National Institute of Economic and Social Research

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Economic Impacts of Climate Change:

Exploring short-term climate related shocks for financial actors with macroeconomic models

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Executive summary

Climate change poses an unprecedented set of challenges to the global economy and by extension to the financial sector. Macroeconomic impacts caused by climate change may create significant credit, market, and operational risks for financial institutions. During the transition to net-zero, policy, technology, and market shifts can create headwinds for clients. Over that same time, physical hazards will increase in frequency and severity, raising costs and potentially disrupting supply chains. Effective preparation requires financial institutions to understand the potential macroeconomic implications of transition and physical risks. Many firms are beginning to explore the integration of macroeconomic impacts into climate scenario analysis in order to fully assess the implications for the financial sector.

Climate-related risks are too often considered long-term risks by financial actors. However, near-term impacts are becoming ever harder to ignore. This can be observed with the worsening of extreme weather events around the world and their attendant economic losses. The interconnectedness of the global economy means climate-related impacts in one area can have ramifications across the world. Near-term transition risks can also create systemic instability as many incumbent industries, such as fossil fuels, will face existential changes. New climate policies and shifting consumer preferences have the potential to rapidly upend current business models.

Limitations of Integrated Assessment Models

Integrated assessment models (IAMs) were initially designed for policymakers in order to assess different trade-offs and policy implications. Comprising a number of sub-models, IAMs seek to provide a detailed picture of the future across dimensions from energy systems to socioeconomic developments. Scenarios from IAMs are now being used by financial institutions and supervisors to assess climate risks. These scenario pathways project changes in energy production and demand, technological advancement, consumption patterns, and climate policy implementation. IAMs show the combination and timing of different emission mitigation approaches to reach a given warming target, making them a useful tool for analysing trade-offs between different climate mitigation pathways (UNEP FI, 2021). IAM scenarios have long time horizons, often extending to 2050 or 2100, to assess the long-term implications of various mitigation strategies. However, the long-term dynamics inherent in the structure of IAMs implies limited granularity over shorter time horizons and less focus on short-term economic volatility, critical to assessing the performance of financial assets. As a result, the financial industry may not be getting a full view of the climate risks they face by only considering long-term IAM-produced scenarios. Table 1 below highlights the key limitations of these scenarios.

Table 1: Key limitations of current IAM scenarios

Feature of IAMs	Limitation
Underlying structure of cost optimization	▪ For IAMs, even disorderly scenarios are premised on least-cost or welfare maximizing solutions to decarbonization ▪ Resulting disorderly scenarios do not reflect high levels of economic disruption or financial losses that are possible in a true disorderly transition ▪ Real-world political considerations and economic barriers to transition are not fully taken into account
Exogenous estimates of macroeconomic factors	▪ Variables produced exogenously or semi-exogenously will not be sensitive to the scenario dynamics
Limited focus on variables used in traditional financial analysis	▪ Important variables for conducting financial analysis (e.g., spot prices of commodities and volatility of price variables) are not the focus of the modelling exercise
Long-time horizon	▪ Users may need to undertake interpolation exercises to produce short-term estimates due to typical 5 to 10 year timesteps ▪ Financial analyses over long horizons become more speculative due to likely economic and business strategy changes ▪ The longer the time horizon, the greater the uncertainty in the scenario projections ▪ Lessened severity of economic impacts when they occur in the far future

To gain a complete understanding of climate risks, financial actors need to use both long-term and short-term scenarios. Long-term scenarios are useful to set a sustainable future operating model and net-zero targets. However, short-term scenarios provide actors with insights into more immediate threats to financial stability and the financial sector's preparedness for them.

To advance the financial sector's knowledge of applying macroeconomic models to climate change scenarios, as part of the United Nations Environment Programme's Finance Initiative's (UNEP FI) Task Force on Climate-related Financial Disclosures (TCFD) Programme, UNEP FI partnered with the U.K.'s National Institute of Economic and Social Research (NIESR), a leading economic research organisation. The latest TCFD programme involved forty-eight global banks and investors. The program contained two parallel components. The first was a climate risk roadmap to empower participants at all stages of their climate disclosure journey. The roadmap featured dozens of interactive discussions with experts including regulators, climate modellers, climate scientists, and financial peers. The second component included a series of "modules" where participants deep-dived into specific questions related to climate risk. This report originated in the Climate Stress Testing and Economic Impacts of Climate Change modules of the programme.

Experts from NIESR provided valuable support in helping participating firms understand the critical assumptions of macroeconomic climate scenarios and the utility of short-term macroeconomic shock scenarios for climate scenario analysis. Financial institutions engaged in a series of webinars, group discussions, surveys and workshops with NIESR to identify near-term risks climate change might pose. For this report, UNEP

FI and NIESR developed three new short-term macroeconomic scenarios for users to explore. The scenarios were developed in consultation with participating financial institutions. The three scenarios are—(i) sudden rise in carbon price, (ii) spike in oil price and, (iii) trade war.

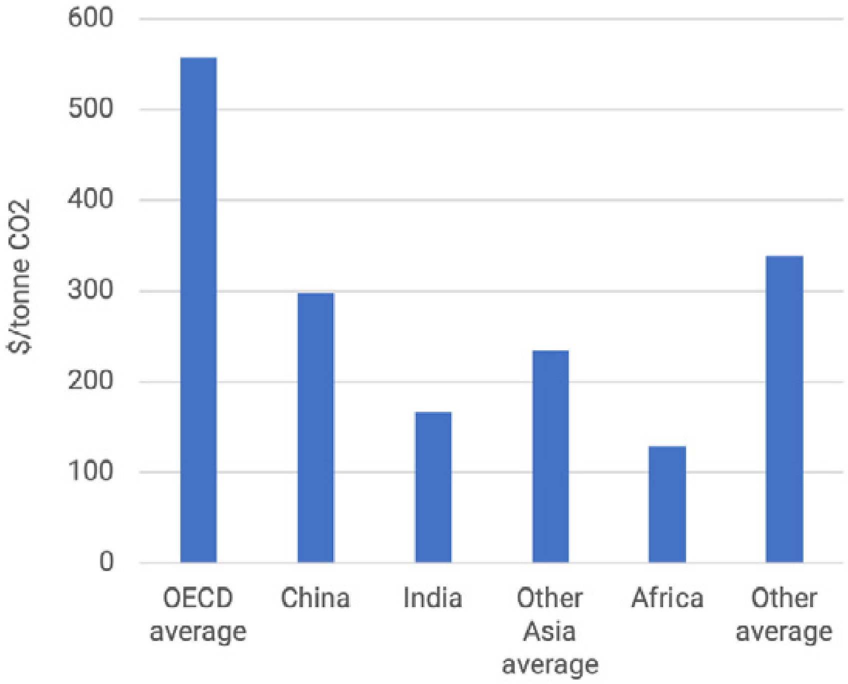
The scenarios and their results have been described below.

Scenario 1: Sudden rise in carbon price

To explore a scenario where the need for aggressive and rapid change could trigger a sudden and sharp rise in global carbon prices for an immediate energy transition, we model a sudden rise in carbon price in 2021.

The carbon price rises by between \$130–\$700 per tonne of CO_2 by 2025, depending on the country (Figure 1). The carbon price rise is introduced at a steady pace over the 5-year period. Advanced economies are expected to introduce more ambitious pricing, with an average carbon price of about \$550 per tonne in 2025. Prices in other regions are expected to remain below \$300 per tonne. The higher price in advanced economies.

Figure 1: Rise in carbon price by 2025



Results

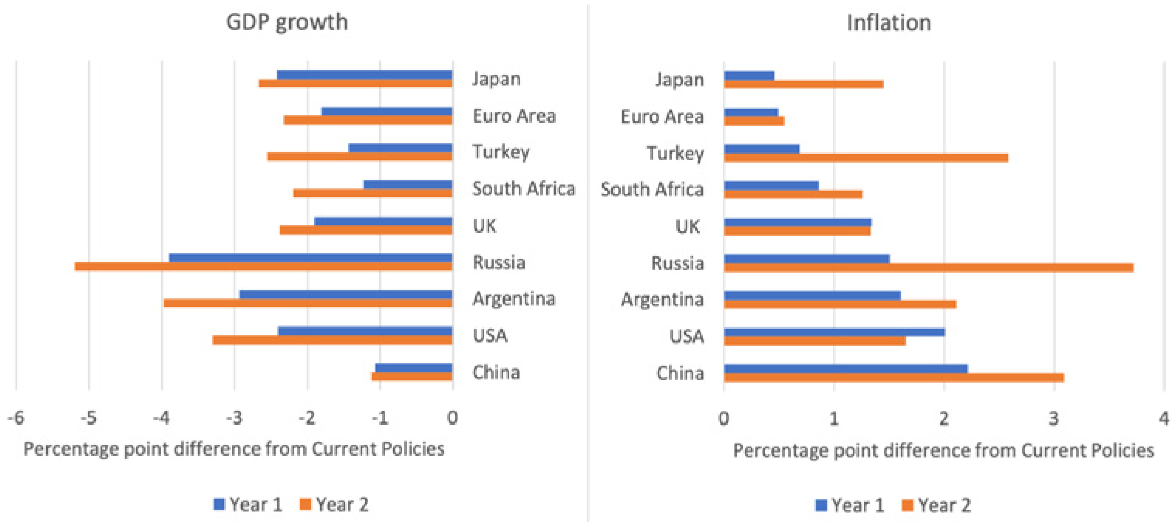
GDP and Inflation

In the first two years, GDP growth would be expected to be 1–4 percentage points lower than under "Current policies" that involve no sudden rise in carbon price. Impacts on GDP growth are expected to be smaller than the losses experienced during the global financial crisis but large compared to other shocks experienced in recent decades.

Inflation would be expected to rise by 1–3 percentage points than under "Current policies". Inflation is expected to rise well above central bank targets in most countries but will remain contained compared to the surge in inflation experienced by many countries during the oil crises of the 1970s.

Less energy and carbon intensive regions are impacted less by a carbon tax compared to other countries, in terms of inflation and GDP (Figure 2). The Euro Area and Japan benefit from improvements in their terms of trade as their fossil fuel consumption is largely imported. Monetary policy in China is expected to allow greater flexibility in inflation, offsetting some of the short-term impacts on GDP growth. Energy-intensive countries suffer terms of trade losses and face domestic pressures, increasing impacts on both GDP growth and inflation.

Figure 2: Impact of sudden carbon tax rise on GDP growth and inflation on selected countries



Source: NiGEM simulation, Scenario 1

Fiscal indicators

The carbon tax generates fiscal revenue in all countries. The quantity of fiscal revenue generated depends on the level of carbon tax applied, the carbon-intensity of production and the impacts on GDP and inflation in each country. In most countries, this is expected to rise by about 5 percentage points after 5 years. The potential of revenue gains from a carbon tax are smaller in countries that have a lower carbon-intensity of production.

With an increase in carbon tax rates rise, income tax rates are able to decrease. As a result, households pay on average 3–4 cents less in tax on every dollar earned. This partially offsets the negative consequences of the higher carbon tax rate.

Government debt is expected to decline as the revenue gains from the carbon tax outweigh the revenue losses from income tax cuts and other expenditure rises. The magnitude of the decline in debt closely mirrors the rise in the effective carbon tax rate, averaging about 4–5 per cent of GDP after 5 years.

Financial markets

A sudden carbon price is expected to push real interest rates up and asset values down. House prices may fall by 1–2 per cent initially, while equity prices are expected to drop by 20–30 per cent in the first year, due to the financial disruptions and uncertainty in firm profitability.

Scenario 2: Spike in oil price

A near-term jump in oil prices can be driven by a combination of factors, such as disruption in supply due to climate regulation or a major climate shock, a collusion between oil exporting countries to increase revenue, market speculation or "unexplained" factors that drive oil markets. For this scenario, we assume that the global price of oil rises by $100 per barrel for 3 years before returning to baseline.

Results

GDP

GDP growth is expected to decline in oil importing countries and rise in oil exporting countries. GDP growth would be expected to decline by 1–2 percentage points relative to the Current Policies baseline in most of the major economies (Figure 3). Though these are significant losses, the impacts would generally be expected to be smaller and less sustained compared to the sudden rise in carbon price scenario. This can be attributed to smaller negative global spill over effects on GDP are smaller and there is less likely to be a significant disruption in asset prices and reallocation of capital in response to a temporary spike in oil prices.

Inflation

Inflation is expected to rise everywhere. Inflation could rise by up to 6 percentage points in the US, as the economy continues to rely heavily on oil (Figure 3).

Figure 3: Impact of oil price spike on GDP growth and inflation on selected countries

Source: NiGEM simulation, Scenario 2

Exchange rates

Inflation could rise particularly high in the Middle East, where exchange rates are largely tied to the dollar and are expected to depreciate. A flexible exchange rate regime in Norway would allow a sharp appreciation of the Norwegian krone in response to the terms-of-trade gains, largely offsetting the inflationary pressures from the oil price hike.

Scenario 3: Trade war

In this scenario, we consider an alternative world that lacks global coordination in decarbonisation. We explore a common policy effort is imposed in a subset of countries, referred to as the Green Club. This Club is comprised of China, the Euro Area, the UK and the US.

A carbon tax imposed in a subset of countries may lead to a loss of competitiveness in the Green Club economies. It could drive a relocation of carbon intensive activities to countries with less stringent emission policies. To restore pre-tax levels of competitiveness and reduce the risks of carbon leakage, the Green Club may introduce border carbon adjustments (BCA), in the form of an import tax on countries with less-stringent emissions standards (non-Green Club countries). If this is met with retaliatory trade tariffs and barriers, it has the potential to spark a form of global trade war. This scenario explores the macroeconomic policy response to the shock, and how different applications of fiscal revenue generated from the carbon price and BCA may impact the results.

Results

The carbon tax and the BCA both generate fiscal revenue. This revenue can be channelled into productive investment and raise the long-run potential output of the economy. This could be used to invest in renewable energy infrastructure, retrofit buildings, or carbon capture technology. It can also be used to pay down debt. For this scenario, we consider two options for spending, which we label as "public investment" and "public debt".

GDP and Inflation

The short-run negative impact on GDP in the Green Club countries is expected to be slightly smaller in the public investment scenario, as the additional investment acts as a short-term stimulus to economic activity. The long-run impacts on the level of GDP are much more significant. When the carbon and border tax revenue is channelled into productive government investment, it leads to a higher level of capital stock to support a higher level of potential output over the longer-term.

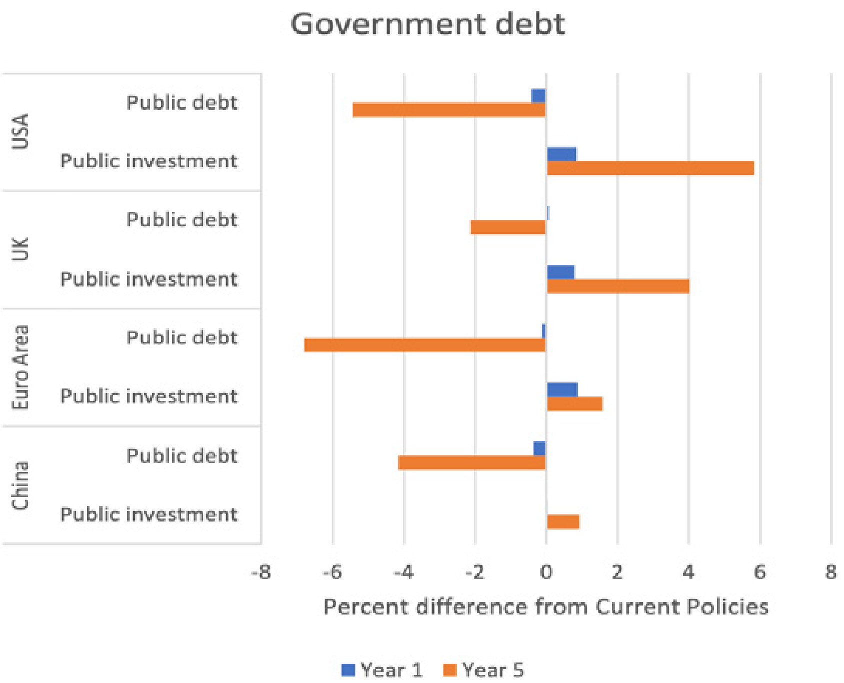
World trade

The stimulus creates jobs and supports consumer spending and pulls in imports from the rest of the world, stimulating world trade. We see a positive long-run impact on GDP in the Non-Green Club countries in the government investment scenario.

Government debt

While GDP growth and world trade would be lower in the public debt scenario, debt would also be expected to decline. After 5 years, the level of government debt would be expected to be 5–10 per cent lower in the public debt scenario compared to the public investment scenario (Figure 4). In countries with a high-risk premium on government borrowing, this added fiscal space could help to provide macroeconomic stability. However, in the Green Club designated for this scenario, the impact on risk premia would be expected to be minimal.

Figure 4: Impact of trade war scenario on government debt in Green Club



Source: NiGEM simulation, Scenario 3

Recommendations for using short-term scenarios

The report showcases the importance of using short-term scenarios by financial actors to assess the impact of near-term climate-related economic risks. All three short-term scenarios developed by UNEP FI and NIESR demonstrate the potential for climate-related shocks to cause financial market disruption. The purpose of this collaborative work was to increase the financial sector's awareness of the nature and utility of short-term macroeconomic scenarios. In the conclusion, we offer three recommendations on how financial institutions and supervisory authorities can best use short-term scenarios to enhance the management of climate-related financial risks.

Three key recommendations for financial institutions and supervisory authorities

Recommendation 1: Use short-term scenarios in climate scenario analysis and strategy setting

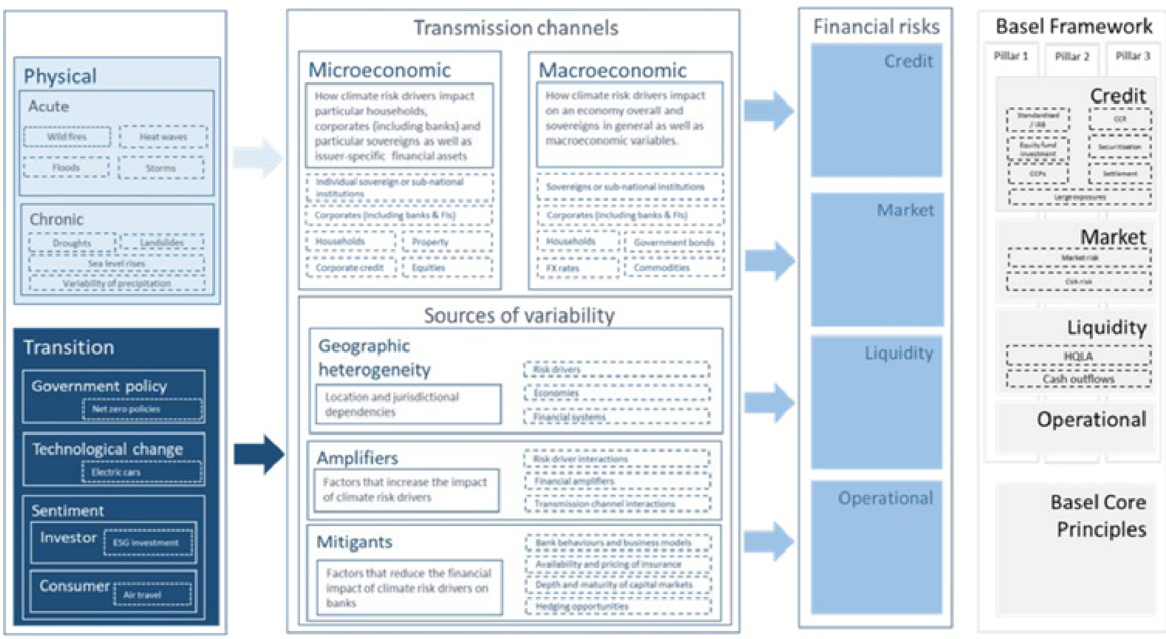
Recommendation 2: Incorporate short-term scenarios into regulatory climate stress testing

Recommendation 3: Consider outputs from long-term and short-term climate scenarios together

1. Introduction: Macroeconomic transmission channels for climate risk

Climate change poses unique and unprecedented risks to the world economy and the global financial system. To understand the nature of climate-related risks, it is helpful to consider two broad categories: physical and transition risks. Physical risks are associated changes in the climate system and the resulting effects. Chronic physical risks involve long-term shifts from historical climatic conditions, such as changes in precipitation patterns and sea-level rise. Acute physical risks reflect event-driven risks, such as the increased severity of extreme events, such as wildfires, hurricanes, and heatwaves. Transition risks arise from dislocations related to the shift to a low-carbon economy and can be driven by changes in policy, legislation, technology, and markets (BIS, 2021). Both physical and transition risks can cascade through the economy and cause financial turmoil. Figure 5 illustrates the macroeconomic transmission channels for these climate-related risks (BIS, 2021).

