-financial impact of transitioning to a net zero economy, including the consequences of severe natural disasters. Notably, they will illustrate how climate risks

[7] The role that an increase in the relative cost of carbon emissions plays in the transition depends, among other factors, on the speed with which new environmentally friendly technologies become marketable, as process that is inherently uncertain.

influences existing vulnerabilities, such as levels of debt, and interacts with cyclical factors like confidence shocks. This approach overcomes some limitations of long-term scenarios, by better capturing shocks with only near-term impacts (such as confidence shocks), allowing for non-linearities in the transmission of shocks and sounder use of static balance sheet or portfolio assumptions.

Short-term scenarios will be crucial for the 2024-2026 phase of the work agenda for Workstream **Monetary Policy** where a more quantitative approach, building on the more conceptual macroeconomic foundation laid over recent years, will be leveraged to explore questions such as:

i. How the trade-offs facing policymakers might evolve or be exacerbated in the face of the unique challenges that climate change and the transition to net zero present (e.g., repeated and more severe physical shocks, one-sided partly anticipated carbon price ratchet);
ii. How to account for climate-related uncertainty and volatility in monetary policy decision making;
iii. Possible implications for the natural rate of interest in the short and long term;
iv. How climate shocks do, or do not, differ from standard macroeconomic shocks and how their impact, transmission and therefore the policy response should evolve and be communicated. This might be particularly important in highlighting heterogeneities across countries.

This will also be complemented with further work to embed climate macroeconomic models into central bank toolkits as well as consider how to integrate climate considerations in to monetary strategy toolkits.