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Matthieu Darracq Pariès, Stéphane Dées, Annabelle De Gaye, Laura Parisi, Yiqiao Sun

NGFS climate scenarios for the euro area: role of fiscal and monetary policy conduct

Opening up the macroeconomic toolbox and its sensitivity to policy settings

No 336

Contents

Abstract

In this paper we analyse the sensitivity of the macroeconomic outcomes under the Network for Greening the Financial System's (NGFS's) Phase III net-zero and delayed transition scenarios to different monetary and fiscal policy settings. In doing so, we provide a rare application of the NGFS climate scenarios to economic assessment through the lens of the macroeconomic modelling frameworks underlying the scenario construction (e.g. NiGEM). Using the model to disentangle the main drivers of the scenarios, we show that gross domestic product (GDP) growth is shaped by physical and transition shocks jointly, whereas transition shocks account for most of the inflationary pressure. As regards alternative policy settings within the model, it turns out that Fiscal recycling options become more discriminant in terms of GDP impact in the medium term. Full recycling through government investment yields the strongest output multiplier, whereas recycling through household transfers or reduced income taxes yields the lowest multiplier. During the transition, euro area macroeconomic variables respond very similarly if two-pillar or price level-targeting monetary policy rules are followed. The Taylor- rule, reacting to inflation and output gap, yields higher and more persistent inflation as well as stronger short-term interest rate increases. These findings are certainly model-specific but do reflect the policy sensitivity embedded of the NGFS scenarios, within the confines of the very model used to build them up.

JEL classification: Q54, E3, E6, D6

Keywords: climate scenarios, modelling strategy, monetary policy, fiscal policy.

Non-technical summary

The Network for Greening the Financial System's (NGFS's) climate scenarios provide a common basis for both the public and private sectors to understand the possible economic and financial implications of the transition to net-zero emissions based on a comprehensive set of policy-related and technological assumptions. The data inputs, modelling strategy and scope of the NGFS scenarios are continually updated in view of the factors necessary to understand climate change and the economy, including major changes in geopolitics and climate policies.

In this paper we focus on the NGFS Phase III climate scenarios for the euro area as driven by an overlay of physical, transition and fiscal shocks, and conduct a sensitivity analysis with respect to fiscal and monetary policy settings. We present the macroeconomic impact of climate-related shocks on euro area real activity, inflation and financial variables such as short-term and long-term interest rates.

We show that gross domestic product (GDP) growth is mostly shaped by physical and transition shocks jointly, whereas transition shocks account for most of the inflationary pressure. By contrast, financial variables are essentially driven by the fiscal actions of debt repayment and transfers following carbon tax collection. The delayed scenario additionally has a higher risk premium due to greater uncertainty, resulting in higher aggregate economic volatility.

We demonstrate that fiscal recycling options only become more discriminant in terms of GDP impact in the medium term. Full recycling through government investment, having the strongest output multiplier, yields the least negative impact on euro area GDP for the overall scenario (-1.2% after ten years compared with around -2.1% for transfers and taxes). Recycling through household transfers or reduced income taxes produces the most adverse impact, having the lowest multiplier in the model.

Under the transition scenarios, the macroeconomic variables respond very similarly if two-pillar or price level-targeting monetary policy rules are followed. The Taylor principle, reacting additionally to growth rate deviations, yields higher and more persistent inflation and stronger short-term interest rate reactions. GDP response is, however, aligned with the outcomes for alternative monetary policy rules.

With the exercises shown in this paper, we open the macroeconomic toolbox to show how NGFS scenarios could be used for macroeconomic policy analysis. At the same time, we are aware of the limitations of and the uncertainty surrounding climate and economic modelling, as acknowledged in the NGFS scenarios. The wider user community has also provided feedback on their shortcomings. Notably, the NGFS scenarios do not serve as forecasts and the NGFS is working to constantly improve the scenarios further, including with regards to physical risks or the consideration of polycrises. It cannot be excluded that, if certain tipping points were reached, the economic effects might turn out far worse than the NGFS scenarios. At a technical level, areas for further development pertain to increasing the scenarios' sectoral and geographical granularity, introducing short-term scenarios and better representing acute physical risk. Obstacles to understanding the underlying model assumptions and levels of uncertainty, finding guidance on how to apply the scenarios and translate them into risk assessment and accessing the relevant data in all facets have also been mentioned. The more accessible the NGFS scenarios become, the more their features can be pruned and tested and, consequently, the more useful they will be for future analysis.