Figure 5: Macroeconomic transmission channels for climate risks



The macroeconomic impacts of climate change often affect financial institutions as credit and market risks among clients or assets. A few examples suffice to demonstrate these transmission mechanisms in action. Policies to increase the carbon price (transition risk) may lead to an increase in production costs and lower profitability, thus reducing the value of a company's equity. Supply chain disruptions from extreme events (physical risk) can lead to reduced output and higher prices, which may erode demand and shrink revenues. For households, more frequent storms can raise insurance premiums and reduce home values or impact the ability to repay a mortgage. Even sovereigns are not immune as research has provided evidence that physical and transition risks may impact a nation's ability to access debt markets (BIS, 2021), thus driving up borrowing costs.

Table 2 elaborates on how key macroeconomic indicators may be impacted by physical and transition risks over differing time horizons.

Table 2: Potential impacts of physical and transition risks on economic variables

Economic Variable	Impacts of Potential Physical Risks	Impacts of Potential Transition Risks
GDP	▪ A temperature rise of 1.5–4°C with no mitigation action has the potential to lower global real GDP by 1.0–3.3% by 2060 and by 2–10% by 2100 (ECB, 2020)	▪ Carbon taxes can increase production costs, reduce profits and increase prices, causing ▫ Decreased investments ▫ Reduced household disposable income ▫ Lower consumption ▪ Decreased consumption and investment reduce GDP
Unemployment	▪ Hazardous work environments (due to climate events) can reduce employment opportunities in certain regions and sectors	▪ Structural shifts when transitioning to a low-carbon economy can create temporary periods of high unemployment ▪ Implementation of carbon emission taxes can reduce GDP and lead to job losses
Inflation	▪ Severe and frequent weather events can impact global supply chains which can lead to a rise in inflation	▪ Implementation of a significant carbon tax can have a short-term impact on inflation (Batten et al., 2020) ▪ Deflation can occur if decrease in foreign demand and lower commodity prices offset the increase in costs due to higher carbon tax

Productivity	▪ Extreme weather events and high temperatures can impact labour productivity ▪ Diversion of resources from improving productivity to tackling climate change ▪ Research shows reduced labour productivity due to climate change can cost the global economy $2 trillion by 2030 in the second half of the 21st century (BIS, 2021)	▪ Technological advancements can improve productivity of electricity generation from renewable sources ▪ Higher energy costs can reduce energy use, limiting production and productivity
Energy Demand	▪ Increased global temperature will lead to an increase in demand for air conditioning ▪ Extreme weather events causing freezing temperatures can lead to an increase in demand for heating	▪ A shift in demand from energy generated from fossil fuels to energy generated from renewable sources ▪ Decrease in energy demand because of improved energy efficiency resulting from technological advancements
Trade Balance	▪ Increased frequency and severity of weather events can disrupt the flow of imports and exports (frbsf.org, 2019)	▪ Climate policies in certain regions can impact imports from other regions ▪ Shift in societal preferences can impact demand for imports and exports ▪ Commodity exporters will be impacted by lower global demand due to new policies, such as those impacting oil prices, and will lower trade (BOC, 2021)
Government Revenue and Debt	▪ Increase severity and frequency of weather events can result in damage which leads to an increase in government spending	▪ Potential for a large proportion of fossil fuel reserves to become stranded resources, reducing government revenue and increasing debt in fossil fuel producing countries (Marsh & McLennan Companies, 2017)
Asset Price	▪ Price of assets vulnerable to extreme weather events and to increased temperatures, such as house prices, may decrease	▪ Uncertainty and diversion of resources caused by new policies, shift in consumer and investor preferences, and technological developments can cause asset prices to decrease ▪ A transition to a low-carbon economy has the potential to cause fossil fuel resources and other high-carbon intensity assets, such as real estate, to become stranded assets

Investment	▪ Uncertainty of climate events can reduce investor confidence (Batten et al., 2020) ▪ Regions and sectors vulnerable to increased temperature and severe weather events may become unfavourable among investors ▪ Extreme weather can erode existing capital, diverting investment from new projects to reconstruction and maintenance costs	▪ Changes in consumer preferences, climate policies and technological developments will influence investment levels ▪ Implementation of higher taxes and increasing costs can lower investments

It is crucial to understand the relationship between climate risks and macroeconomic impacts. The financial sector has shown a growing appreciation for the destabilizing potential of climate-related effects. Private institutions and supervisors alike are calling for the greater integration of macroeconomic impacts into climate scenario models in order to fully assess the implications for the financial sector(BdI, 2021). To that end, groups such as the Network for Greening the Financial System (NGFS), a collection of central banks and financial regulators, included macroeconomic models in their latest suite of climate scenarios (NGFS, 2021). However, further analysis is needed to fully understand the relationship between macroeconomic factors and climate-related risks.

To advance financial industry knowledge on this important topic, the United Nations Environment Programme's Finance Initiative (UNEP FI) partnered with the U.K.'s National Institute of Economic and Social Research (NIESR), a leading economic research organisation. With expertise in economic models and qualitative methods, NIESR frequently assesses macroeconomic drivers and offers policy recommendations. NIESR's National Institute Global Econometric Model (NiGEM) is used by central banks and private institutions across the world. More recently, NiGEM was used by the NGFS as part of their latest set of climate scenarios, and is increasingly used to gain insights into the macroeconomic implications of climate change.

The report features three new climate-driven macroeconomic shock scenarios and provides an in-depth analysis of the economic impacts of these scenarios. Section 2 of the report explores the limitations of using only long-term climate scenarios for risk analysis and explains the need for risk managers and supervisors to more fully assess short-term climate scenarios. Section 3 provides an overview of the work conducted by UNEP FI and NIESR as part of UNEP FI's Taskforce on Climate-related Financial Disclosures (TCFD) Programme and introduces the three short-term scenarios developed as part of the programme. Section 4 details scenario outputs and assesses their implications for financial actors. Finally, the report provides suggestions for enhancing climate scenario analysis for the financial sector.

2. Current state of scenario analysis

2.1 Overview of scenario analysis

Climate scenario analysis is increasingly being used as a tool by financial institutions to better understand their climate preparedness. Outputs of climate scenario analysis can serve a variety of functions: setting climate-related limits and targets, developing a climate strategy, making internal and external climate disclosures, improving underwriting and investment criteria, and meeting regulatory requirements (Figure 6). Climate scenario analysis is explicitly recommended by the TCFD framework to assess potential business, strategic, and financial implications of climate-related risks and opportunities (tcfdhub.org).

Figure 6: Applications of climate scenario analysis for financial institutions

With the understanding that the financial sector is exposed to significant risks from climate change, regulators have begun developing scenario-based climate stress testing to understand the financial sector's resiliency to climate risks.

The European Central Bank (ECB) published the results of its economy-wide climate stress Eurozone test in September 2021 (ECB, 2021). The Bank of England (BOE) launched their climate stress test Climate Biennial Exploratory Scenario (CBES) in June 2021 with results expected in May 2022. L'Autorité de Contrôle Prudential et de Resolution (ACPR) published the results from its pilot climate stress test in May 2021 (ACPR, 2021). In 2021, De Nederlandsche Bank (DNB) released its report on climate risks following its climate stress test (DNB, 2021). Furthermore, the Monetary Authority of Singapore (MAS) has also proposed climate stress testing, with the first results by June 2022 (MAS, 2021). The Hong Kong Monetary Authority (HKMA) published the results of its pilot climate stress test exercise in 2021 (HKMA, 2021). The Australian Prudential Regulation Authority (APRA) will complete its climate stress test known as the Climate Vulnerability Assessment (CVA) in 2022 (APRA, 2021).

As a forward-looking exercise, climate stress tests measure a firm's exposure to climate risks using severe climate risk scenarios. Climate stress testing results can inform institutions' decisions regarding their business models, planning and strategy (UNEP FI, 2021).

2.2 Commonly used models and scenarios

2.2.1 Brief overview of Integrated Assessment Models

Scenarios from Integrated Assessment Models (IAMs) are used by financial institutions and supervisors alike to assess climate risks. IAMs were initially developed for policymakers to describe the relationship between economic activities, greenhouse gas emissions, and climate change. The pathways produced by IAMs project changes in energy production and demand, technological changes, consumption patterns and climate policy implementation. IAMs typically provided the greatest level of detail on energy systems, while making some simplifying assumptions regarding the climate system and land use. However, IAMs are also continually refining their input data and sub-models to produce more realistic representations of different future states. IAMs show the combination and timing of different emission mitigation approaches to reach a given warming target, making them valuable for analysing trade-offs between different climate mitigation pathways (UNEP FI, 2021). Table 3 below highlights some of the IAMs commonly used by the financial sector.

Table 3: Examples of popular complex IAMs used

Complex IAMs	Description	Open-source/License required
REMIND-(PIK)	Combines socio-economic, climate, and land-use assumptions. Used in NGFS reference scenarios and initial climate stress test scenario design.	Fully open-source
MESSAGE-(IIASA)		
GCAM - (PNNL-UMD)		
IMAGE - (PBL)	Combines socio-economic, climate, and land-use assumptions.	
WITCH-(FEEM-CEMCC)	Combines interactions between the economy, technological options and climate change, fully integrates the energy sector with the rest of the economy.	
AIM (NIES)	Assesses the economic impact of policies to reduce GHG emissions, with a focus on the Asia-Pacific region.	Free of cost

With their original purpose to assess the long-term implications of various mitigation strategies, IAMs have long time horizons, often extending to 2050 or even 2100. These horizons allow for the gradual changes in climatic behaviour, the development and deployment of new technologies, and the economic transition to a new energy system. However, the focus on long-term dynamics means that IAMs have limited granularity over shorter horizons and may not include economic volatility that would have meaningful effects on performance of financial assets. A typical business planning horizon for a financial institution is much smaller. For example, capital planning horizons at banks use forecasts spanning for 2–3 years and strategic planning occurs at 3–5-year intervals (BIS, 2021). Similarly, supervisory risk time horizons for banks have historically been short-term as traditional stress tests typically span shorter horizons, such as 2–5 years to even just days or months (IIF, 2021). In comparison to traditional time horizons, the time horizons of IAMs present challenges for financial decision-makers (UNEP FI, 2021). The limitation of IAMs will be further discussed in section 2.3.

2.2.2 Common scenario narratives

Common scenario narratives used by financial institutions can include various scenario pathways with different temperature outcomes. Below we briefly describe the narratives of the Network for Greening the Financial System (NGFS) Phase II reference scenarios which are commonly used by financial institutions as part of their climate scenario analysis (NGFS, 2021).

- **Net-zero 2050**—Implementation of stringent climate policies and green innovation reduces carbon dioxide emissions to reach net zero by 2050 and limit global warming to 1.5C.
- **Below 2C**—A gradual and steady increase in climate policy which results in a 67% chance of limiting global warming to 2C.
- **Divergent Net Zero—**A pathway to reaching net zero by 2050 and limiting global warming to 1.5C but with higher transition risks and economic costs due to the varied implementation of policies in different regions and different times.
- **Delayed Transition—**Strong climate action does not take place until 2030 which requires the implementation of aggressive policies and limited of used of negative emissions technologies to limit global warming to just below 2C.
- **Nationally Determined Contributions (NDCs)**—All policies currently pledged by governments are implemented but no additional policies are set, resulting in global warming of likely around 2.5C.
- **Current Policies**—Only currently implemented climate policies are considered which leads to a slow and incomplete transition with severe physical risks, resulting in global warming of above 3C.

2.3 Limitations of long-term scenarios

Climate-related risks are too often considered long-term risks by financial actors, who fail to take urgent action on mitigation and adaptation. Former Bank of England Governor Mark Carney called this "the tragedy of the horizon" (BOE, 2015). However, the near-term impacts are becoming ever harder to ignore, and their potential for financial disruption is significant, as the United States Federal Reserve Board's (FRB) Financial Stability Report indicated (FRB, 2020).

Physical risks can create near-term financial challenges. The growing frequency and severity of extreme weather events are causing major climate-related losses around the world. With unprecedented wildfires from Australia to Brazil and increasingly destructive storms in the Atlantic and Pacific basins, few areas are safe from climate impacts. AON estimated globally insured losses of USD 42 billion and economic losses of USD 93 billion from natural disasters in the first half of 2021 alone (Straits Times, 2021). As COVID-19 showed, the interconnectedness of global supply chains and the world economy means that problems in one area rarely remain there but have ramifications in many other places.

Transition risks may be an ever greater driver of financial system instability. The scale of the low-carbon transition means many incumbent industries (such as fossil fuels) may be disrupted. As the U.K.'s Climate Financial Risk Forum (CFRF) explained:

> **"Firms need to be aware however that while the transition away from fossil fuels will take a number of decades to achieve, the crystallisation of macro-financial risks from transition could occur considerably sooner and take multiple pathways in the short term."**
>
> **CFRF, 2020**

New climate policies, technological advancements, and shifts in consumer preferences all have the potential to rapidly upend current business models. For example, the sudden imposition of significant carbon taxes can quickly change the economics for oil and gas companies as dual supply and demand shocks in 2020 demonstrated for U.S. producers. (UNEP FI, 2021). Likewise, the automobile sector is currently experiencing disruption due to the advancement of electric vehicle (EV) technology that has led to improved performance and falling costs.

The fact that fossil fuels are so enmeshed in the global economy presents numerous avenues for near-term transition risk. Chemicals, agriculture, transportation, industrial manufacturing, and electricity are just some of the major components of modern life with dependencies on the fossil fuel supply chain. Risks can cascade from one affected sector into others and from one affected region to others. Consider how reduced oil revenues can threaten the stability of major oil-producing states. Instability in those states can cause energy price volatility that can put a damper on consumption halfway around the world.

Another potential transition risk comes from the huge reserves of fossil fuels already discovered. To keep to global climate goals, most of these reserves must remain unburned (McGlade & Ekins, 2015). That means that hundreds of billions of dollars of reserves (at today's prices) are at risk of becoming stranded assets. As investors increasingly see evidence of the accelerating climate transition, those holding these assets may need to take massive write-downs. These write-downs could throw some companies into insolvency and present major market and credit risks for exposed financial institutions.

Limitations of IAM assumptions and uses for the financial sector

Despite rising physical and transition risks and widespread acknowledgement by the financial sector that climate risks are financial risks, the industry may not be getting a full view of the risks they face. This is predominantly due to the focus on long-term climate scenarios from IAMs for climate scenario analysis. As mentioned previously, the insights from IAMs can be exceedingly valuable. Indeed, a long-term view of the policy, market, and financial actions necessary to achieve climate goals is critical. However, when only long-term IAM-derived scenarios are used in reporting and stress testing to the exclusion of shorter macroeconomic scenarios, important limitations emerge (Table 4).

To date, the economic stresses seen in most long-term scenarios are comparatively mild (even the disorderly transition scenarios) when compared to historical stresses of periods such as the Global Financial Crisis. This is largely driven by the structure of the underlying IAMs, which look for least-cost or welfare-maximizing solutions to decarbonization. Even when the overall economic impacts are appreciable, they are spread over multiple decades, lessening their severity. As a result, many initial stress testing exercises have reported only modest climate and transition risks to financial actors. An example can be seen in the results of the Banque de France and ACPR, whose climate scenario exercise indicated that French financial actors are only "moderately" affected by transition risks (ACPR, 2021). Similarly, the top-down, economy-wide climate stress test by the ECB showed relatively small changes in the probability of default (PD) across a variety of scenarios (ECB, 2021).

IAM scenarios are also not focused on producing realistic estimates of many of the key economic indicators that are used in traditional risk models. GDP estimates are often produced exogenously or semi-exogenously, meaning that the nature of the scenario has a limited effect on the values of this crucial variable. Other important variables for conducting financial analysis such as spot prices of commodities (and the volatility of these price variables over time) are not the focus of most IAM models. In addition, many other important variables such as interest rates and equity index values are rarely included as IAM model outputs.

Other limitations of IAM-based outputs have been raised by the modelling community regarding how the following factors are integrated into the scenarios (Gambhir et al., 2019):

- Real-world policies, political feasibility and policy goals
- Technological innovation, such as low-carbon technologies, and challenges in deployment
- Societal behaviour changes
- Economic barriers to transition

Scenarios with long time horizons demand additional assumptions from users. Most financial institutions set business strategy and risk appetite using far shorter timeframes than those that are the focus of IAM outputs. Therefore, financial institutions often need to undertake significant interpolation exercises to produce the required short-term estimates (UNEP FI, 2021). On the other hand, when considering the final states (e.g. net zero by 2050) of many of these long-term models, the longer the time horizon analysed, the greater the uncertainty in the model projections (BIS, 2021). As the ECB notes, the "long-term nature of climate-related scenarios burdens the estimates with intense uncertainty and opens new modelling demands" (ECB, 2021).

Financial institutions also must make assumptions about their business activities over long time horizons, which can pose challenges. For example, if a firm assumes a static balance sheet over decades, the analysis itself may become less realistic and relevant. Likewise, assumptions of changes for a dynamic balance sheet can also be highly speculative (BIS, 2021).

Table 4: Key limitations of current IAM scenarios

Feature of IAMs	Limitation
Underlying structure of cost optimization	▪ For IAMs, even disorderly scenarios are premised on least-cost or welfare-maximizing solutions to decarbonization ▪ Resulting disorderly scenarios do not reflect high levels of economic disruption or financial losses that are possible in a true disorderly transition ▪ Real-world political considerations and economic barriers to transition are not fully taken into account
Exogenous estimates of macroeconomic factors	▪ Variables produced exogenously or semi-exogenously will not be sensitive to the scenario dynamics
Limited focus on variables used in traditional financial analysis	▪ Important variables for conducting financial analysis (e.g., spot prices of commodities and volatility of price variables) are not the focus of the modelling exercise
Long-time horizon	▪ Users may need to undertake interpolation exercises to produce short-term estimates due to typical 5 to 10-year timesteps ▪ Financial analyses over long horizons become more speculative due to likely economic and business strategy changes ▪ The longer the time horizon, the greater the uncertainty in the scenario projections ▪ Lessened severity of economic impacts when they occur in the far future

2.4 The value of near-term macroeconomic scenarios

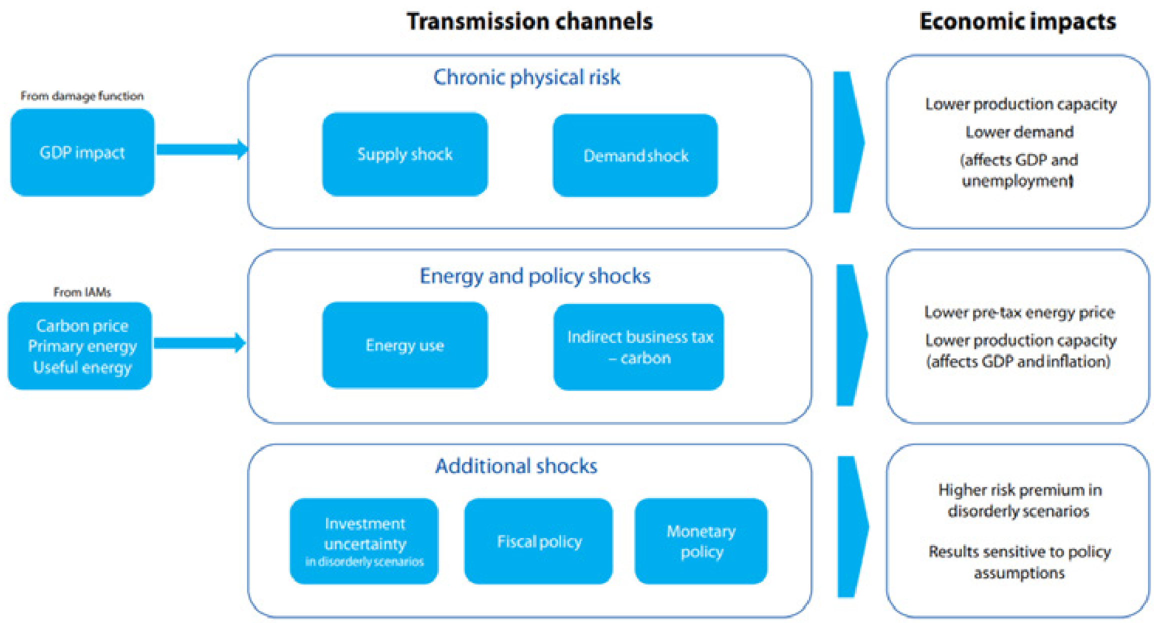
To gain a complete understanding of the climate risks faced by the financial sector, it is important that both long-term and short-term scenarios are used in assessing climate risks. Long-term scenarios hold value in helping set long-term goals and targets to support a sustainable future and global climate goals. Short-term scenarios enable the evaluation of short-term threats to financial stability and an institution's preparedness. Short-term scenarios are also similar in design to traditional stress test scenarios but have narratives that are adopted to incorporate climate change. As a result, short-term scenarios can be easily integrated into future climate stress test exercises to evaluate capital impacts of climate change.