1 Introduction

The role of macroeconomic policy assumptions in the Network for Greening the Financial System's (NGFS's) climate scenarios has attracted a lot of attention, as they are part of the narratives that condition the scenarios. In 2018 the National Institute of Economic and Social Research (NIESR) started developing a climate module for its National Institute Global Econometric Model (NiGEM) with the aim of understanding the interactions between the macroeconomy and climate-related shocks and climate-related policy. Since joining the NGFS, NIESR has been helping to explore the macroeconomic impact across the NGFS climate scenarios. In the latest Phase III iteration, the NGFS scenarios were updated with new data, for example pertaining to the coronavirus (COVID-19), and enriched with more sectoral granularity, while NiGEM added new damage estimates from both chronic and acute physical risks to also incorporate new countries' commitments to reach net-zero emissions[1].

NiGEM complemented the comprehensive energy modelling of the integrated assessment models (IAMs) used by the NGFS to provide greater macroeconomic detail and to elaborate the macroeconomic policy channels. When designing the policy conditionality of the Phase III scenarios, the different policy settings were therefore carefully considered as explained in Darracq et al (2022). In order to assess the sensitivity of results to fiscal and monetary policy assumptions, Darracq et al. (2022) also provides a sensitivity analysis on stabilization policy settings around the Phase II shocks for net zero scenario.

This paper expands on sensitivity analysis presented in Darracq et al (2022), focusing on the Phase III scenarios and on the euro area outcomes. The analysis is conducted through the lens of NiGEM using input shocks from the satellite climate modules, providing alternative simulations according to different policy options. Under the Phase III scenarios, the policy environment continues to play an important role in scenario set-up as well as for the interpretation of the impact of climate change shocks on economies. In particular, transition scenarios involving some form of carbon tax or other stagflationary types of shocks imply a higher trade-off between inflation and gross domestic product (GDP) objectives. Combining them with revenue recycling schemes may amplify the inflationary effects and intensify this trade-off. The sensitivity analysis regarding fiscal and monetary policy, mainly applied to the net-zero and delayed scenarios, shows that different forms of carbon tax revenue recycling have different impacts on economic variables, both in the short and long term. Depending on the type of monetary policy environment chosen, they can mitigate as well as amplify the effects of fiscal policy.

This paper is structured as follows: Section 2 presents the macroeconomic modelling framework underlying the NGFS scenarios. Section 3 analyses the sensitivity of the

[1] Phase IV scenarios have been released on 7 November 2023. The analysis presented is this paper, although based on the previous scenario vintage, is applied on two specific scenarios (the net-zero 2050 scenario and the delayed disorderly transition scenario) that are still included in the new release. The sensitivity analysis around these two scenarios remain therefore valid.

scenarios to the chosen fiscal assumptions. Section 4 analyses their sensitivity to monetary policy assumptions. Finally, Section 5 concludes by reviewing the insights gained from the analysis and highlighting aspects for possible future studies.

2 Macroeconomic modelling strategy underlying the NGFS scenarios

2.1 NGFS strategic directions

Since 2018 the NGFS has been developing climate scenarios to represent what our economies might look like under different assumptions in terms of transition policies and physical risks. The NGFS climate scenarios answer key questions like "what could happen?" or "what should happen?" to enable a common understanding of how climate change and climate change mitigation could affect our economies in the long run (until 2100). The first vintage of NGFS climate scenarios was released in 2020, and two more followed in autumn 2021 and 2022. Over time, the NGFS's climate scenarios have become deeper, broader and richer in terms of modelling tools, output results, risk coverage and geographical scope. This progress and the continual updates reflect the innovative nature of climate scenario development, being at the frontier between climate science, macroeconomic analysis and policy assessment.

The Phase III NGFS scenarios released in September 2022 present two new elements compared with the previous versions: they include projections on acute physical risk and have been enriched with further sectoral granularity. All scenario trajectories have also been updated to reflect the latest real GDP and population pathways, as well as the most recent country-level commitments made at the United Nations Climate Change Conference (COP26) in November 2021. Alongside the impacts of chronic climate changes on the macroeconomy, the Phase III NGFS scenarios include, for the first time, estimates of potential losses from extreme weather events (floods and tropical cyclones). A new scenario vintage (Phase IV) has been recently released (NGFS, 2023a), featuring additional innovations such as improved modelling of acute physical risks and new scenario narratives. The two scenarios selected in the present analysis (the net zero scenario and the delayed transition scenario) are still part of the new vintage.

The NGFS scenarios feature unique tools compared with other climate scenarios that make them particularly suitable for a wide range of applications. Besides being regularly updated and improved with each new iteration, the NGFS scenarios provide a common starting point to analyse climate-related risks and their impact on the economy and financial system. They produce results that combine transition, physical and macro-financial risks in an internally consistent manner (Section 2.2), are applicable at the global level and are comparable across regions. Importantly, they also provide freely accessible pathways via a web portal interface, which ensures transparency and provides a valuable public good to a wide user community and the general public.

The NGFS scenarios are helping a wide range of public and private sector players to better understand the financial risks stemming from a changing

climate as well as the opportunities of climate change mitigation. One of the most common approaches to forward-looking assessments of climate change is scenario analysis, which can shed light on the possible future implications of such an unprecedented phenomenon. A recent report by the Financial Stability Board (FSB) and the NGFS[2] provides an overview of scenario models, data and metrics used by FSB and NGFS members in their climate scenario analysis exercises. The report confirms that the NGFS scenarios are at the core of these exercises, with most of the sampled institutions worldwide making use of them, either with or without adjustments to some of their components or outcomes. A public survey was also launched in February 2023 to collect feedback from the user community on the NGFS scenarios. The survey was addressed to both the public sector (e.g. central bank and supervisory authorities) and the private sector (mostly financial institutions and consulting firms) and confirmed that 72% of respondents use the NGFS scenarios in their analyses, either alone (57%) or in combination with other scenarios (15%), compared with 7% of respondents who use only non-NGFS scenarios and 22% who do not use any climate scenarios. Compared with other alternatives, the answers to the survey confirm a very positive evaluation of the macroeconomic module combined with the modelling of transition and physical risk, which is perceived as a unique feature of the NGFS scenarios.

The NGFS scenarios can also help policymakers and central banks to understand the impacts of transition policies on the macroeconomic outlook, which can in turn inform relevant policy decisions. Via the implications of climate change and mitigation policies for key macroeconomic indicators, such as GDP, inflation and unemployment, these scenarios are useful to identify potential sources of future risk within the real economy, as well as their transmission to financial institutions and markets. At the same time, the scenarios provide information on the evolution of the energy sector depending on different climate policy ambitions, which include the investment needed in specific sectors. This supports policymakers in identifying sectors and activities with development potential, as well as informing private businesses of future opportunities. The NGFS scenarios are also an important tool to assess the macroeconomic implications of climate change and their forward-looking impact on macroeconomic fundamentals, which central banks may consider in their policymaking processes.

Although the NGFS scenarios have improved over the last three years, further work is still needed to increase their scope, improve their granularity and make them more easily accessible to a wider range of users. One of the more pressing challenges ahead is to translate the long-term developments modelled so far by the NGFS into short-term scenarios that can be more easily implemented in stress-testing exercises to better identify growing risks in the real economy and financial sector. The NGFS has recently published a conceptual note on short-term climate scenarios (NGFS 2023b), to inform the public on the conceptual framework reflecting the NGFS's thinking on short-term scenarios, ahead of their analytical implementation in 2024. Furthermore, the NGFS scenarios tend to underestimate the impact of physical risk, mostly due to limitations in their assessment of future acute

2 See FSB-NGFS (2022).

events. In Phase IV (NGFS, 2023a), acute physical risk modelling was improved to provide economic impact estimates at the country-level, to include more hazards, and to more accurately capture their transmission to the economy. Further improvements in terms of data availability and modelling capacity are however needed to more precisely assess the costs of unfettered climate change. Finally, while the global nature of the NGFS scenarios is an extremely important feature to ensure comparability across geographies and thus foster policy coordination, their country-sector granularity should be enriched to ensure a level playing field across jurisdictions and to account for each country's specificities.

2.2 A suite-of-models approach

The NGFS scenarios combine the analysis of transition, physical and macro-financial risks to shed light on the long-term trade-offs between the costs of climate change mitigation and the consequences of unfettered climate change. To make this possible, the NGFS scenarios are based on three essential features. First, they take a long-term perspective, which is necessary to assess the benefits of reduced physical risk over the coming decades driven by effective climate policies. By contrast, a scenario focused on the next few years would only capture the costs of climate action, while omitting the future but long-lasting benefits of meeting the Paris temperature targets – which is the very reason why climate action and climate scenarios are needed. Second, the NGFS scenarios cover the global economy, thus providing consistent results and comparable applications across geographies and facilitating international climate policy coordination. Third, the scenarios are based on international collaboration between research institutes to combine different models and capture the interactions between transition, physical and macro-financial risk.