It is vital that supervisory authorities begin assessing the near-term risks of climate change as well. A few authorities have begun confronting short-term risks by including short-term scenarios in their climate stress tests. For example, the European Central Bank (ECB) has incorporated near-term physical and transitions risks into their upcoming supervisory climate stress test. The exercise assesses vulnerability to two hypothetical near-term physical risk scenarios. The first scenario assesses the impacts of the entire EU being hit by a heatwave in 2022. The second scenario considers a severe flood in Europe over a one-year horizon. The test also includes a severe but plausible scenario of a three-year disorderly transition due to a rapid increase in carbon price (ECB, 2021). The materialization of transition risks through various channels in the short-term were also evaluated in De Nederlandsche Bank's (DNB) energy transition risk stress test (2018). These channels included the implementation of carbon taxes and emission restrictions by governments and sudden breakthroughs of technology to replace carbon-intensive technologies (DNB, 2018).

However, IAMs were not designed to assess short-term macroeconomic stresses with many of the economic variables considered are exogenous. Therefore, to assess near-term climate risks, additional models need to be considered and existing models must be adapted.

As a first step to remedying this, NGFS partnered with NIESR. In June 2021, NGFS released Phase II of its reference scenarios which included detailed information on the macroeconomic implications of physical and transition risk. NIESR added detailed macroeconomic modelling to complement the IAM outputs and estimates of physical risk by using NiGEM, their well-known multi-country macroeconomic model. Four main transmission channels were selected to capture transition risks, including energy, policy and uncertainty. Figure 7 below illustrates the shocks introduced to the macroeconomic model for the economic scenarios (NGFS, 2021).

Figure 7: Shocks introduced to NiGEM for NGFS Phase II Scenarios

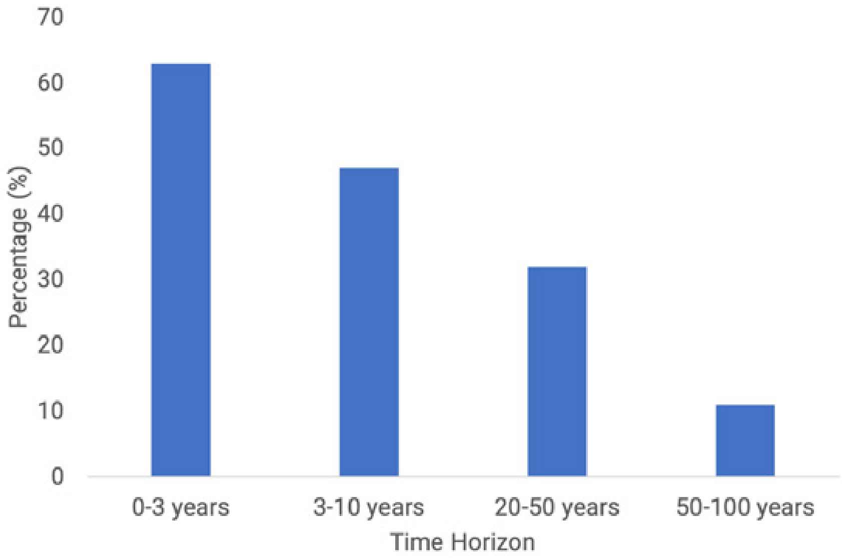


The Phase II scenarios also include potential macroeconomic damages from physical risks that were estimated through damage functions using temperature outcomes from emissions trajectories of transition scenarios. This was then integrated with macro-economic modelling.

The NGFS Phase II scenarios are a good step forward in incorporating an economic dimension to climate scenario analysis. For near-term analysis, the NGFS explores two alternative assumptions regarding short-term policy in Phase II. Firstly, the immediate scenarios assume that optimal carbon prices that align with long-term targets are implemented immediately after the 2020 model time step. Secondly, the disorderly delayed transition scenario follows a current policies scenario until 2030, after which a carbon price trajectory is implemented with long-term targets.

Short-term economic scenarios are useful to understand how a firm might perform today if faced with a macroeconomic shock, however, further expansion of short-term scenarios is needed for the integration of short- and medium-term risks into scenario analysis. Survey results with participating institutions in UNEP FI's TCFD programme showed that 63% of institutions believe that a 0–3-year time horizon is highly relevant to their institution and 47% believe that a 3–10-year time horizon is highly relevant for their institution. In comparison, 32% of institutions believe a 20–50-year time horizon and only 11% of institutions believe a 50–100-year time horizon is highly relevant for them (Figure 8). Highlighting the relevance of shorter time horizons, the survey shows the usefulness and applicability of short-term scenarios in providing insights to financial institutions on near-term risks.

Figure 8: Timelines considered relevant for climate scenario analysis by UNEP FI TCFD Programme Participants



2.5 UNEP FI's TCFD program

This report is one of the outputs of UNEP FI's TCFD programme. Since the publication of the FSB's TCFD recommendations in 2017, UNEP FI has run a series of pilot programs to assist members in exploring physical and transition risks and developing practical approaches for evaluating these risks using climate scenario analyses. Over 100 financial institutions (banks, investors, and insurers) from all around the world have participated in these pilots. Participating institutions have been supported by over a dozen technical partners including climate modellers and climate risk experts.

The latest TCFD programme (beginning in March 2021) involved forty-eight global banks and investors. The program contained two parallel components. The first was a climate risk roadmap to empower participants at all stages of their climate disclosure journey. The roadmap featured dozens of interactive discussions with regulators, climate modellers, climate scientists, as well as peer presentations. The second component included a series of "modules" where participants could dive deeply into specific questions related to climate risk.

This report originated in the Climate Stress Testing and Economic Impacts of Climate Change modules of UNEP FI's TCFD programme. In those targeted modules, experts from NIESR worked with TCFD programme participants to help them understand the NGFS macroeconomic scenarios created by NiGEM and the macroeconomic concepts that underpinned the NiGEM model. Financial institutions engaged in webinars, group discussions, surveys and workshops with NIESR to identify the near-term risks that extreme events and rapid decarbonisation might pose to various sectors and regions. NIESR provided valuable support in clarifying the critical assumptions of macroeconomic climate scenarios and demonstrating the utility of short-term macroeconomic shock scenarios for climate scenario analysis.

For this report, UNEP FI and NIESR developed three new short-term macroeconomic scenarios. During the initial stages of development, UNEP FI and NIESR engaged in discussions with programme participants to develop relevant storylines for the potential scenarios. Following the development process, scenario narratives and the underlying data were shared with the programme participants, who were given the opportunity to explore the scenarios using their own models and methodologies. Feedback from these post-development sessions was incorporated into the final versions of the scenarios presented in this paper.

3. Macroeconomic shock scenarios

3.1 Overview of the NiGEM model

These scenarios are conducted using a modified version of the National Institute Global Econometric Model, NiGEM, which is developed and maintained by the National Institute of Economic and Social Research (NIESR). NiGEM is a peer-reviewed global econometric model that has been in the public domain for over 30 years. It is widely used by central banks, finance ministries and other public and private bodies around the world for forecasting, scenario analysis and stress testing.

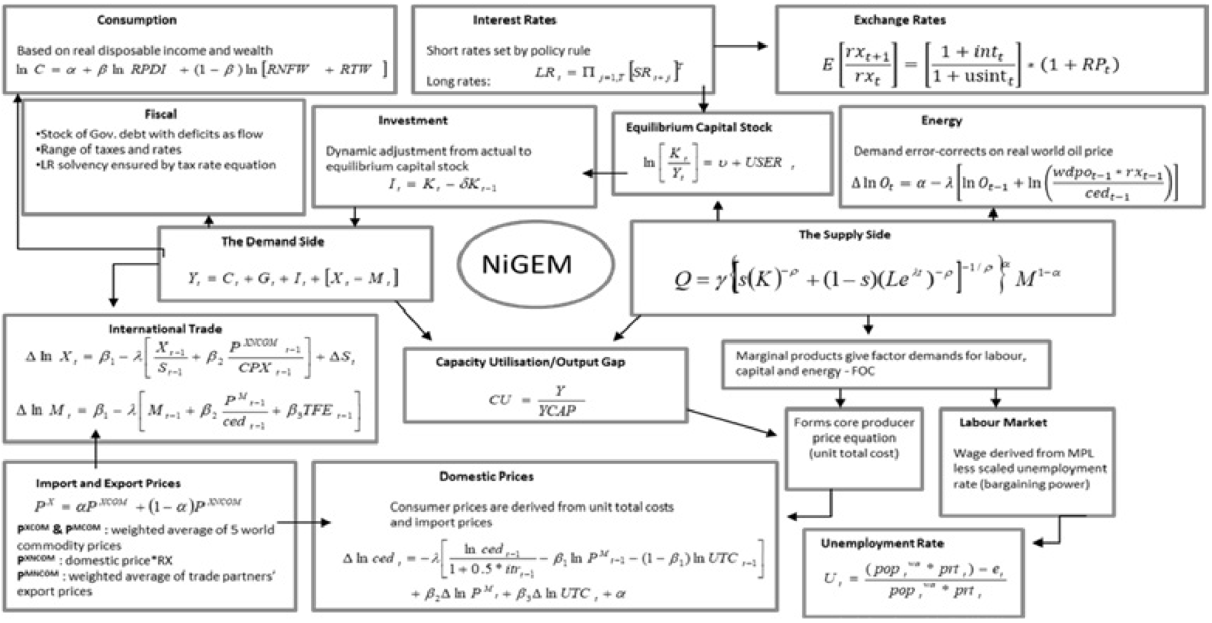
NiGEM is a **Global** model that consists of individual country and regional models, which are linked together through trade in goods and services and integrated capital markets. So it can be used to look at policy developments in a single country, but also see how those policies interact with developments in the rest of the world. It represents a closed world, where outflows from one country or region are matched by inflows into other countries and regions.

NiGEM is an **Econometric** model, in that key behavioural equations are econometrically estimated using historical data. This ensures that the dynamics and key elasticities of the model fit the main characteristics of individual country data. From a theoretical perspective, NiGEM can be classed among global general equilibrium macroeconomic models. It, therefore, strikes a balance between theoretical underpinnings that guide economies towards long-run market clearing equilibria, and data-driven individual country characteristics that fit the main characteristics of real-world data outturns.

NiGEM is based on a broadly New Keynesian structure: prices and wages adjust gradually; interest rates impact investment and consumption decisions; shifts in domestic demand impact employment and production decisions in the short run; over the longer term, economic activity is guided by the supply side. It shares many of the characteristics of dynamic stochastic general equilibrum (DSGE) models, which are theory-based models that are grounded in microeconomic foundations (see Galí and Gertler, 2007, for a simple exposition of this class of models). A key distinction between NiGEM and DSGE models is that the equations in NiGEM are econometrically estimates, and so reflect the historical relationships between macro-level variables.

Individual country models are grounded in textbook macroeconomic foundations, with features such as sticky prices; rational or model-consistent expectations; and endogenous monetary policy based on standard specifications such as a Taylor rule. Taylor rules are simple monetary policy rules that prescribe how a central bank should adjust its interest rates to maintain macroeconomic stability in response to developments in inflation and macroeconomic activity. Country models are built around the national income identity, and contain the determinants of domestic demand, trade volumes, prices, current accounts, and asset holdings. Figure 9 below illustrates a broad schematic overview of full country models in NiGEM.

Figure 9: NiGEM overview schematic



The long-run is anchored by supply inputs, which include labour, capital, and energy. Energy is disaggregated into coal, oil, gas, and non-fossil fuels (mostly renewables). NiGEM incorporates endogenous monetary and fiscal policy responses, which interact with price and wage adjustments to stabilize output and inflation and move towards equilibrium between demand and supply in the long run. For a full description of the standard model, see Hantzche, Lopresto and Young (2018).

The NiGEM climate model applied in this study is an expanded version of the standard model that introduces channels to model climate policy instruments, energy transition and physical climate shocks. The key channels relevant for these scenarios are detailed in the Annex.

3.1.1 The role of NiGEM in climate modelling

NIESR started developing its Climate Model in 2018, with an aim of understanding the interactions between the macroeconomy and climate-related shocks and climate-related policy. Some of this early work was carried out in collaboration with the Dutch National Bank (Vermeulen et al, 2018).

The climate module in NiGEM is used internally at NIESR, but has also been used by the Bank of England, the Banque de France, the Dutch National Bank and others as part of their stress testing exercises and climate scenarios.

In 2021, NIESR joined the Network for Greening the Financial System (NGFS), which is a group of central banks and financial supervisors from across the world, to contribute to the NGFS Climate Scenarios (NGFS, 2021). In particular, NiGEM complements the detailed energy modelling of the Integrated Assessment Models (IAMs) used by the NGFS to provide greater macroeconomic detail and to elaborate the macroeconomic policy channels. These scenarios are used as a common reference framework for long-term climate pathways for central banks and supervisors across the world.

The scenarios developed for this paper were produced in collaboration with UNEP-FI, focussing on short-term climate-related risks and shocks, in contrast to the NGFS scenarios, which take a long-term perspective. Box A provides a brief overview of the main NGFS scenarios, which are used as a reference point for the scenarios short-term scenarios discussed below.

Box A: An overview of the main NGFS scenarios

The NGFS scenarios provide a common reference point for understanding how climate change (physical risk) and climate policy and technology trends (transition risk) could evolve in different futures. Each scenario was chosen to show a range of higher and lower risk outcomes. These scenarios can be broadly categorised into orderly, disorderly, and hot house world categories. The summary narratives behind the scenarios are as follows:

Orderly

- Net-zero 2050—strong climate policies and green innovation efficiently reduces carbon dioxide emissions to net zero by 2050. Global warming is limited to 1.5°C.
- Below 2°C—a more gradual (but still steady) rise in climate policy ambition. Global warming has a 67% chance of being kept below 2°C.

Disorderly

- Divergent Net Zero—another pathway to net zero, but with higher transition risks (rapid oil phase out) and economic costs due to varied policies introduced in different regions at different times. Global warming is limited to 1.5°C.
- Delayed Transition—strong climate action is delayed until 2030, so aggressive policies are needed thereafter and there is limited use of negative emissions technologies. Warming is likely limited to just below 2°C.

Hot House World

- Nationally Determined Contributions (NDCs)—this pathway assumes that all policies pledged by governments are implemented, but no additional ones. Global warming is likely around 2.5°C.
- Current Policies—this is the least ambitious climate scenario as currently implemented policies are the only climate policies considered. As a result, a slow and incomplete transition leads to more severe physical risks. Global warming may be above 3°C.

In order to assess some of the short-term risks associated with climate policy, we model three hypothetical scenarios using NiGEM. The first (1) entails a sudden, unexpected hike in the carbon price. The second (2) considers a near-term jump in oil prices in response to a disorderly adjustment in fossil fuel supply and demand. And the final scenario (3) considers a “trade war” sparked by the uneven rollout of carbon pricing instruments across countries.

3.2 Scenario 1: Sudden rise in carbon price

3.2.1 Underlying assumptions

GHG emissions are set to continue rising without dramatic changes in behaviour, including a seismic shift in the energy mix, towards low carbon and no-carbon sources. There is broad consensus that carbon pricing is likely to form an important element of the global policy measures that are required to curb global greenhouse gas emissions to a level that is consistent with commitments to reach net zero and keep global warming well below 2 degrees Celsius. A carbon tax, or carbon price, is a policy instrument that can create the necessary incentives to spur the energy transition and encourage energy efficiency gains. It raises the costs of carbon-intensive activities relative to low-carbon activities, transferring some of the social costs of emissions back to the emitter and encouraging households, firms and governments to invest, adopt and instil practices that limit or even help reverse the damage caused by carbon-intensive activities.

Under an orderly energy transition, carbon prices are expected to rise gradually over the coming decades. For example, for the Below 2°C NGFS scenario, the MESSAGEix-GLOBIOM modelling system estimates that carbon prices would need to rise by less than $5 per annum.

But what if it suddenly becomes clear that much more aggressive and rapid change is necessary? This could trigger a sudden and sharp rise in global carbon prices to support a more immediate energy transition. To explore this scenario, we model a sudden rise in carbon price in 2021. The 2022 ECB Climate Risk Stress Test will ask banks to consider a similar scenario, to assess how vulnerable they are to a sharp increase in the price of carbon over the next three years. The scenario is similar to the Delayed Transition NGFS scenario described in Box A, where climate action is put off until 2030, requiring a more aggressive adjustment in order for the world to have a decent chance of restricting global warming to well below 2 degrees Celsius. We shift this shock forward to 2021.

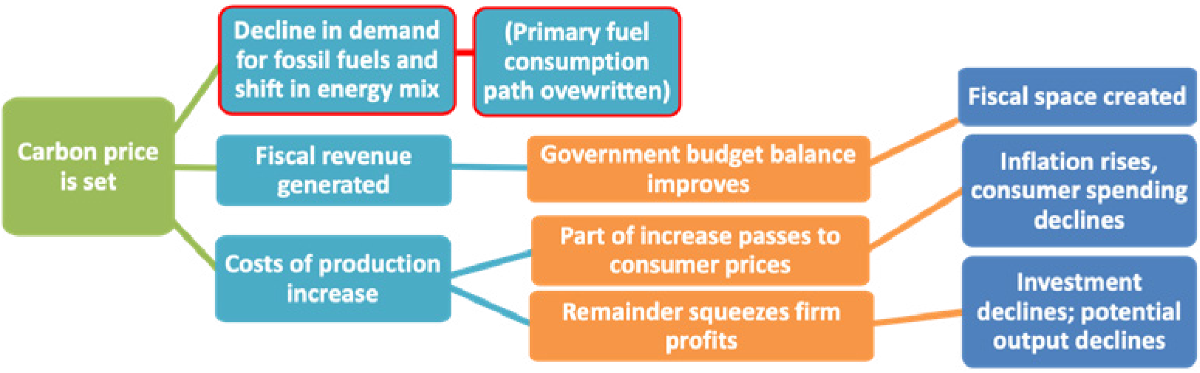
In order to align this experiment with the familiar NGFS scenarios, the full set of shocks from the *Delayed Transition* NGFS scenario are applied in 2021, using the REMIND-MAgPIE IAM inputs as an example. In addition to the carbon price settings, this includes shocks to primary fuel consumption (oil, gas, coal and renewable); "useful" energy input, which is adjusted for energy efficiency gains; as well as a 2-year rise in global credit constraints to capture the heightened uncertainty associated with the disorderly scenario.[1] We can explore the macroeconomic responses to each of these exogenous shocks in turn.