The NGFS scenarios are based on a suite-of-models approach to jointly but indirectly capture climate, macroeconomic and financial contingencies. The models used to derive the NGFS scenarios can be classified into three broad categories: physical risk models, transition risk models and macro-financial models. The three model categories are broadly described in Chart 1, including the contributing institutions, the input variables used, the output variables produced and the time horizon. The first category includes all physical risk models that are part of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) and CLIMADA and provides climate and economic indicators as a result of changes in climate. The second category includes three IAMs that derive the impacts of different policy ambitions on the energy sector, emissions and land use. The third and final category includes NiGEM (a version specifically modified for the purpose of producing the NGFS scenarios) to understand the consequences of transition and physical risk on key macro-financial fundamentals.

Chart 1

Three categories of models to produce NGFS scenarios

	Physical risk impact	Transition risk impact	Macroeconomic impact
Models	Climate models participating in ISIMIP project and CLIMADA	Remind-MAgPIE GCAM MESSAGEix-GLOBIOM	NiGEM (NGFS version IAMs)
Input	Atmospheric concentrations of emissions and associated radiative forcing. Economic exposures	Constraints on emissions dependent on temperature targets, combined with country commitments	Carbon tax prices and revenues, energy consumption, energy needs, physical risk damage functions
Output	Climate indicators (e.g. temperature precipitation, etc). Economic indicators (e.g. direct losses from natural disasters, area and population exposed, etc)	Energy demand, energy capacity, investment in energy, energy prices, carbon prices, emissions trajectories, temperature trajectories, land use	GDP, unemployment, inflation, productivity, personal disposable income, house prices, interest rates, exchange rates, equity prices
Time horizon	Time steps of 5 years up to 2100	Time steps of 5 years up to 2100 (10 years steps from 2060 onwards for Remind and Message)	Annual steps up to 2050

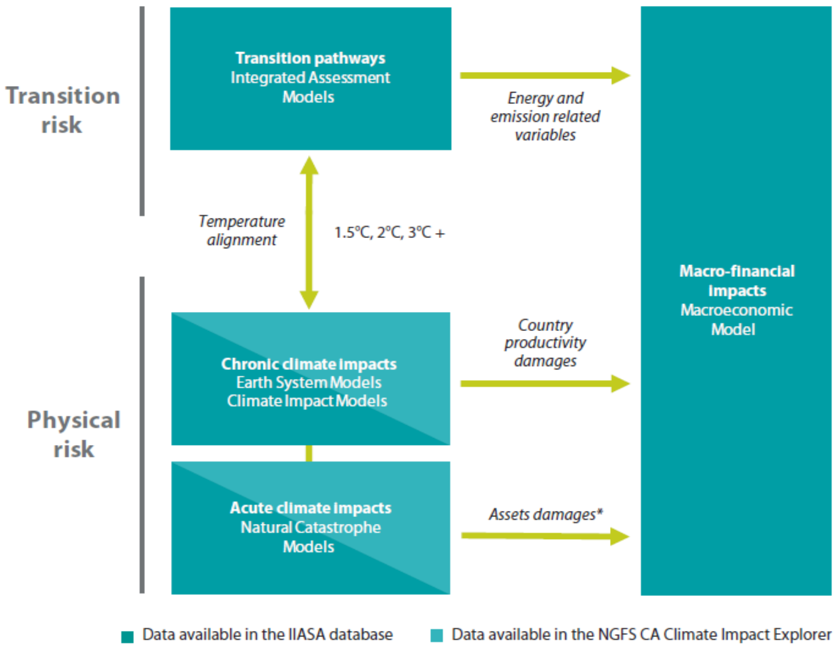
Source: ECB based on NGFS technical documentation.

Seven different institutions or initiatives joined forces under the aegis of the NGFS to ensure the overall consistency of the scenario framework while still relying on state-of-the-art and peer-reviewed academic literature. One of the key advantages of this suite-of-models approach is the opportunity to use existing models, each of them being specialised and extremely advanced in capturing one single part of the framework. This allows the reactions of economic sectors to climate change and/or climate policies to be analysed with a higher level of granularity, coverage and precision than otherwise possible. The models chosen for the NGFS scenarios also inform the Intergovernmental Panel on Climate Change's (IPCC's) reports[3], thus ensuring a high level of consistency between the NGFS and the IPCC frameworks. Furthermore, this collaboration has facilitated dialogue across extremely specialised institutions, enabling the cross-fertilisation of ideas and skills to improve existing methodologies and advance our understanding of climate scenarios further. The interactions between the different models listed in Chart 1 are displayed in Chart 2. In particular, transition and physical risk models have been aligned in terms of temperature pathways to ensure that the impacts of both on the economy are consistent and comparable. The way transition and physical models combine with the macro-financial NiGEM is instead sequential. Energy-related and emission-related variables produced by the three IAMs are used as an input by NiGEM; a similar mechanism is applied to the damage functions obtained with the physical risk models.