Carbon price

Figure 10 provides an overview of how a carbon price passes through the supply and demand channels in NiGEM.

1 As we are primarily interested in the short-term economic reactions in this paper, we abstract from the physical shocks associated with climate change, as differences between orderly and disorderly scenarios would be expected to be relatively small over the first five years.

Figure 10: NiGEM transmission channels of a carbon price



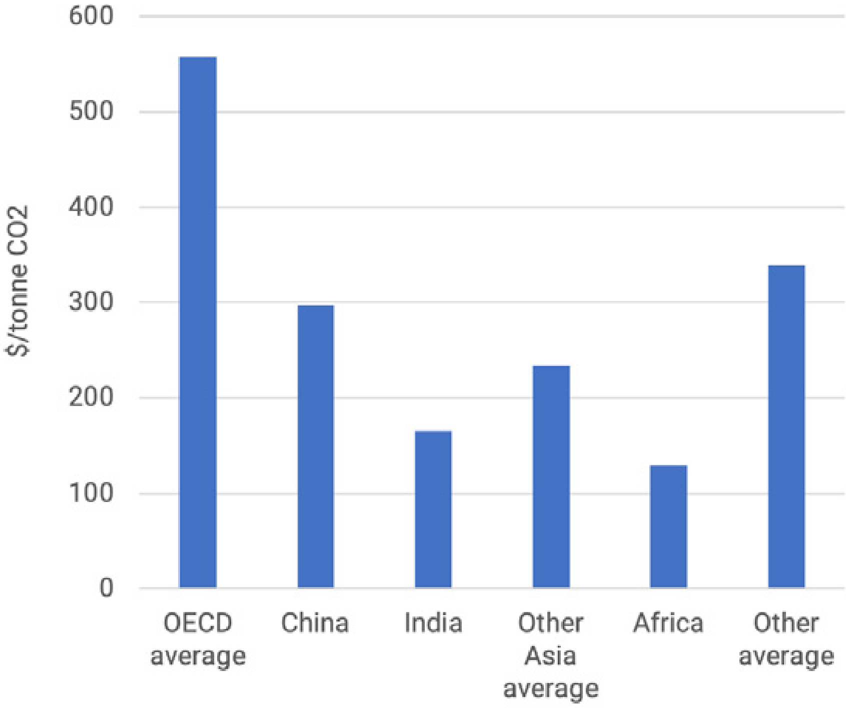
We assume that the carbon tax is applied upstream as a rise in production costs. The majority of global CO_2 emissions stem from burning fossil fuels. A carbon tax, therefore, has a direct impact on the cost of burning fossil fuels, shifting the relative costs of primary fuel sources in proportion to the carbon that is emitted by each fuel. While NiGEM delivers an endogenous shift in energy mix in response to the change in relative prices, this channel is overwritten for the purposes of this scenario to take advantage of the more detailed energy modelling available within the NGFS IAM models. This transmission channel is modified by a set of exogenous shocks to primary fuel consumption, with further transmission channels detailed below.

In this paper we focus on an explicit carbon tax, with the potential to generate government revenue. The rise in fiscal revenue improves the government budget balance, creating fiscal space. The government, in turn, can recycle the tax revenue to households through the taxation system, use it to invest in an expansion of renewable energy supply, surgically target the more vulnerable sections of society through transfers, or reduce corporation taxes and provide incentives to encourage private sector investment in green technologies. Alternatively, the carbon revenue can be used to pay down government debt or can be directed towards other fiscal priorities.

The carbon price also has a direct impact on producer and consumer prices. NiGEM allows roughly half of the tax to pass directly to consumers through higher consumer prices, constraining domestic demand via the consumption channel. The other half is absorbed through squeezed profit margins of firms, constraining investment, the accumulation of capital, and ultimately potential output.

In Scenario 1, the carbon price rises by between \$130–\$700 per tonne of CO_2 by 2025, depending on the country (Figure 11). The carbon price rise is introduced at a steady pace over the 5-year period. Advanced economies are expected to introduce more ambitious pricing, with an average carbon price of about \$550 per tonne in 2025, while prices in most other regions are expected to remain below \$300 per tonne. The higher price in advanced economies is indicative of the policy efforts that are required to make further behavioural changes in countries where much of the “low-hanging fruit” has already been absorbed. While these values may seem high, they are in line with other stress testing exercises.

Figure 11: Rise in carbon price by 2025, Scenario 1



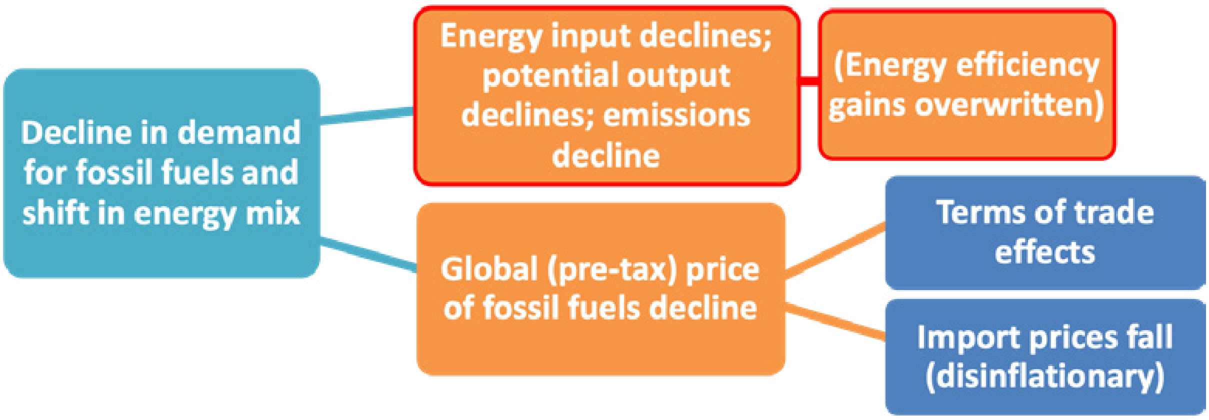
Source: NiGEM Scenario 1 assumptions

Primary fuel consumption

Figure 12 traces the transmission channels of the shocks to primary fuel consumption in NiGEM. In response to the higher carbon price, demand for carbon-heavy fuels such as coal and oil can be expected to decline, and with them, carbon emissions will decline. Country-specific adjustments in energy consumption depend on a range of factors, including the level of carbon price in the country, the energy intensity of production, the baseline energy mix and the flexibility of the economy. To quantify this decline, the IAM models also consider factors such as the capacity for and rate of introduction of energy conversion and carbon sequestration technologies, transitions in the buildings, industry and transportation sectors, and shifts in land use.

The decline in demand for carbon-heavy fuels can also be expected to put downward pressure on the (pre-tax) price of fossil fuels. Countries that continue to rely heavily on fossil fuel exports can be expected to suffer a significant loss in potential export revenue, stemming from both a decline in the volume of demand for fossil fuels and a decline in the value of each ton of fossil fuel that continues to be exported. This will deliver significant terms of trade losses for fossil fuel exporters, acting as a constraint on GDP as income losses feed into lower levels of domestic demand.

Figure 12: NiGEM transmission channels of a decline in fossil fuel demand

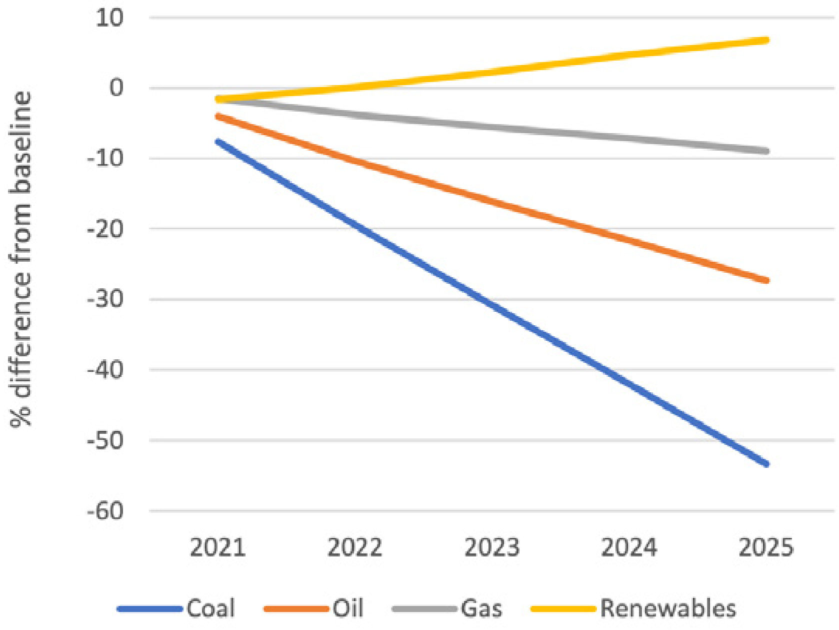


Meanwhile, fossil fuel importers benefit from the lower import price, which offsets some of the inflationary impacts of the carbon price itself. Many fossil fuel importers may also experience gains in terms of trade as they transition towards a production structure that includes a greater share of domestically produced energy from renewable sources. The magnitude of terms of trade shocks experienced in each country will depend on factors such as the share of domestic income derived from fossil fuel exports, the flexibility of the exchange rate regime, and the capacity for and speed of structural transition in the economy towards low-carbon industry and domestically produced renewable energy sources.

The carbon price will raise the average price of primary fuel inputs, even after allowing for the shift in the energy mix. As a result, total primary fuel consumption declines, leading to a fall in the total energy input into the economy. This restricts productive capacity, unless the decline in primary fuel consumption is fully offset by energy efficiency gains. NiGEM does not, by default, model an endogenous shift in energy efficiency in response to an energy price rise. For the purpose of this scenario, we apply an exogenous shock to energy efficiency by adjusting total "useful energy input" in line with the endogenous efficiency gains suggested by the REMIND-MAgPIE model in the NGFS scenarios. This channel is elaborated on below.

Figure 13 shows the expected short-term adjustments in energy consumption at the global level, relative to the baseline scenario that excludes the rise in carbon price. As energy prices rise, all primary fuel consumption declines initially. Coal consumption is expected to decline rapidly as its price rises sharply, declining by 50% by 2025. Oil and natural gas consumption are also expected to decline at the global level, by 25 and 9 per cent, respectively. Renewable energy consumption is expected to rise as the costs of using renewables decline relative to other fuels.

Figure 13: Global shift in energy consumption by fuel type, Scenario 1

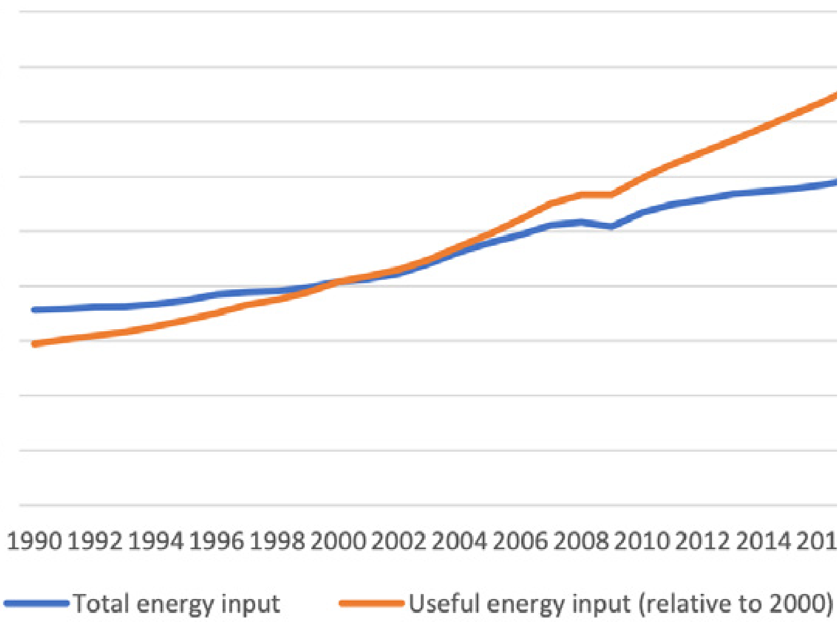


Source: NiGEM Scenario 1 assumptions

Energy efficiency

Imposition of a sizable carbon tax is likely to drive technological advances that will lead to improved energy efficiency. The speed of adoption of these new technologies will vary across different economies. In order to capture efficiency gains, total energy input into the economy via the production function is adjusted to reflect what the IAM models term "useful" energy input. For example, if total energy input declines by 5 per cent, but energy efficiency increases by 4 per cent, "useful" energy would fall by just 1 per cent. Figure 12 compares the global trends in total energy input and useful energy input since 1990 as an example. Energy efficiency gains have allowed useful energy to grow at an average annual rate of roughly 1.5 percentage points faster than the actual energy consumed.

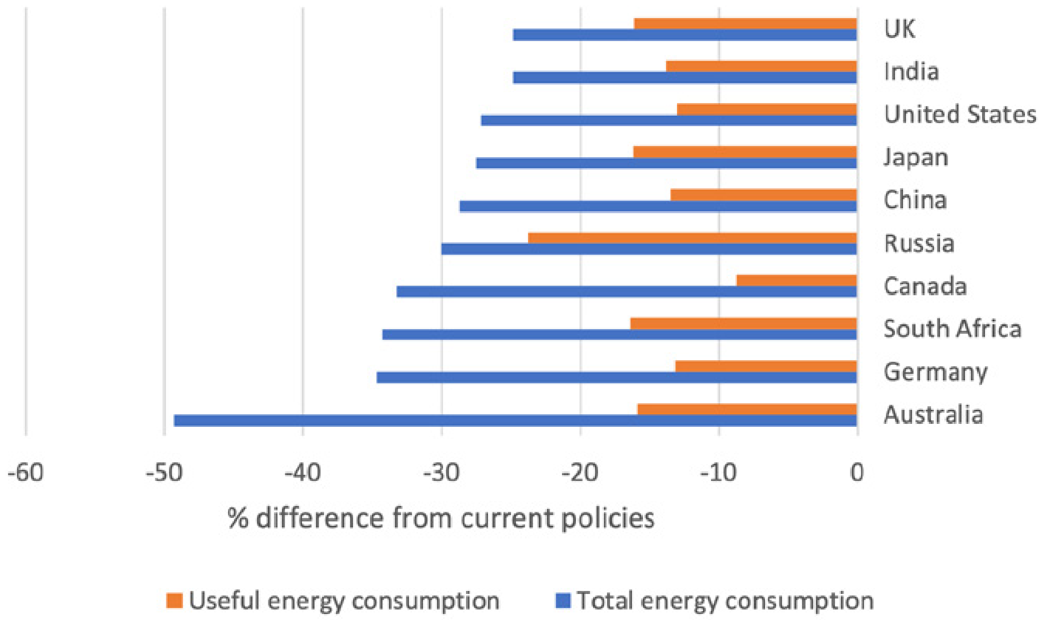
Figure 14: Global energy consumption



Source: NiGEM database

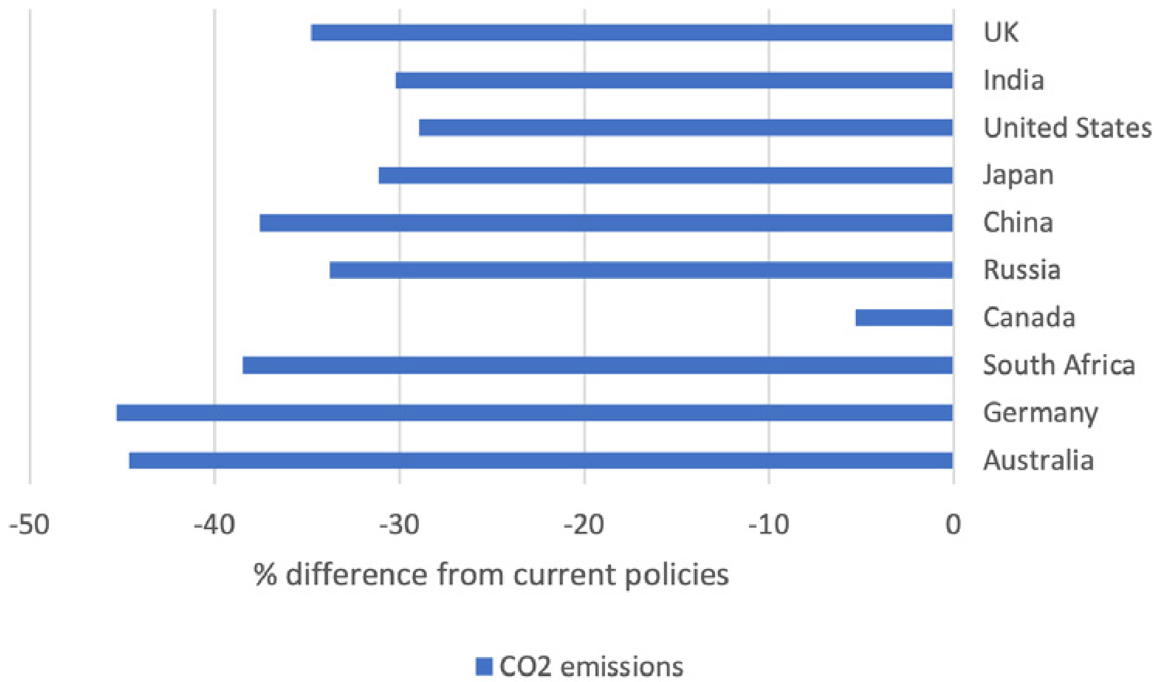
In the carbon tax scenario, efficiency gains are expected to offset a significant share of the decline in total energy input, reducing much of the long-run impact on potential output. However, in the short term, these supply-side changes take time to materialize, leading to greater disruption in economic activity. Figure 15 compares the aggregate shocks to total energy consumption and useful energy input in selected countries by 2025 in Scenario 1. As a guide, the greater the decline in useful energy input, the greater the impact on long-run potential output. So, for example, Russia is likely to face greater long-term losses than Australia or Germany, even though total energy consumption in Australia and Germany are expected to decline more rapidly. Figure 16 illustrates the expected impact on CO_2 emissions, relative to the baseline current policies scenario. Differences across countries reflect both the total decline in energy consumption and the current energy mix.

Figure 15: Shocks to total energy consumption and useful energy input, 2025, Scenario 1



Source: NiGEM Scenario 1 assumptions

Figure 16: Impact of decline in fossil fuel consumption on CO_2 emissions, 2025, Scenario 1



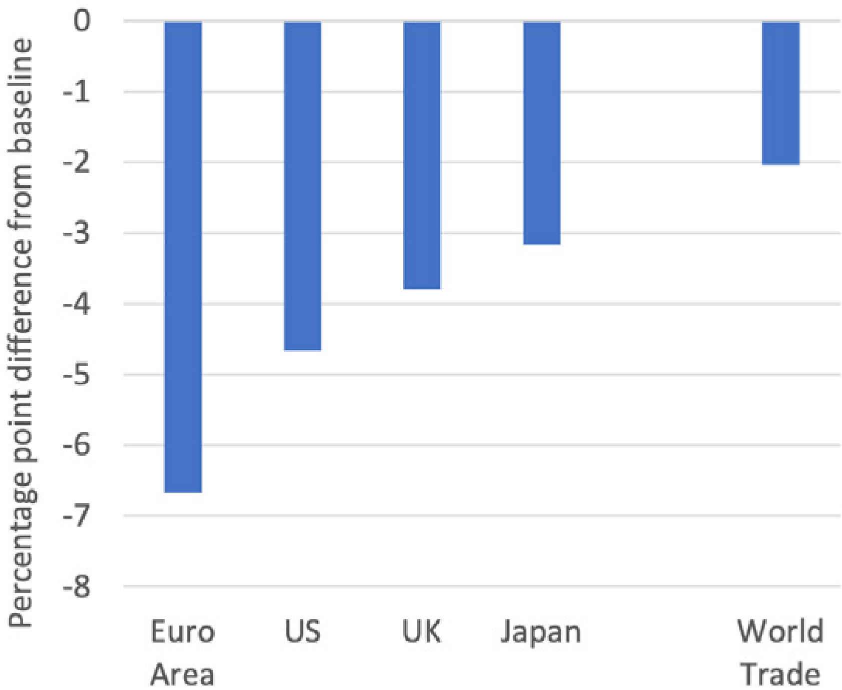
Source: NiGEM Scenario 1 assumptions

Credit constraints

A sharp and unexpected rise in the price of carbon can be expected to introduce a heightened period of financial uncertainty. The phase-out of fossil-fuel use will expose widespread vulnerabilities among holders of carbon-intensive assets, some of which will ultimately become “stranded” or written off prematurely. Certain firms will clearly struggle to adjust to the unexpected rise in their input costs, pushing them towards insolvency. While there has been some progress towards improving transparency of asset sensitivities to climate change and climate policy in some countries, we are still a long way off from having a clear understanding of how individual firms and sectors will respond to stresses of this magnitude. In the short term, this opacity may trigger “fire sales” and strains on the financial system, similar to the experience of the Global Financial Crisis in 2008.