[3] See IPCC (2022).

Chart 2

Interactions between the three model categories in the NGFS framework



Source: NGFS technical documentation.

The suite-of-models approach proposed by the NGFS can be complemented by alternative solutions that enrich traditional macroeconomic models with environmental policy considerations. Several classes of models can be considered, including computable general equilibrium (CGE) and dynamic stochastic general equilibrium (DSGE) models. Compared with IAMs, these models are typically richer in economic variables and can explore a wide range of sectors, thus effectively capturing the impact of transition policies. At the same time, CGE and DSGE models are not grounded in climate science and, if implemented alone and not in combination with physical risk models, are unlikely to lead to any conclusions on the impact of physical risk.[4] One example in this category is G-Cubed (Box 1), a multi-country, multi-sector, intertemporal general equilibrium model that integrates emissions and energy data with a sectoral model of the economy. It can therefore be seen as a hybrid DSGE and CGE model that also allows a variety of climate policies to be assessed. When looking at the results obtained across G-Cubed and the three IAMs used in the NGFS framework, important divergences emerge: some due to the different structures of the models and others driven by substantially different underlying philosophies and future prospects for the energy system and macroeconomy. For example, G-Cubed achieves a net-zero economy with materially lower carbon prices compared with the NGFS IAMs, as a result of greater substitutability across high-carbon to low-carbon sectors given a certain emission target.

4 See NGFS (2022b).

Box 1

Model-specific versus suite-of-models approach: perspectives from G-Cubed contribution to Phase III

This box offers an alternative modelling perspective that relies on an integrated approach to macro-climate scenarios rather than the suite-of-models approach, based on the G-Cubed general equilibrium model. The G-Cubed model is a multi-country, multi-sectoral model including a detailed representation of the energy sector according to the input and output data of the world economy. G-Cubed uses a top-down macroeconomic approach and was selected by the Network for Greening the Financial System (NGFS) to contrast the bottom-up engineering approach taken by the three IAMs[5].

As carbon prices are the central driver of transition scenarios, we conduct a simple exercise that compares the simulation results of G-Cubed with the National Institute Global Econometric Model (NiGEM) when the same calibration of a carbon tax is implemented in both models. The calibration chosen reflects the recent climate commitments set out in the EU's Fit for 55 packages to cut greenhouse gas emissions by 55% (relative to 1990 levels) to achieve the net-zero target by 2050 (Chart A1, panel a). For the rest of the world, the carbon tax imposed is relatively mild compared with the range of existing studies.

The (preliminary) results of the exercise show small differences in the simulation outcomes of the two models. The overall impact of the carbon tax scenario on euro area gross domestic product (GDP) and inflation is rather contained, with a decline in real GDP of less than 1.5% by 2030 and a slight increase in headline inflation, except for a strong initial reaction in G-Cubed (Chart A1, panels b and c). The decline in real activity entails both a negative output gap and a permanent decline in potential output. While the output losses and price level increases caused by the carbon tax are permanent, the effects on inflation are transitory, with inflation returning to its baseline by 2030.

The comparison of G-Cubed with NiGEM shows that the effects simulated by G-Cubed are stronger[6]: GDP losses over time are larger until 2030, but the gap to NiGEM closes by 2040. In the first year following the shock, annual inflation deviates from the baseline by 6% upward under the G-Cubed scenario but drops quickly and steadily in the years afterwards, while NiGEM shows a gradual and small increase in headline inflation up to 2030. By 2040, both models' results converge.

While the transition in the NGFS integrated assessment models (IAMs) is driven by a substitution between energy sources driven by the carbon price, G-Cubed achieves the transition by lowering overall energy production and reducing the carbon intensity of non-electricity sectors via greater substitution between activities in these areas. G-Cubed assumes a lower degree of substitutability between electricity-generating technologies than in the IAMs and models the adjustment costs associated with rapid large-scale deployment of new technologies, which leads to a greater slowdown in aggregate economic activity in the long run. By contrast, the NGFS IAMs rely heavily on the penetration of wind and solar technologies to reach net-zero, and steady growth in energy consumption.