To capture the impact of these strains, the scenario introduces a two-year rise in global credit constraints. This raises the costs of borrowing and constrains access to finance, driving a sharp adjustment in investment. The shock also has a significant impact on trade via global spillovers, given the high import content of investment goods in many large countries. To isolate the impact of this channel on the scenario, Figure 17 illustrates the impact on private sector investment in selected countries and on world trade in response to a temporary global rise in credit constraints. We calibrate the shock so that impact on credit constraints is roughly one-third of the size of the shock experienced in 2008–2009. The higher sensitivity in the Euro Area largely reflects the exacerbation of the shock via spillovers, as a result of the high level of intra-regional trade in investment goods.

Figure 17: Impact of rise in credit constraints on investment and world trade after 2 years



Source: NiGEM simulations, 1 percentage point rise in credit constraints

3.2.2 Scenario results

A sudden rise in the carbon price would be expected to both push up costs and trigger a sudden shift in asset valuations. A carbon tax bears many similarities to other indirect taxes, such as VAT. Recent examples of VAT rate hikes, such as in Japan in 2013 and then again in 2019 or in the UK in 2011, have been met with a sharp but transitory impact on inflation, as well as a drop in household spending and investment.

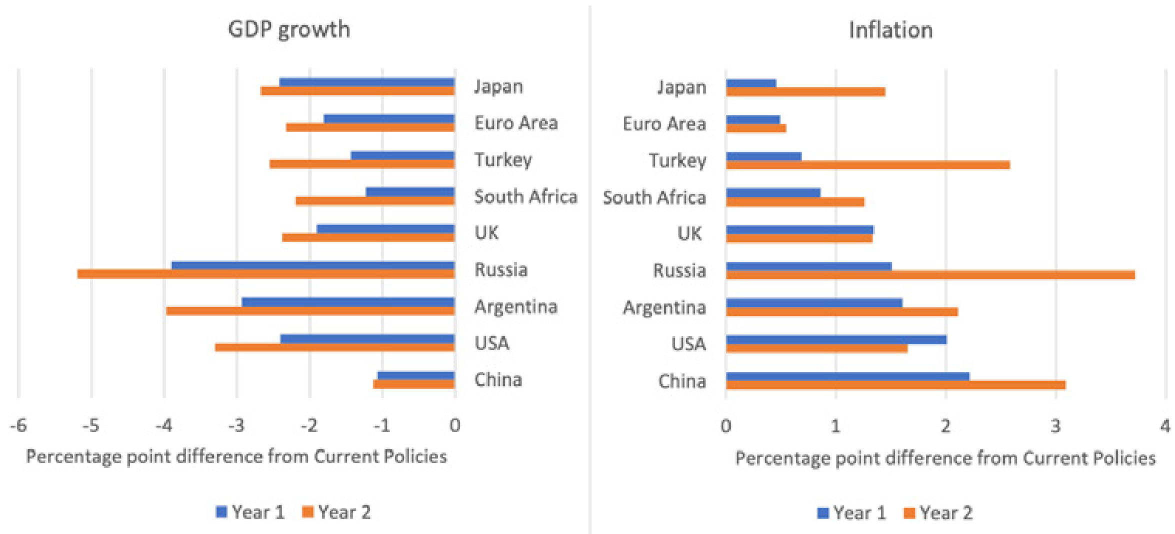
Meanwhile, the Global Financial Crisis (GFC) of 2008–09 offers a recent example of how an unexpected change in asset valuations can spark an international crisis and freeze in bank lending. A sudden rise in carbon price would mean that some high-emitting economic activities are simply no longer viable, while some low-emitting activities may suddenly become far more profitable. This will necessarily lead to some shake up in valuations. Do we know who holds the vulnerable assets? Financial supervisors are fervently working to develop a framework to assess sensitivities to climate policy, but in the near term there remains enormous uncertainty around how individual firms and sectors will respond to major stresses such as a large carbon price shock. Stiglitz (2021) warns that the value of assets subject to repricing as a result of climate change and climate policy is many times larger than the world's asset base that was linked to US subprime mortgages in 2008, which triggered the GFC.

Below we illustrate the expected impact on key macroeconomic variables of a sudden rise in carbon tax that triggers a temporary tightening of global credit conditions.

GDP and inflation

In the first two years, GDP growth would be expected to be 1–4 percentage points lower than under "Current policies" that involve no sudden rise in carbon price, while inflation would be expected to rise by 1–3 percentage points (Figure 18).

Figure 18: Impact of sudden carbon tax rise on GDP growth and inflation, selected countries



Source: NiGEM simulation, Scenario 1

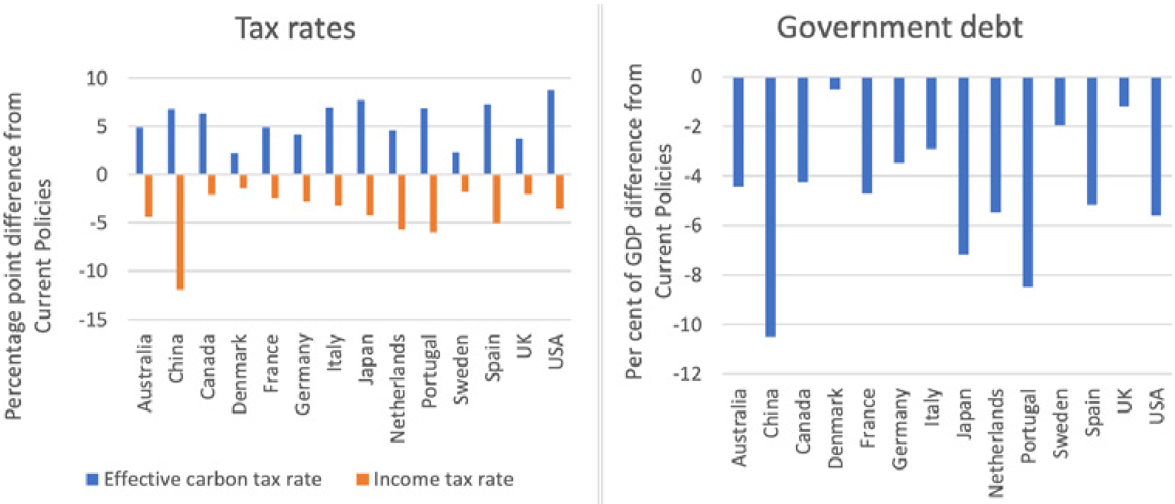
Broadly speaking, the impacts on GDP growth are expected to be somewhat smaller than the losses experienced during the global financial crisis or the first year of the Covid-19 pandemic, but large compared to other shocks experienced in recent decades. Inflation would be expected to rise well above central bank targets in most countries, but will remain contained compared to the surge in inflation experienced by many countries during the oil crises of the 1970s.

In regions such as the Euro Area, which is less energy and carbon intensive than other parts of the world, the net impacts on inflation and GDP growth are relatively subdued compared to other countries. The Euro Area, as well as countries such as Japan, will also benefit from improvements in their terms of trade in response to the shock, as their fossil fuel consumption is largely imported. Monetary policy in China is expected to allow greater flexibility in inflation, offsetting some of the short-term impacts on GDP growth. Energy-intensive countries such as Russia, on the other, suffer terms of trade losses on top of the domestic pressures, exacerbating impacts on both GDP growth and inflation.

Fiscal indicators

The carbon tax generates fiscal revenue in all countries, and creates new fiscal space. The quantity of fiscal revenue generated depends on the level of carbon tax applied, the carbon-intensity of production and the impacts on GDP and inflation in each country. Figure 19 shows the expected rise in the effective carbon tax rate in selected countries, which is defined as total carbon revenue as a share of GDP. In most countries, this is expected to rise by about 5 percentage points after 5 years. In countries such as Denmark and Sweden, which have a lower carbon-intensity of production, the potential revenue gains from a carbon tax are smaller.

Figure 19: Impact of sudden carbon tax rise on tax rates and debt after 5 years, selected countries



Source: NiGEM simulation, Scenario 1

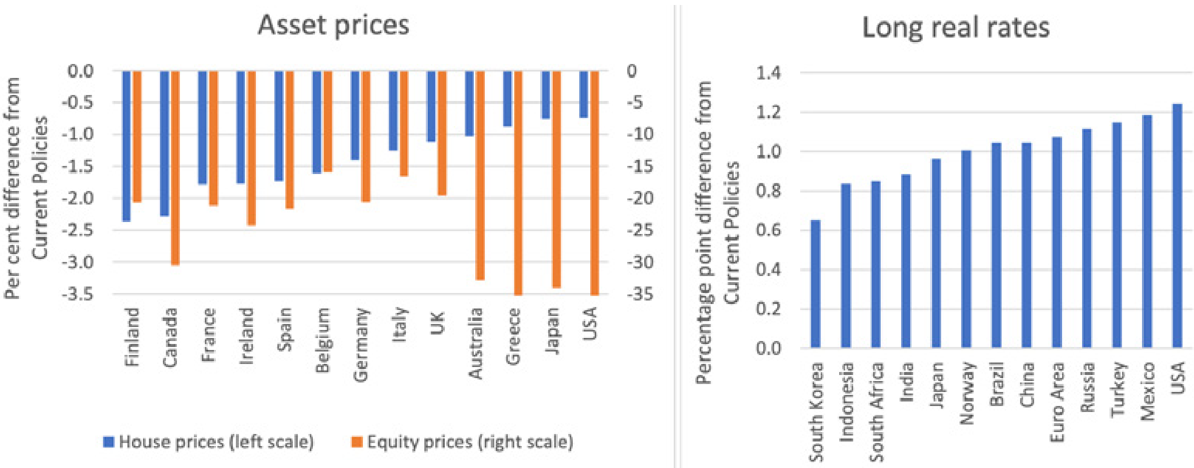
As carbon tax rates rise, this allows income tax rates to come down, so that households are paying on average 3–4 cents less in tax on every dollar earned. This partially offsets the negative consequences of the higher carbon tax rate. Tax policy could be designed so that these income tax cuts target the more vulnerable households, to minimize the negative impacts on those who can least afford it.

Government debt is expected to decline in this scenario, as the revenue gains from the carbon tax outweigh the revenue losses from income tax cuts and other expenditure rises. The magnitude of the decline in debt closely mirrors the rise in the effective carbon tax rate, averaging about 4–5 per cent of GDP after 5 years. Of course, this revenue could also be channelled back into the economy, and we explore the implications of more aggressive fiscal support in Scenario 3.

Financial markets

The disruption and reallocation of resources caused by the sudden carbon price is expected to push real interest rates up and asset values down (Figure 20). House prices may fall by 1–2 per cent initially, while equity prices are expected to drop by 20–30 per cent in the first year, due to the financial disruptions and rise in uncertainty regarding firm profitability. By comparison, during the global financial crisis, major equity markets dropped by 40–60 per cent initially before rebounding. This suggests there is some further downside risk to equity markets and the real economy, given that the value of assets subject to repricing as a result of carbon pricing is significantly larger than the world's asset base that was linked to US subprime mortgages in 2008.

Figure 20: Impact of sudden carbon tax rise on asset prices and real interest rates in year 1, selected countries



Source: NiGEM simulation, Scenario 1

3.3 Scenario 2: Spike in oil price

3.3.1 Underlying assumptions

As the world transitions towards a low-carbon economy, this will entail a dramatic shift in the composition of energy demand. Burning all of the known recoverable resources of oil, gas and coal would be expected to release at least 11,000 Gt of CO_2 into the atmosphere (McGlade and Ekins, 2015). But if the world is to have at least a 50 per cent chance of limiting global warming to 1.5 degrees Celsius, cumulative emissions of CO_2 should remain below 1,100 Gt, meaning that the vast majority of remaining resources must remain untapped.

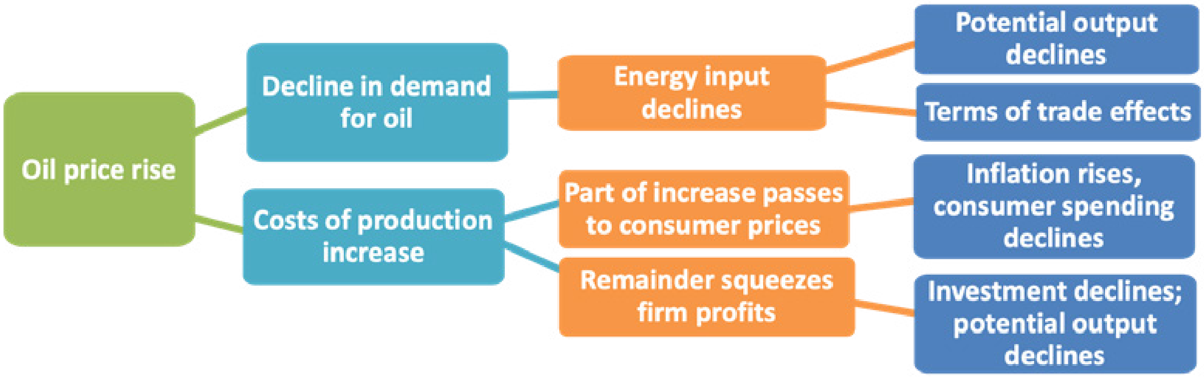
The profitability and viability of a number of sectors and technologies will inevitably be significantly impacted. This has serious economic implications for the many governments and firms that continue to rely on fossil fuel production, fossil fuel-based power supply, and fossil fuel-intensive industry. Firms may face bankruptcy, bank balance sheets face deterioration, and Governments that rely on income streams from these activities face increasing budget constraints and a deterioration in sovereign bond value.

Fossil fuel exporters are facing significant losses in export revenue and high levels of stranded assets. In anticipation of these changes, those who stand to face major losses may seek to build up sufficient financial reserves in the near term to compensate. This may be effected, for example, by driving the price of fossil fuel exports higher, to partially offset the expected decline in the volume of sales. Others may exit the market prematurely, leading to disruptions in supply that could also drive prices higher in the short term. For example, coal prices in China surged in mid-2021, as new regulations came into force with strict limits on coal production, leading to widespread coal shortages and power cuts. Transitional shortages of fossil fuels may also arise as a result of underinvestment. Widespread cuts in investment, in anticipation of the future decline in demand, could drive a price spike if supply capacity declines faster than demand.

In this scenario, we consider the impact of a near-term jump in oil prices driven by some combination of these factors. For the specific scenario, we assume that the global price of oil rises by $100 per barrel for 3 years before returning to baseline.

The macroeconomic transmission of an oil price rise has many similarities to that of a carbon price. The higher price reduces demand for oil overall, leading to a decline in the energy input into the economy and, therefore, potential output. One important difference compared to the carbon price scenario is that the higher oil price delivers a positive terms of trade shock for oil exporters, stimulating domestic demand, although this is partially offset by the decline in the volume of oil exported. Production costs rise, pushing up inflation and squeezing firm profits, putting downward pressure on consumer spending and investment. Two other distinctions relative to the carbon price scenario are that (1) the oil price does not necessarily impact the price of coal and gas, so country-specific responses may differ significantly in the two scenarios depending on their energy composition, and (2) a higher oil price does not generate fiscal revenue for oil importing countries.

Figure 21: NiGEM transmission channels of an oil price rise



In general, we expect a positive impact on GDP in oil-exporting countries in the short term, and a negative impact in oil importers.

3.3.2 Scenario results

Global oil prices have exhibited a high level of volatility since the first oil price shocks of the 1970s and are notoriously difficult to forecast. Supply considerations are clearly important. The oil crises of 1973 and 1979 were driven by restricted supply from OPEC, which at the time controlled more the half of global crude oil production. The capacity to control oil prices through supply agreements of this nature has diminished over time, both as a result of a more diversified market and a decline in reliance on oil driven by energy efficiency gains and alternative energy sources. Nonetheless, since 2016 OPEC and Russia have periodically agreed to oil production cuts in order to prop up the price, with some degree of success. Demand also plays a role in the price. For example, the steady rise in the price of oil between 2003 and 2006 is widely attributed to rapid growth and demand for oil in China over this period. Geopolitical events or climatic events, with the potential to disrupt oil deliveries, can also drive prices temporarily higher, while market speculation also plays an important role. There remains a large "unexplained" component to the oil price, which is not fully captured by any of these factors.

This scenario considers the impact of a sudden rise in the oil price that is sustained for three years. This could be driven by a disruption in supply, either as a result of climate regulation or a major climate shock, or through collusion among oil exporting countries to boost revenues in advance of the anticipated declines in demand. It could also be the result of market speculation or part of the "unexplained" factors that drive oil markets.

In percentage terms, the magnitude of the shock is akin to that experienced in 1973 and 1979, which saw inflation soar above 10 per cent in the US and Canada and above 20 per cent in the UK and Japan.

GDP and inflation

Figure 22 illustrates the expected impacts of a $100 rise in the oil price on GDP growth and inflation in selected economies. Inflation is expected to rise everywhere, but GDP growth is expected to decline in oil importing countries and rise in oil exporting countries, including much of Africa, the Middle East and Norway.

Figure 22: Impact of oil price spike on GDP growth and inflation, selected countries

Source: NiGEM simulation, Scenario 2

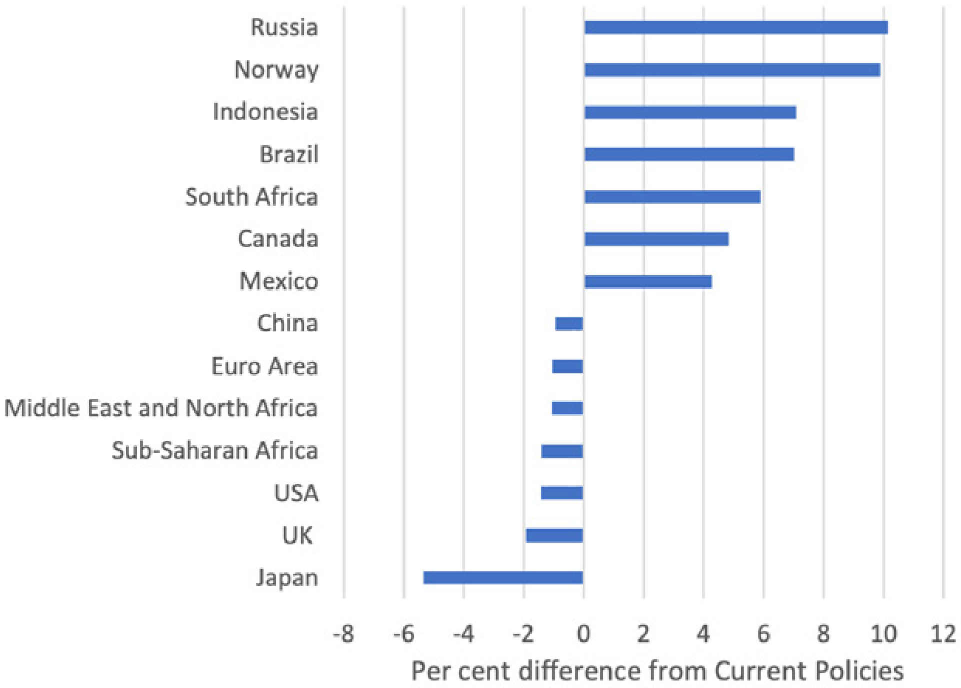
GDP growth would be expected to decline by 1–2 percentage points relative to the Current Policies baseline in most of the major economies. While these are significant losses, the impacts would generally be expected to be smaller and less sustained compared to the sudden rise in carbon price scenario, despite the bigger short-term impacts on inflation. This can be attributed to two factors. First, negative global spill over effects on GDP are smaller, as some countries gain from the rise in carbon price. Second, there is less likely to be a significant disruption in asset prices and reallocation of capital in response to a temporary spike in oil prices.