The lessons learnt from the exercise are essentially twofold. First, the strength of an integrated global macro-modelling approach, like in G-Cubed, is that it internalises transition mechanisms

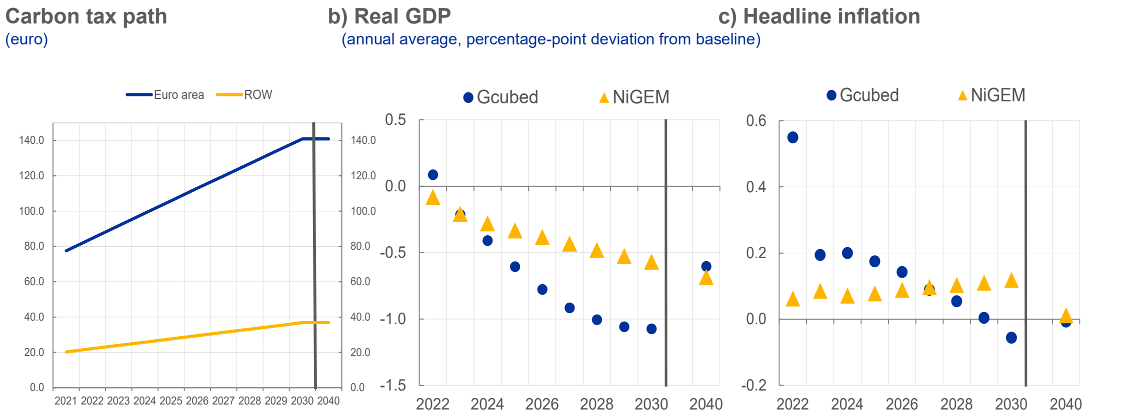
[5] See NGFS (2022a).

[6] See also Brand, Claus, et al. "The macroeconomic implications of the transition to a low-carbon economy." Economic Bulletin Articles 5 (2023).

coherently within the economic systems, benefiting from modelling dynamics available at sectoral and regional levels, while preserving plausible aggregate economic impacts, comparable with NiGEM results. Second, the particular weakness is that economic shocks in G-Cubed are an abstraction of the impact of physical risks, which are carefully modelled in IAMs and are detailed representations of climate science principles. Both approaches can be complimentary, either to increase the understanding of impacts on economic agents or to primarily improve the modelling of climate pathways, which in turn provides guidance on policy measures.

Chart A

Impact of carbon tax on euro area GDP and inflation: G-Cubed vs NiGEM



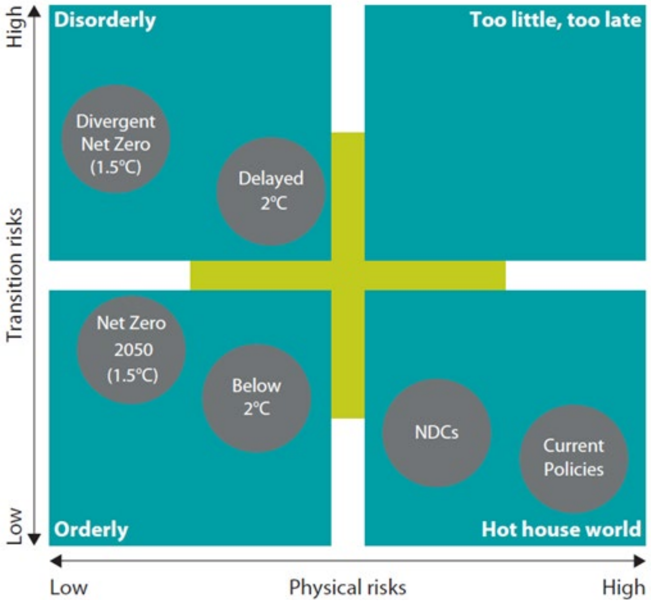
Source: ECB staff calculations

2.3 The scenario narrative

The NGFS scenarios explore a set of six possible transition pathways, depending on different levels of ambition and coordination in terms of climate policies. The NGFS scenarios can be grouped into three categories: orderly transition, disorderly transition and hot house world scenarios. The two orderly transition scenarios (labelled Net Zero 2050 and Below 2°C) assume that climate policies are introduced early on and become gradually more stringent to effectively mitigate climate change and meet the Paris targets (either 1.5°C or below 2°C temperature increase) by 2100. The two disorderly transition scenarios explore higher transition risk due to climate policies being delayed or divergent across economic sectors. They also assume that the Paris targets are met by the end of the century, although at higher economic costs. The two hot house world scenarios assume that climate policies are implemented in only some jurisdictions, while global efforts remain insufficient to halt significant global warming. These scenarios translate into severe physical risk, especially in the second half of the century, with irreversible impacts. The scenario mapping is also displayed in Chart 3. Phase IV NGFS scenarios include two new narratives: a new orderly scenario (Low Demand) and a "too little, too late" scenario (Fragmented World)[7].