Inflation could rise by up to 6 percentage points in the US, as the economy continues to rely heavily on oil, while low tax rates on petrol mean the pump prices and much more responsive to movements in crude oil compared to Europe.

Exchange rates

Inflation could rise particularly high in the Middle East, where exchange rates are largely tied to the dollar, which is expected to depreciate. In Norway, on the other hand, a flexibly exchange rate regime would allow a sharp appreciation of the Norwegian krone in response to the terms-of-trade gains, largely offsetting the inflationary pressures from the oil price hike (Figure 23).

Figure 23: Impact of oil price spike on nominal effective exchange rates, selected countries



Source: NiGEM simulation, Scenario 2

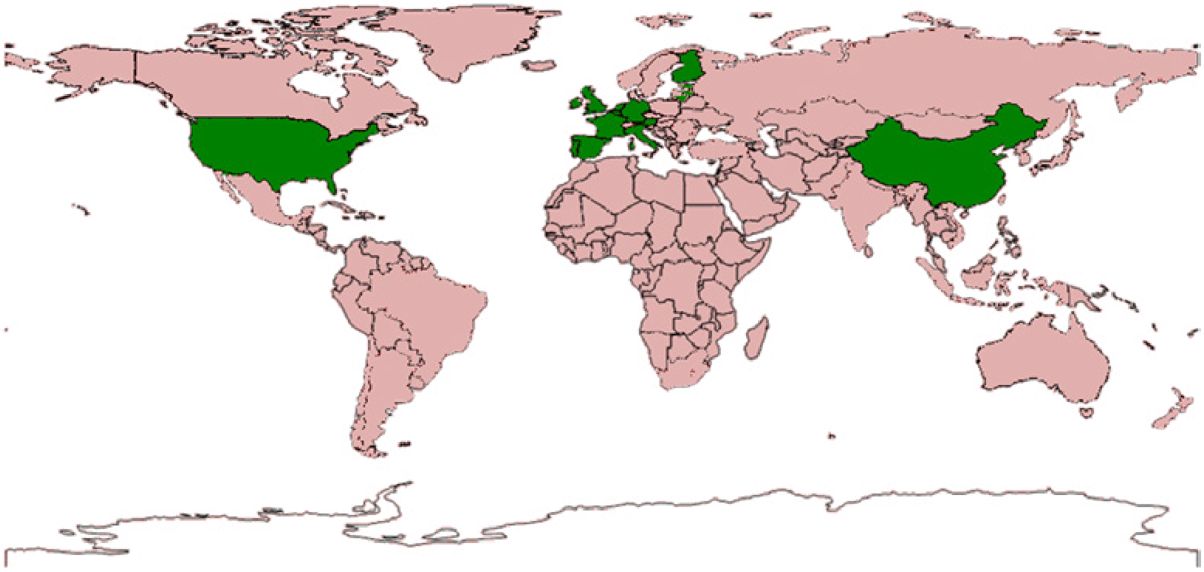
3.4 Scenario 3: Trade war

3.4.1 Underlying assumptions

The carbon price shock in Scenario 1 is built around an assumption of a coordinated level of global policy efforts towards climate change mitigation. The carbon price may differ from country to country, but that is more a reflection of differences in the marginal abatement costs in each country rather than differences in the policy effort. In this scenario, we consider an alternative world that lacks this level of global coordination. The economic costs of decarbonisation differ significantly across countries, depending on their current energy mix and reliance on fossil fuel-related export revenue. As such, policy efforts may differ substantially across countries. We explore the implications of a lack of global coordination in this scenario.

In Scenario 3, a common policy effort is imposed in a subset of countries, which we refer to as the Green Club. For the purposes of this scenario, this Club is comprised of China, the Euro Area, the UK and the US (Figure 24). As in Scenario 1, we benchmark the shocks with reference to the familiar NGFS scenarios. We extract shocks from the REMIND-MAgPIE Net-zero 2050 scenario for the Green Club countries only. As before, in addition to the carbon price settings, this includes shocks to primary fuel consumption and "useful" energy input (see details under Scenario 1 above).

Figure 24: Green Club Countries, Scenario 3



Without coordinated global action, a carbon tax imposed in a subset of countries may lead to a loss of competitiveness in the Green Club economies. It could also drive a relocation of carbon intensive activities to countries with less stringent emission policies, rendering the policy instrument largely ineffectual in terms of reducing global carbon emission (McKibbin et al, 2018). To restore pre-tax levels of competitiveness and reduce the risks of carbon leakage, the Green Club may introduce border carbon adjustments (BCA), in the form of an import tax on goods and services from countries with less-stringent emissions standards. The European Union's Carbon Border Adjustment Mechanism, currently under discussion, is an example of this type of policy (European Commission, 2021).

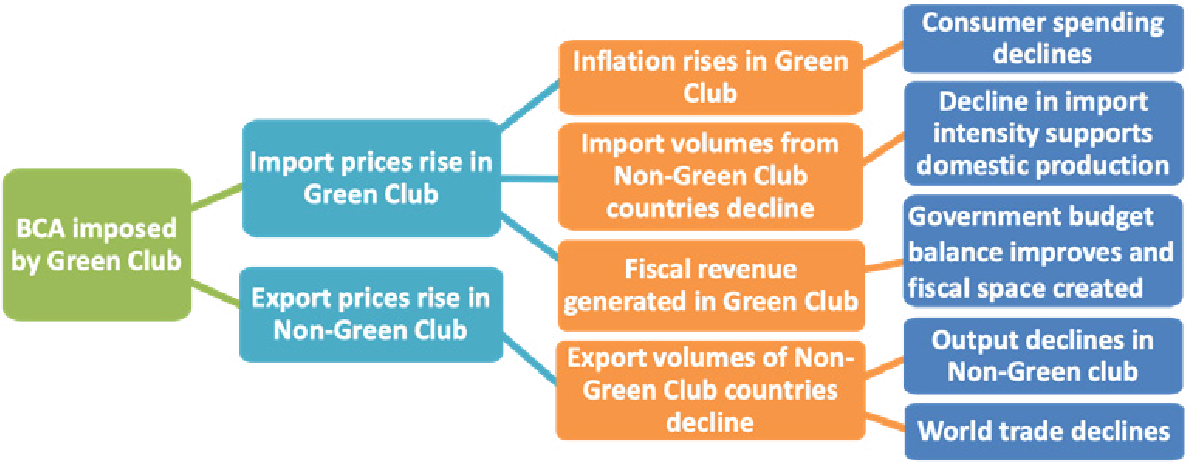
A BCA acts essentially as a direct trade tariff on non-Green Club countries. If met with retaliatory trade tariffs and barriers, this has the potential to spark a form of global trade war, similar to the sharp rise in retaliatory measures following the Trump Administration's introduction of tariffs on steel, aluminium and Chinese products in 2018 (Liadze, 2018). In this scenario we also explore the macroeconomic policy response to the shock, and how different applications of fiscal revenue generated from the carbon price and BCA may impact the results.

The macroeconomic pass-through of the carbon tax shock in Green Club countries is the same as described for Scenario 1. On top of this we layer a second set of shocks to capture the BCA tariffs on Non-Green Club countries.

The BCA acts as a barrier to trade. Barriers to trade may shield rent-seeking behaviours, strengthen monopolistic positions, reduce productivity and slow the adoption of state-of-the-art technology. Trade opens opportunities to specialize in areas where the country has a comparative advantage, while importing goods and services for which the country has a comparative disadvantage. This reducing costs to the consumer, maximizes returns on investment and broadens the variety of available goods and services. There is a broad academic literature supporting the beneficial effects of international trade on both the quantity and quality of potential output in an economy (see e.g. Winters et al., 2004; Singh, 2010).

Figure 25 illustrates the key transmission channels of the BCA tariffs in NiGEM. The BCA raises import prices in the Green Club, pushing up inflation and constraining consumer spending. This may be partially offset by a decline in import intensity, which supports domestic production, and fiscal space created by revenue from the tariffs. In the Non-Green Club countries, the BCA reduces competitiveness and export volumes, leading to a loss of output and decline in world trade. This decline in world trade also has second round effects on the Green Club countries.

Figure 25: NiGEM transmission channels of Border Carbon Adjustment (BCA)



For the purpose of this scenario, a common flat BCA rate is applied on all imports into Green Club countries from the Non-Green Club. The magnitude of the tariff is calibrated to offset the net rise in costs related to the carbon tax in the Green Club, so that on average the Green Club do not experience a loss of competitiveness.[2]

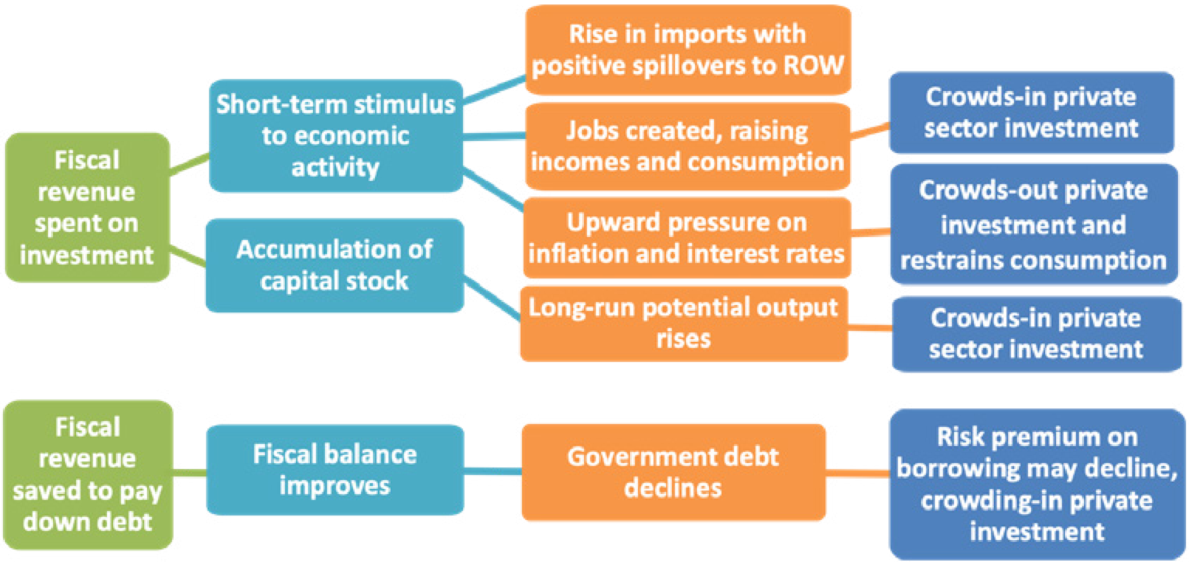
The net impact of the Green Club carbon price with BCA will depend in part on how the fiscal revenue from the policies is spent. Revenue can be recycled back into the economy via: cuts in income taxes or corporation taxes; investment in priority areas such as renewable energy supply, health or education; or transfers to vulnerable households to offset the costs associated with a higher carbon price. Alternatively, the carbon revenue can be used to pay down government debt or can be directed towards other fiscal priorities. We consider two policy options: (1) 100 per cent of the generated revenue is channelled into government investment, (2) 100 per cent of the generated revenue is used to pay down debt. While there are many alternative policy scenarios, in terms of the net impact on GDP, other fiscal policy options can be expected to fall somewhere between the extreme options presented here.

Figure 26 illustrates the pass-through of these two fiscal channels in NiGEM. If all carbon and BCA revenue is spent on investment, there is minimal net impact on the fiscal balance, although as a stimulus to the economy there will be a small improvement in the budgetary position. The investment acts as a short-term stimulus to economic activity, while simultaneously building up the capital stock to support a higher level of potential output over the longer-term. The stimulus creates jobs and supports consumer spending, and also pulls in imports from the rest of the world, stimulating world trade. The net

2 An alternative approach would set country-specific tax rates on the Non-Green Club countries, according to the average carbon content of their exports.

impact on private sector investment is country-specific, and will depend on whether the upward pressure on interest rates fully offsets the impact of the higher level of output on investment decisions.

Figure 26: NiGEM fiscal policy transmission channels



If, instead, the fiscal revenue is saved, the fiscal balance will improve and government debt will decline, with no short-term stimulus to the economy. However, the decline in government debt may allow the risk premium on borrowing to decline, stimulating private sector investment.

The country-specific impacts of the trade war scenario will depend on a range of factors:

- Is the country in the Green Club?
- What is the magnitude of the carbon tax applied?
- What is the energy intensity of production and the energy mix currently in use?
- How flexible is the production structure, including the potential for substitution between capital, labour and energy?
- How sensitive is the economy to inflation?
- How price-sensitive are Non-Green Club exports?
- What share of Non-Green Club country exports are sent to the Green Club?
- How quickly do monetary authorities adjust interest rates?
- How much revenue (in Green Club countries) is raised by the new taxes?

Cross-country differences in any of these factors can deliver significantly different impacts on the key macroeconomic indicators.

3.4.2 Scenario results

In this scenario, we explore the potential implications of a lack of global coordination in carbon pricing. A rise in carbon price and policy effort in a subset of countries is coupled with an increase in trade barriers towards countries with less stringent climate policies to restore pre-tax levels of competitiveness in the Green Club and reduce the risks of carbon leakage. The Green Club in this scenario consists of China, the Euro Area, the UK and the US.

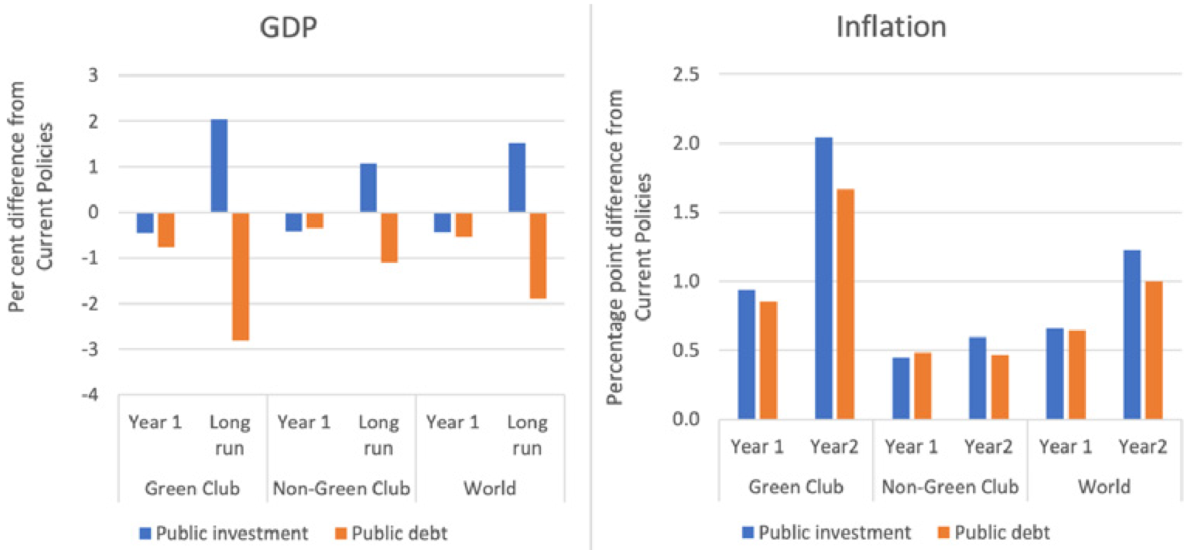
While there may be strong arguments to support Border Carbon Adjustments (BCA), trade barriers are economically damaging. York (2018) demonstrates that following the imposition of steel tariffs by the US in 2002, the higher price of steel led to more US job losses than the total number of people employed by the steel industry itself. Bergsten (2019) found that the 2018 steel tariffs did save US jobs in the steel sector, but that each job cost US consumers $900,000 per year. World trade growth dropped to 1 per cent in 2019 following the rise in US tariffs and global retaliations.

In this scenario we also explore how the fiscal reaction function impacts the results. The carbon tax and the BCA both generate fiscal revenue. This revenue can be channelled into productive investment, which will raise the long-run potential output of the economy. This could be used, for example, to invest in renewable energy infrastructure, retrofitting of buildings, research to support energy efficiency gains or carbon capture technology. It can also be used to pay down debt, to help put public finances on a stable long-run trajectory. There are many other ways to prioritise spending, but for the purpose of this scenario we consider the two options, which we label as “public investment” and “public debt”.

GDP and inflation

Figure 27 compares the expected impacts on GDP and inflation in Green Club countries and Non-Green Club countries in the two scenarios. The short-run negative impact on GDP in the Green Club countries is expected to be slightly smaller in the public investment scenario, as the additional investment acts as a short-term stimulus to economic activity. Much more significant, however, are the long run impacts on the level of GDP. When the carbon and border tax revenue is channelled into productive government investment, this accumulates into a higher level of capital stock to support a higher level of potential output over the longer-term.

Figure 27: Impact of trade war scenario on GDP and inflation

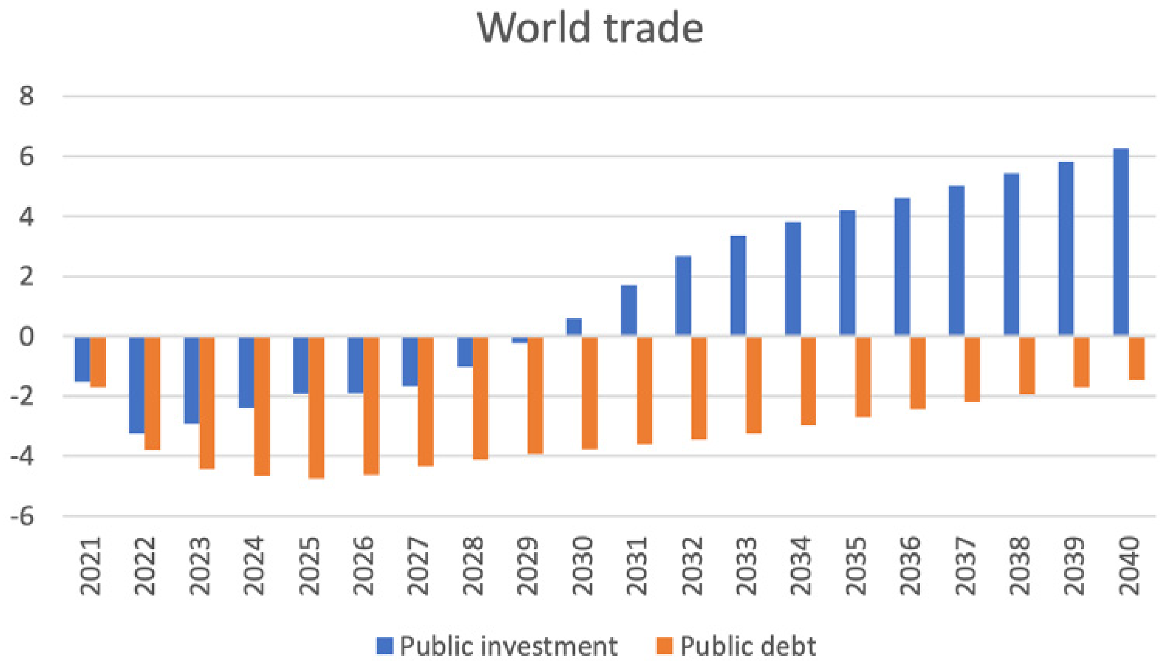


Source: NiGEM simulation, Scenario 3

World trade

The stimulus creates jobs and supports consumer spending, and also pulls in imports from the rest of the world, stimulating world trade (Figure 28). Therefore, we also see a positive long-run impact on GDP in the Non-Green Club countries in the government investment scenario.