[7] For more details on the Phase IV NGFS climate scenarios, please see NGFS (2023a).

Chart 3
NGFS scenario framework



Source: NGFS technical documentation.
Note: Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100.

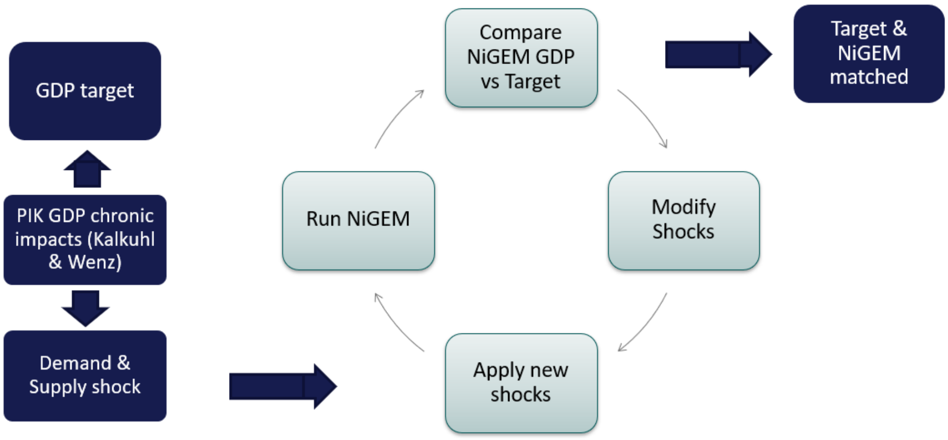
2.4 Scenario wedges and simulation modalities in NiGEM

This section reviews the main drivers of the macroeconomic scenarios consistent with the climate change scenarios as included in Phase III. These outcome scenarios shed light on the transmission channels from the climate to the aggregate economy by implementing a range of climate shocks to which the macroeconomic responses are generated. Three groups of calibrated shocks are devised to translate the impact of physical damages, transition and fiscal policies into a set of exogenous shocks on both the demand and supply side, constituting the main scenario wedges that overlay on top of each other.

Physical shocks consist of those calibrated to match the chronic GDP damage proposed by Kalkuhl and Wenz (K&W) as well as additional ones capturing acute physical effects. Simulations are carried out with global linkages such as trade and monetary policy shut-off in order to be closer to the K&W methodology. More specifically, energy sector and trade volumes, and adaptive expectations about monetary policy are exogenous in this stage. The K&W GDP chronic impacts are directly applied as supply-side shocks to productivity, which are more severe in comparison with Phase II. Subsequently, additional demand-side shocks, notably domestic demand components and business investment premia (only if not net-zero scenarios), are implemented reiteratively until the overall GDP damage target values are matched (Chart 4). In this way, acute physical effects are also included as both supply and demand shocks, as they directly affect capital stock (supply), which in turn exerts its impact on GDP via investment (demand).

Chart 4

Climate to macroeconomic NGFS scenarios: physical shocks

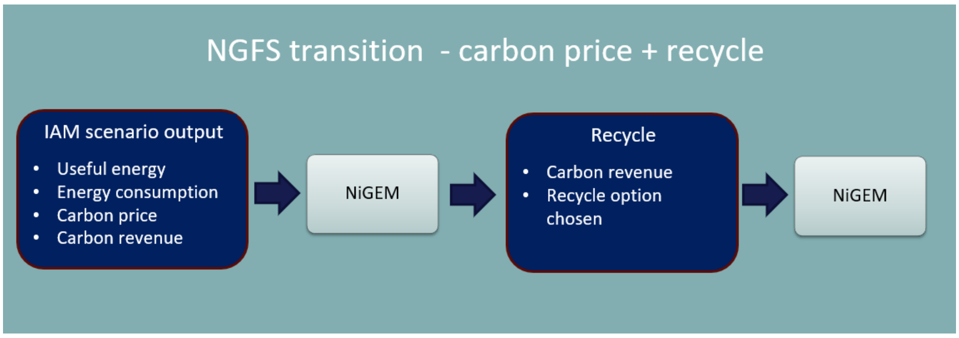


Source: NiGEM technical documentation.

The transition shocks are a combination of carbon price inputs (introduced as carbon tax in NiGEM) from the IAMs and recycling choices for carbon tax revenues, featuring as fiscal shocks. Carbon tax revenue in Phase III is provided directly from the IAM models rather than being determined from consumption and carbon tax within NiGEM. Moreover, consumption effects are made fuel-specific to capture country-specific export ratios, and they affect final share values rather than individual country coefficients. All recycling (fiscal shocks) is now introduced as a second-round shock rather than integrated into the carbon price shock (Chart 5).