Figure 28: Impact of trade war scenario on world trade

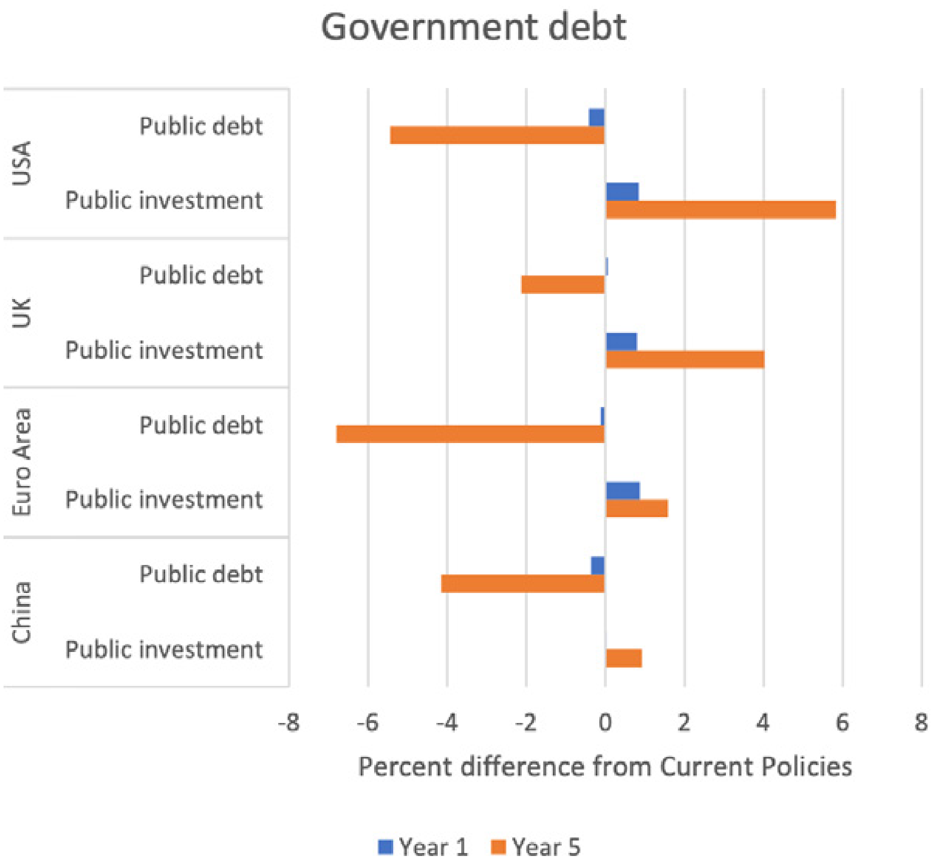


Source: NiGEM simulation, Scenario 3

Government debt

While GDP growth and world trade would be lower in the public debt scenario, debt would also be expected to decline. After 5 years, the level of government debt would be expected to be 5–10 per cent lower in the public debt scenario compared to the public investment scenario (Figure 29). In countries with a high risk premium on government borrowing this added fiscal space could help to provide macroeconomic stability. However, in the Green Club designated for this scenario, the impact on risk premia would be expected to be minimal.

Figure 29: Impact of trade war scenario on government debt in Green Club



Source: NiGEM simulation, Scenario 3

An important caveat to the trade war scenario is that we have not, so far, modelled any retaliatory measures from the Non-Green Club. There remains considerable controversary over whether a BCA would be fully compliant with WTO rules. Until a final ruling is reached, which could take several years, Non-Green Club members may opt for retaliatory tariffs leading to a spiralling trade war. This could more than double the negative impacts on GDP illustrated here, and wipe out the potential gains in world trade expected in the government investment scenario. The scenario highlights the importance of coordinating global climate policy efforts.

3.5 Scenario summaries

Table 5 pulls together a summary of the key scenario results presented in this paper, and compares these to some of the main NGFS scenarios for context. All figures are reported relative to the NGFS current policies scenario. The most costly scenario in the short-term, in terms of GDP losses, is the sudden rise in carbon price (scenario 1). The carbon price rises more rapidly than in the NGFS Divergent Net-zero scenario, where the impact on GDP is also high in the short term.

Inflation rises most sharply in response to the spike in oil prices (scenario 2), although the impacts in this scenario are short-lived.

Government debt can be expected to decline in response to a rise in carbon price, assuming the price is introduced as a tax that generates fiscal revenue.

Table 5: Summary comparison of scenario results

		Scenario 1: Carbon price	Scenario 2: Oil price	Scenario 3: Trade war (public investment)	NGFS Net Zero 2050*	NGFS Below 2°C*	NGFS Delayed Transition	NGFS Divergent Net Zero
GDP (Year 1) % impact relative to current policies	World	-3.8	-0.5	-1.1	0.3	0.3	0.4	-2.5
	US	-5.5	-1.6	-2.6	-0.2	0.0	0.4	-3.6
	Japan	-4.9	-2.0	-0.9	0.3	0.3	0.3	-3.3
	Euro Area	-4.0	-1.0	-1.6	0.1	0.2	0.3	-2.8
	China	-2.1	-1.3	0.6	1.0	0.5	0.3	-1.5
	Canada	-4.6	-1.5	-2.1	-0.6	-0.3	0.1	-3.6
	UK	-4.1	-1.5	-2.2	-0.1	0.1	0.2	-2.7
Inflation (Year 1) percentage point impact relative to current policies	US	1.6	6.7	1.6	1.8	0.6	-0.1	0.7
	Japan	1.5	4.4	0.0	1.2	0.4	0.0	0.5
	Euro Area	0.5	5.3	1.1	1.0	0.3	0.0	0.1
	China	3.1	7.4	3.0	2.4	0.8	0.0	1.4
	Canada	1.1	4.6	1.8	1.3	0.5	0.0	0.5
	UK	1.3	3.8	1.5	1.1	0.3	0.0	0.8
Exports (Year 5) % impact relative to current policies	US	-1.7	-6.6	-1.9	4.5	2.0	0.6	-1.0
	Japan	-3.2	-6.4	-1.1	3.3	1.6	0.6	-1.7
	Euro Area	-2.8	-6.9	-2.5	3.8	1.8	0.5	-1.7
	China	-1.9	-5.3	-5.2	1.3	1.0	0.8	0.1
	Canada	-11.2	-11.2	-2.5	-1.3	-0.5	0.5	-8.6
	UK	-1.3	-6.1	-1.5	4.3	1.9	0.5	-1.1
Government debt (Year 5) % impact relative to current policies	US	-3.3	1.1	5.4	-10.8	-3.6	0.1	-2.4
	Japan	-1.9	0.5	-0.2	-0.1	-0.1	-0.1	-0.9
	Germany	-5.0	1.7	3.8	-1.7	-0.8	-0.1	-3.6
	China	-3.2	0.4	0.8	-6.4	-2.3	0.0	-1.8
	Canada	-2.3	1.7	1.9	3.7	1.5	0.0	-2.4
	UK	-2.4	2.8	3.8	2.2	0.6	0.1	-2.0

*** 50% of carbon revenue channelled into government investment in the NGFS Net-zero 2050 and Below 2°C scenarios.**

Note: NGFS scenarios shown here are based on the NiGEM results applying output from REMIND-MAgPIE.

4. Conclusion and recommendations

4.1 Conclusion

Too often, climate risks are considered as primarily long-term risks. This perception is exacerbated by the long planning horizons demanded by 2050 decarbonization targets, as well as in the architecture of integrated assessment models. While climate change demands major economic and societal shifts in the ensuing decades, the effects of physical climate change and the accelerating low-carbon transition are already being felt today. Recent events such as the unprecedented hurricane season in the Atlantic and historic flooding in China are reflective of the rising frequency and severity of extreme weather. Similarly, new climate policies, technological innovations, and changes in consumer behavior are upending current business models in the energy, transportation, and industrial sectors (among others).

The financial consequences of physical and transition risks are already manifesting. The International Monetary Fund (IMF) estimated that direct damages from climate disasters in the past decade have cost $1.3 TN, with far more in indirect losses of disrupted economic activity (IMF, 2020). In 2019, PG&E Corp., California's largest utilities provider, became the first major corporation to declare bankruptcy due to wildfires, citing over $30 billion in liabilities (Washington Post, 2019). Similarly, the 2019/2020 Australian bushfires are estimated to have cost the insurance industry $1.3 billion in losses (Insurance Journal, 2020). Financial actors from institutions and regulators are looking for the tools to assess and prepare for these emergent risks. To gain a complete understanding of climate risks, these actors need to use long-term and short-term scenarios. Long-term scenarios are useful to set a sustainable future operating model and net-zero targets. However, short-term scenarios allow users new insights into the near-term threats to financial stability and the financial sector's preparedness for them.

In this report, the three scenarios developed by NIESR and UNEP FI were used to model the short-term economic risks of climate-related events. The first scenario entailed a sudden hike in carbon price estimated reduction in GDP growth, increase in inflation, decrease in house prices and equity prices. The second scenario considered a near-term spike in oil prices resulted in high inflation rates in economies heavily reliant on oil. The final scenario was a "trade war" related to carbon pricing.

In each of these scenarios decreased GDP growth, higher inflation rates, and greater volatility in other macroeconomic indicators demonstrate the potential for climate-related events to cause economic and thereby financial market disruption.

4.2 Recommendations for using short-term scenarios in climate analyses

This report showcases evidence for the importance of using short-term scenarios by financial actors to assess the impact of near-term climate-related economic and financial risks. The purpose of this exercise was to increase the financial sector's awareness of the nature and utility of short-term macroeconomic scenarios. Below are three recommendations on how financial institutions and supervisory authorities can make use of short-term scenarios in their climate risk practices.

Recommendation for financial institutions: Use short-term scenarios in climate risk analysis and business strategy setting

As financial institutions develop their climate risk capabilities, they should work to incorporate outputs from short-term climate scenario analysis. These outputs can offer insights into the impact of climate change on a firm's operations and assess the resiliency of the current strategy. Short-term macroeconomic shock scenarios can enable a firm to develop the policies and practices that ensure solvency and viability under a wide range of conditions. Short-term scenarios can allow for the assessment of which clients are most exposed to physical or transition risks now and encourage engagement with them to mitigate those risks in the future. Analysis of short-term scenarios can also promote the identification of commercial opportunities produced by economic disruption.

Recommendation for financial supervisors: Incorporate short-term scenarios into regulatory climate stress testing

Financial supervisors should include short-term macroeconomic shocks into their climate stress tests and disclosure requirements. Short-term macroeconomic climate impact scenarios are similar in nature to traditional stress test scenarios but incorporate climate change into their narratives. Short-term climate-related shock scenarios can produce more severe macroeconomic responses than the relatively "mild" economic impacts observed in most IAM transition scenarios. As the Global Financial Crisis demonstrates, a dislocation in one sector of the economy can rapidly infect financial markets. Assessing scenarios where climate-related stresses cause the collapse of a fossil fuel supermajor or spark a trade war are important ways to understand risks to financial stability.

Short-term climate scenarios can be easily integrated into regulatory exercises given their similarity to traditional stress test scenarios. Like those traditional scenarios, they are well-suited for conducting assessments of capital adequacy. The shorter time horizon and macroeconomic factors make evaluation of capital erosion under adverse conditions more reflective of the current risks a firm faces as compared to attempting to use IAMs for that purpose. On market risk, short-term scenarios are already widely used to assess responses to major market-moving events. This approach can be extended to climate-related scenarios such as a major storm hitting US refining capacity or a sudden imposition of a carbon tax in a major import market.

Recommendation for all financial actors: Consider outputs from long-term and short-term climate scenarios together

Both short-term and long-term scenarios should be used for climate scenario analysis. Considering the two together enables a fuller assessment of climate risks than either alone. Indeed, the insights generated from one set of scenarios can inform interpretations of the other set. Short-term scenarios can assess the degree of risk a firm currently faces from climate change and its ability to manage that risk. Long-term scenarios can be used to set decarbonization targets, determine long-term strategy, and develop a transition plan.

4.3 Next steps for macroeconomic modelling of climate change

Macroeconomic modelling of climate change remains in its infancy within the financial sector. As financial institutions continue to advance in conducting climate scenario analysis, the demand for short-term scenarios will likely grow. Financial supervisors can accelerate the development of additional short-term scenarios by integrating the scenarios into their regulatory exercises and disclosure expectations. In addition, financial institutions need to develop the skills to evaluate the implications of these climate-related scenarios or produce their own sets of scenarios.

4.4 Next steps on macro scenarios at UNEP FI

At UNEP FI, we are working with expert partners like NIESR and our member financial institutions to develop additional short-term scenarios of relevance to the financial sector and help institutions build the knowledge to effectively use these scenarios. As part of this year's TCFD and Climate Risk programme (launched in Spring 2022), UNEP FI will continue its work on macroeconomic modeling of climate change. As next steps, the programme will explore the use of short-term scenarios and their implication for climate stress testing and understanding portfolio impacts. Through the programme, UNEP FI and participating members will further collaborate on identifying relevant and plausible short-term scenarios to use for analysis and develop a new set of short-term scenarios for climate risk identification. UNEP FI will work with the financial sector with the aim to further understanding of how to assess the consequences of short-term climate-related economic impacts.

5. Case studies on macro scenarios

Case Study: NatWest

Any scenario analysis starts with the scenarios. There are a number of climate scenarios from several providers, which describe the interplay between climate policy, energy systems and global warming. And while those scenarios provide us with rich climate and energy pictures, we also need to understand how changing policy and physical environment will influence the economy.

While preparing for the Climate Biennial Exploratory Scenario exercise (CBES), NatWest Group collaborated with the National Institute of Economic and Social Research (NIESR) to develop climate macro scenarios consistent with the NGFS climate scenarios. By now climate macro scenarios from NGFS and from the PRA are also available. In time, other providers will make their scenarios available. Therefore, it is possible that few institutions will invest in developing their own climate macro scenarios. But it is still important to understand how they are created. For that reason, we would like to share our experience.

Two components are required for this type of modelling: a macroeconomic model, which can capture the key links between the climate change and the economy; and climate-related shocks the effect of which on economy we would like to model.

For our analysis we selected NiGEM—structural global macroeconomic model developed by NIESR. The key requirements for the model were global coverage with country-specific results for main countries, relative flexibility of possible shocks and policy options, and good track record. NiGEM was additionally updated to allow the production of specific climate scenarios. In particular, we were able to explore the following links between climate change and the economy:

1. Transition channels—affect domestic level of prices, economic competitiveness, corporate profits, and government tax revenues:
    a. Carbon prices
    b. Energy demand by fuel
    c. Energy prices by fuel
    d. Energy intensity
2. Physical channels—affect level of productive capacity in the economy:
    a. Annual average damages from acute physical risks
    b. Labour and agricultural productivity

The next step is to calibrate the size of each of the selected shocks for modelled scenarios. We used the NGFS database for all transition shocks, as we wanted our scenario to be consistent with them. Vivid Economics estimated for us physical shocks associated with the temperature increase predicted by the NGFS scenarios.

We found this project using NiGEM very insightful and would like to share some lessons learned from it.

1. Orderly and early transition is strongly preferable to disorderly. Delaying action will cause not only more physical risks to the environment but also damage the economy.
2. Physical effects are very uncertain. It is hard to predict the level of global warming resulting from a given level of emissions. But on top of that, there is no agreement between the economists on how global warming will influence the economy. For example, for Northern Europe, the estimates for Current policy scenarios range from slightly positive to significantly negative.
3. Government policy matters. For example, what the government decides to do with the carbon tax revenues significantly influences the effect on the economy. The most favourable option in our analysis was to spend these revenues on government investment. This has a short-term positive impact through higher demand and a long-term positive impact through improved productive capacity.
4. Investment financing also matters. It is well known that transition to net zero will require substantial investment. Assumption about the source of this investment significantly influences the assessment of economic results. The most conservative assumption is that there will be no additional investment, but some part of the investment flow will be redirected to green projects. The most optimistic assumption is that all transition-related investment will come from new sources and the total flow of investment in the economy will significantly increase. This assumption could change the overall effect on the economy from negative to positive.
5. Climate affects the economy in a complex way, and individual impact channels interact with each other. For example, higher carbon price and physical effects of climate change depress GDP growth. But the spending of carbon tax revenues and lower energy intensity stimulate GDP growth. For that reason, it is not easy to predict the direction of changes due to the combination of multiple shocks.
6. Global interaction can lead to surprising results. Even if all countries are negatively affected through one channel, for example, higher risk of flooding, but some countries are affected more than others, this could lead to competitive advantage for the less affected countries and positive overall effect.
7. We only model a partial picture. Climate influences economy in society on multiple ways. Some of the channels are easier to predict than others. Some of the potentially largest societal effects are not modelled by anyone at the moment, because they are very hard to predict. This includes the impact of climate change on local and international conflicts, the spread of infectious diseases and migration flows.

Case Study—A Global Bank

Scenario Construction for Climate Minsky Moment

Introduction

This case study illustrates an approach for calculating a set of market risk-type shocks, representing a climate-driven "Minsky moment" scenario. Under this scenario, following unforeseen and globally-coordinated announcements of strict climate policies—such as punitive carbon taxes—market participants reprice expected future cash flows for both traditional and green businesses in light of the realization that the world is about to experience a rapid and disorderly transition to a low-carbon economy.

The approach presented in this note allows to generate scenario-consistent instantaneous price shocks for the following security types:

1. Shares
2. Equity mutual funds

Reference Datasets

The two primary datasets used for this exercise are the following:

- MSCI Low Carbon Transition (LCT) Score dataset at issuer level
- NGFS Disorderly Transition Scenario (REMIND-MAgPIE)

MSCI LCT Score dataset

The Low Carbon Transition (LCT) score is a company-level score produced by MSCI. The score measures companies' exposure to and management of risks and opportunities related to the low-carbon transition. The score is industry agnostic and represents an absolute assessment of a company's position vis-à-vis the transition.

The score has a range from 0 to 10. Companies with higher LCT score are more aligned with the low-carbon transition compared to the companies with lower scores. In particular, companies with an LCT score of 7 or higher are classified as "solutions" and are thereby expected to benefit from a the transition to a low-carbon economy (see MSCI[2019]).

NGFS Climate Scenarios

The NGFS Climate Scenarios were selected by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) to provide a common starting point for analysing climate risks to the economy and the financial system. In particular, the NGFS scenarios describe pathways for the period 2020–2050 under the following assumptions on economic transition:

- **Orderly:** Early, ambitious action to a net-zero CO_2 emissions economy;
- **Delayed/Disorderly:** Action that is late, disruptive, sudden and/or unanticipated;

- **Hot house world:** Limited action leads to a hot-house world with significant global warming and, as a result, strongly increased exposure to physical risks.

Out of the three primary NGFS scenarios, the pathway described by the **NGFS Disorderly-transition scenario** is the one that carries the greatest risk of sudden market dislocations, because it describes an economic transition that is abrupt, unanticipated and very rapid. As such, it represents the most suitable reference for this exercise.

The specific narrative of the NGFS Disorderly-transition scenario assumes climate policies are abruptly introduced from 2030, triggering a rapid economic transformation, particularly over the following five years. Because our exercise is about assessing what would be the impact on security prices if such disorderly transition were to start **today**, we refer to the changes described in the scenario over the five-year period 2030–2035—particularly those of real economic variables (such as production in climate-sensitive sectors—e.g. coal)—and use them as targets for the calibration of instantaneous shocks to today's security prices. In doing so, we are assuming markets would immediately price-in the medium-term impact of such broad economic change on expected future cash flows.

Methodology

The main part of the methodology is an approach to calculate instantaneous shocks applicable to the share price of issuers, given their LCT score. In particular, the approach includes the following steps:

1. Calibration of general map from LCT score to equity price shocks
2. Calculation of company-level baseline shocks and industry-level shocks
3. Application of industry-based and country-based caps/floors
4. Final adjustments
5. Calculation of price shocks for mutual funds

Below we describe the details of each step.

Calibration of general map from LCT score to price shock

The general map from an LCT score to a price shock is calibrated by targeting the relative shocks over the period 2030 to 2035 from the NGFS Disorderly Transition scenario (see below).

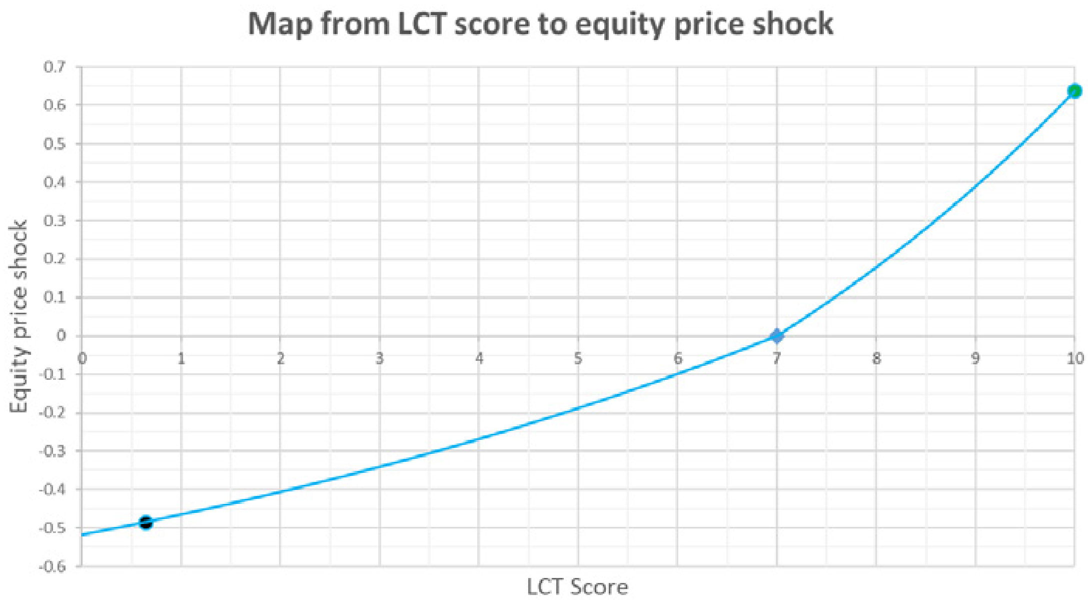
Variable	2030[3]	2035	2040	2045	2050
Primary Energy | Coal	1.000	0.516	0.324	0.171	0.128
Primary Energy | Non-Biomass Renewables	1.000	1.637	2.798	4.253	5.673

3 Scenario values normalized by setting 2030 values to 1.0.

In particular, the map is constructed around three points:

1. The average LCT score for sub-industry "Coal & Consumable Fuels" is mapped to a shock equal to the relative change1 in primary energy production for Coal (2030 to 2035) from the NGFS scenario.
   - As of year-end 2020 this gives: LCT=0.64 -> Shock=-48.4%
2. The highest LCT score,10, which characterises many companies in the sub-industry "**Renewable Electricity**" is mapped to a shock equal to the relative change in primary energy production for **Non-Biomass Renewables** (2030 to 2035) from the NGFS scenario
   - As of year-end 2020 this gives: LCT=10.0 -> Shock=+63.7%
3. The LCT score of 7.0 (i.e. the lower bound of the LCT category "Solutions") is mapped to 0% shock
   - i.e. LCT=0.0 -> Shock=0.0%

The map is then completed by exponential extrapolation (see figure below).



Calculation of company-level baseline shocks and industry-level shocks

Company-level baseline shocks are calculated by applying the calibrated map to the MSCI LCT score of each issuer.

In addition, using MSCI LCT scores at issuer level, weighted-average scores are calculated for each industry in the granular GICS Level 4 sub-industry classification. Reference industry-level shocks are then calculated by applying the calibrated map to the industry-average LCT scores.

Application of industry-based and country-based caps/floors

Once baseline company shocks have been calibrated, we restrict the range of admissible values at industry level by applying caps/floors to company shocks to within +/- 10% (calibration may be modified) of their reference industry shock. This means, for example, that oil companies with higher transition readiness score may have a shock up-to 20% more benign than the one applied to oil companies with lower transition readiness score. These constraints are designed to guarantee consistency of the framework and improve ease of interpretation and robustness of the results. Furthermore, one could argue that, as a first reaction to surprising announcements indicating a rapid transition, unsophisticated market participants may contribute to selling/buying pressures that affect industries as a whole, with limited discrimination between individual companies.

Although climate risk transition stress testing is normally applied at industry level, we believe that certain countries will be impacted as a whole. For this reason, we apply a -5% minimum equity shock (calibration may be modified) to all issuers incorporated in a major oil-producing country. For instance, every bank in GCC countries will fall by at least 5%.

Additionally, we expect certain countries will respond to climate Minsky moment events with significant government intervention, which will constraint the size of the larger negative short-term shocks. For example, equity shocks on Chinese companies are floored at -20% (calibration may be modified).

Final adjustments

Finally, the calibrated shocks are bucketed to the closest value on a 5%-steps grid (..,-10%,-5%,0%,+5%,..), this is done to prevent issues of false precision and to facilitate analysis.

Calculation of price shocks for mutual funds

For equity mutual funds, we calculate price shocks (wherever possible) for all available fund holdings,[4] following the same logic described for equity shares. The shock to be applied to the price of the fund is then calculated as the weighted-average[5] price shock of the available holdings.

Example

Baseline company shock

- Company LCT score: 2.64
- Company baseline shock: $f_{LCT}^{Scen}(2.64) = \mathbf{-36.5\%}$

Sub-Industry analysis

- Sub-Industry: Oil & Gas Exploration & Production
- Number of companies in the dataset: 88
- Average (weighted) LCT score: 2.35
- Reference industry shock: $f_{LCT}^{Scen}(2.35) = -38.4\%$
- Sub-Industry admissible range: $-38.4\% \pm 10\% = [-48.4\%, -28.4\%]$

4 This may be limited to the most material holdings—e.g. top 20—in case of data sourcing restrictions.
5 Weighted by the relative weight of the available holdings

Final company-level shock

- Shock after cap/floor: $min(\max(-\mathbf{36.5\%}, \ -48.4\%), -28.4\%) =$ **-36.5%**
- Country ceiling (USA): N/A

Conclusion

The approach presented in this case study offers a simple, yet granular, way of building a stress scenario for global equity prices designed to assess the impact of the sudden shocks that could result from an abrupt introduction of strict climate policies through globally-coordinated action.

Key benefits of the approach can be summarized as follows:

- Price shocks are calibrated to the industry-standard NGFS scenarios
- Captures specificity of each company's exposure to transition risk
- Provides a balanced view accounting for both industry dimension and company specificities

Table 1 and Table 2 below contain examples of shocks calculated using the methodology (excluding final rounding step), covering a sample of industries and companies within those industries.[6] We observe that shocks calculated at industry level provide a good indication of the overall exposure of industries to transition risk. On the other hand, risk exposures can vary significantly among companies within the same industry.

Table 1: Examples of reference industry-level shocks

Industry	Reference Shocks
Coal & Consumable Fuels	-48.4%
Electric Utilities	-19.4%
Steel	-19.3%
Airlines	-18.3%
Automotive	-3.0%
Systems Software	+3.4%
Renewable Electricity	+20.4%

6 Shocks calculated as of year-end 2020

Table 2: Examples of company-level shocks

Coal & Consumable Fuels		Electric Utilities		Steel		Airlines	
Company A	-20.0%	Company A	-21.7%	Company A	-15.6%	Company A	-21.0%
Company B	-51.8%	Company B	-9.4%	Company B	-9.8%	Company B	-19.2%
Company C	-48.1%	Company C	-29.4%	Company C	-26.7%	Company C	-16.3%

Automotive		Systems Software		Renewable Electricity	
Company A	+7.0%	Company A	+4.7%	Company A	+10.4%
Company B	-13.0%	Company B	+8.5%	Company B	+28.2%
Company C	-13.0%	Company C	+13.4%	Company C	+30.4%

References

- MSCI—Climate Change Metrics—Low Carbon Transition Risk Assessment—Methodology—March 2019
- NGFS Climate Scenarios

Annex. NiGEM V3.21 Climate Model

For a full description of the standard NiGEM model, see Hantzche, Lopresto and Young (2018). The NiGEM climate model is an expanded version of the standard model that introduces channels to model climate policy instruments, energy transition and physical climate shocks. The key channels relevant for the scenarios in this study are detailed in this Annex.

Production function

The production function in NiGEM has an outer Cobb-Douglas function for energy and the capital-labour bundle. This means that in value terms, energy is modelled as a constant share of input costs, with the share given by alpha. In other words, a 1 per cent rise in energy price is offset by a 1 per cent decline in energy volume for a given level of output. The adjustment happens gradually over several years, so does not necessarily hold at any specific point in time.

$$YCAP = \gamma\left\{\left[s(K)^{-\rho} + (1-s)(Le^{\lambda t})^{-\rho}\right]^{-1/\rho}\right\}^{1-\alpha} M^{\alpha}$$

Where

YCAP = Potential output

γ = Scaling factor

K = Productive capital stock

L = Potential labour input

λt = Labour augmenting technical progress

M = Effective energy input, adjusted for energy efficiency gains

α = The energy share of production costs

ρ = A parameter related to the elasticity of substitution between capital and labour ()

s = Scaling factor

This 3-factor production function can be transformed into a growth rate equation if we differentiate, convert to log differentials, and use marginal product conditions that set marginal products equal to their real cost:

$$\frac{dlog(YCAP)}{dt} = (1-\alpha-\theta_L)\frac{dlog\left(\frac{K}{L}\right)}{dt} + (1-\alpha)\frac{dlog(L)}{dt} + \alpha\frac{dlog(M)}{dt} + \theta_L\frac{d\lambda t}{dt}$$

Where θ_L is the labour share of income. This has a very intuitive interpretation, which allows the growth rate of potential output to be quickly decomposed into contributions from capital deepening, labour input, energy input, terms of trade and TFP. It allows any changes in estimates of the growth rate of potential output from one period to the next to be readily explained by shifts in these components or changes in alpha or the labour share of income. It skirts the need for the non-linear production function to be explicitly used as a model equation.

Alpha is constant by design, but θ_L is time varying to allow for shifts in the labour share, as consistent with the CES production function structure.

For reduced country models this equation is approximated in the long run as:

$$\ln(YCAP) = \alpha_2 + \lambda t + \ln(POPT) + \beta_1\ln(USER) + \beta_2 ln(M)$$

Where

POPT = Total population to proxy potential labour input

USER = The user cost of capital, to proxy desired capital stock

The key channels in the production function relevant to the climate model include: total energy input into production (*M*), which will decline in response to a rise in energy prices (unless fully offset by energy efficiency gains); and the accumulation of capital stock (*K*), which will decline in response to a profit squeeze faced by firms from a rise in the user cost of capital, e.g., in response to a rise in carbon tax.

Country energy prices

The effect of a carbon tax on country energy prices follows the methodology developed by the Dutch National Bank (Vermeulen et al., 2018). This adjusts the global pre-tax price by the country-specific carbon price:

$$price_{fuel} = world\ price_{fuel} + \delta_{fuel} * carbon\ tax$$

Where δ is fuel's emission factor, given by the average CO_2 produced while burning a barrel (equivalent) of the fuel. All prices are in US$.

δoil = 0.432

δgas = 0.316

δcoal = 0.652

δnon-carbon = 0.0

CO_2 emissions

Carbon emissions are modelled as the sum of emissions from consuming coal, gas and oil. The emission factors detailed above are adjusted by the appropriate conversion factor to convert barrels of oil equivalent to tonnes of oil equivalent.

$$CO2 = \sum_{fuel} \delta_{fuel} * \beta_{barrel} * C_{fuel}$$

Where

βbarrel = Conversion to barrels

Cfuel = National consumption of fuel (oil, gas, coal)

Energy intensity

The volume of energy input as a share of GDP (OIVOL) is modelled as a weighted average of fuel consumption per unit of GDP:

$$oivol = \sum_{fuel} \beta_{fuel} * \gamma_{fuel} * oi_{fuel}$$

β = Converts the fuel consumption units to million barrels of oil equivalent

γ = Price of 1 barrel of oil equivalent in world base year (currently 2017)

oi = energy intensity, measured as fuel consumption per unit of GDP

This ensures that fixed price and conversion differences for the different fuel types do not affect the change in the energy intensity. Fuel consumption per unit of GDP (OI) error corrects on the effective country price of the fuel. The effective price reflects the importance of that fuel type in a particular country in the energy mix. This also means that we have "decreasing returns" to a rise in carbon tax.

$$dlog(oi_{fuel,t}) = -\alpha * \left[log(oi_{fuel,t-1}) + log\left(\frac{price^{*}{}_{fuel,t-1} * rx_{t-1}}{ced_{t-1}}\right) + \beta\right]$$

Where

rx = Nominal exchange rate

ced = Consumer expenditure deflator

$$price^{*}_{fuel} = price_{fuel} * \frac{Consumption_{fuel}}{Total\ energy\ consumption}$$

Domestic inflation

Inflation (INFL) in the standard NiGEM model is based on the consumer expenditure deflator (CED) which (for full country models) includes a VAT effect (ITR) and can be described as:

$$dlog(ced_t) = dlog(1 + \delta * itr_t)$$

$$+\alpha_1 * \left[log\left({}^{ced_{t-1}}\!\big/_{(1 + \delta * itr_{t-1})}\right) + \beta * log(pm_{t-1}) + (1-\beta) * log(utc_{t-1})\right]$$

$$+[short\ run\ dynamic]$$

Where

pm: price of imports

utc: unit total costs

Short run dynamics also include import prices, unit total costs and inflation expectations

In the climate model, the VAT rate is adjusted to include a proxy energy tax rate (ETAXR). This enters the equation in the same way as ITR above. δ determines the pass-through of the carbon price to inflation, and is estimated for each country.

Energy tax rate

The level of energy tax collected (ETAX) is computed as the level of the carbon tax in terms of US$ per tonne of CO_2, adjusted by the exchange rate (RX) to convert to domestic currency, multiplied by the tonnes of CO_2 emitted (CO_2):

$$etax = rx * CO2 * carbon\ tax$$

The energy tax rate (ETAXR) is then determined as the carbon revenue relative to nominal GDP:

$$etaxr = \frac{etax}{nom}$$

Import price

The price of imports (PM) is modelled as a weighted average of commodity import prices (PMCOM) and non-commodity import prices (PMNCOM):

$$pm = \beta * pmcom + (1 - \beta) * pmncom$$

The price of commodity imports (PMCOM) is modelled as a weighted average of prices for five commodity baskets: food prices, beverage prices, prices for agricultural raw materials, metal prices and energy prices:

$$pmcom = \frac{\alpha_1 * wdfdv + \ \alpha_2 * wdpfld + \ \alpha_3 * wdpanf + \alpha_4 * wdpmm + \alpha_5 * wdpt}{rx}$$

Where

wdpfdv: Global food prices
wdpfld: Global beverage price
wdpanf: Global prices for agricultural raw materials
wdpmm: Global metal prices
wdpt: Global price of energy (weighted average of oil, gas, coal, and non-carbon)
rx: nominal exchange rate

αi and β are country specific, currently based on 2017 trade data.

Weights in wdpt are time varying, to reflect shifts in the composition of energy demand. This delivers an effective world price, and ensures that the contribution of fossil fuel prices to import costs is adjusted to reflect the declining share of fossil fuels in the import basket. The same adjustment is applied to commodity export prices (PXCOM).

Fiscal balance

In the standard version of NiGEM, the fiscal balance (BUD) for full country models is defined as follows:

$$bud = personal\ tax + corporation\ tax + miscellaneous\ tax - transfers - govt.consumption \\ - govt.interest\ payments - govt.investment$$

In the climate model, the revenue from the tax on carbon emissions is added directly into the budget balance:

$$bud = [as\ above] + etax$$

This channel can also be switched off in simulations, to model a climate policy that has similar impacts to a carbon price in terms of inflation and fossil fuel demand, but does not generate fiscal revenue.

Profits

Profits (PROF) include an adjustment so part of any indirect tax or energy tax acts as a squeeze on profits, while the remainder is passed on directly to consumers via higher consumer prices.

$$prof = \frac{nom}{1 + \left(etr * {}^{c}/_{y}\right)} - comp * \frac{e}{ee} - 0.25 * kdep * py * k$$

prof: Corporate profits

nom: Nominal GDP

etr: indirect tax, including energy tax

c: Consumption

y: GDP

comp: Total compensation

e: Total employees

ee: Employees in employment

kdep: Depreciation rate of capital stock

py: GDP deflator

k: capital stock

External demand

The decline in global demand for fossil fuels as a result of carbon pricing will have a significant negative impact on countries whose export revenue is dependent on the sale of fossil fuels. To capture this impact on external demand, we modify their external demand share equation (S).

In the standard version of NiGEM, external demand for each country is modelled as a weighted average of import volumes all the other countries and region in the world:

$$s_j = \sum_{i \neq j} \alpha_i * mvol_i$$

i: country/region in NiGEM

αi: importance of country i's import market to country j, based on 2017 trade patterns

mvoli: import volume for country i (in US$)

The share equation determines the bilateral trade sensitivities. This external demand variable feeds directly into country j's export volume equation:

$$dlog(xvol_j) = \cdots + \beta * dlog(s_j)$$

However, fossil fuel exporters may face a loss of global trade share as global demand for fossil fuels declines if they are not able to transition to other export sectors. To capture this potential impact, time varying weights are applied to major fossil fuel exporters, so αi is modified by the change in fossil fuel consumption in country i:

$$s_j = \sum_{i \neq j} \gamma_j * \frac{consumption_i^{simulation}}{consumption_i^{base}} \alpha_i * mvol_i$$

Where γ_j is the importance of fossil fuels in country j's export price (px)

This modification has been applied to the major fossil fuel exporters: Africa, Brazil, Canada, Latin America, Middle East and Norway.

Border Carbon adjustment (BCA)

The BCA model allows carbon adjustment tariffs to be introduced. This acts as a tariff between Green Club and Non-Green Club countries, to offset any losses of competitiveness related to a carbon tax and to reduce the risks of carbon leakage.

Import effects—Green countries only

Import prices are disaggregated, so that an additional tax (BCAcountry) is applied on imports from Non-Green Club countries:

- Price of imports (from Green) PM
- Price of imports (non-Green) PMX1

$$pmx1 = pm * (1 + BCA_{country})$$

These prices are then used in the following volume equations

- MVX1: Volume of trade imported by Green club from Non-green countries (use PMX1)
- MVX2: Imports from Green club into Green (PM)

Final import volumes are based on the relative share of imports (from green and non-green)

$$mvol = \alpha * mvx1 + (1 - \alpha) * mvx2$$

α is the share of imports from non-Green club

Competitiveness effects

Export from non-green to green proportion (D??GCLBX or β)

$$dgclbx_j = \sum_i \beta_i{}^{green}$$

Export tariff value (non green to green) (D?? BCAXV)

$$dbcaxv_j = \sum_i \beta_i{}^{green} * Country\ tariff_i$$

β: proportion of country j's exports which go to country i

tariff: import tariff levied by country i

$$pxnctt = pxncom * (1. + dbcaxv)$$

Country specific price of exports to world, PXNCTT which is used in the competitiveness equation (CPX). The effective tariff applied is related to both the size of the tariff imposed by the green countries as well as the importance of that market to the non-green country.

Revenue–Green countries only

The Tariff revenue is based on the proportion of Non-green imports and the size of the tariff applied and is directly added to BUD for the green country

$$etax = import\ share_{non-green} * tariff * import\ volumes_{affected\ by\ tariff} * \frac{CED}{100}$$

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