Chart 5

Climate to macroeconomic NGFS scenarios: transition shocks



Source: NGFS technical documentation.

All recycling choices share a common environment (i.e. the same set of key simulation options, for instance regarding expectations or monetary policy rules). Energy sector changes due to transition shocks come only from input derived from IAM models, and the resulting carbon tax revenue recycling is run with adaptive expectations. To ensure that the link to IAM output is maintained, the energy sector in NiGEM, which by default is endogenous, is set as exogenous, therefore fully reflecting changes in energy mix coming from IAMs. Finally, monetary policy is exogenised so that the fiscal impact remains unaffected by the central bank's reaction (i.e. the central bank does not react to the fiscal shock).

Carbon pricing is used as the main determinant of transition. Expressed in price level terms, it is a shadow price necessary to keep temperatures on track rather than a prevalent carbon tax equivalent. Chart 6 illustrates some of the main underlying transition shocks in price level terms under the 1.5°C net-zero scenario as an example, in which case the transition shocks are strongest. The carbon price shown here as an exogenous shock is a shadow price derived from the reduction of emissions necessary in order to keep the temperature increase below a certain threshold. While the carbon price shock is common for all countries, carbon revenues and energy consumption may be country-specific depending on their individual greenhouse gas (GHG) emission paths, which in turn are linked to the country's primary energy input mix (Chart 7). For instance, Germany at the start is far more dependent on highly polluting primary energy inputs, namely oil and coal, compared with other countries and less reliant on clean energy such as hydrogen. Consequently, carbon revenues are highest at the start while, due to the elevated penalties, total energy consumption quickly decreases thanks to the rapid decline of oil and coal use within five years as the carbon price increases most steeply. Instead, renewable energy sources such as solar and wind see quick take-up. From 2040 onwards, carbon prices start to fall as total emissions decline significantly and eventually below zero given the assumed favourable technological advances. Energy consumption across all countries falls to a significantly lower level, partly reflecting a 60% increase in energy efficiency by 2050 thanks to electrification. In the long run, the euro area economies converge and become less energy-intensive in terms of total energy consumption, while electrification picks up rapidly. Although some differences in the cross-country energy mix remain, up to 50% of overall oil, gas and coal use is replaced by carbon-neutral electricity by 2050 across all industrial sectors, construction and transport. Over time, carbon storage and removal technologies are assumed to be able to remove CO_2 from the atmosphere, reducing emissions further in meeting the temperature increase target.

Simulating the scenarios with distinct shocks allows the contribution of each shock to be separately identified, disentangling for example the role of the transition shock from alternative tax recycling options. In the new setting, carbon tax revenue recycling is treated as rational, meaning that, unlike the Phase II simulation output, NiGEM is used with its forward-looking mode based on model-consistent expectations. Finally, monetary policy is kept endogenous in order to address previously identified issues related to inflation persistence and unrealistic interest rate paths.

To sum up, Phase III scenarios all include the following features regarding the use of NiGEM[8]:

- endogenous monetary policy, implying more realistic output-inflation paths;

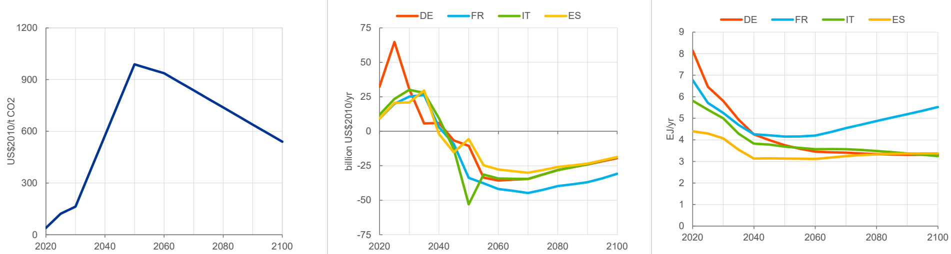
[8] All these features remain valid in Phase IV released in November 2023.

- an exogenous energy sector, which does not significantly affect the main variables of interest, while maintaining a close link with the energy components simulated with the IAMs;
- the assumption – as in Phase II – that fiscal revenues are recycled with higher government investment (50%) and public debt reimbursement (50%) under the net-zero 2050 scenario; different recycling options are chosen for disorderly scenarios.

Chart 6

Transition shocks: carbon price, carbon revenue and energy consumption

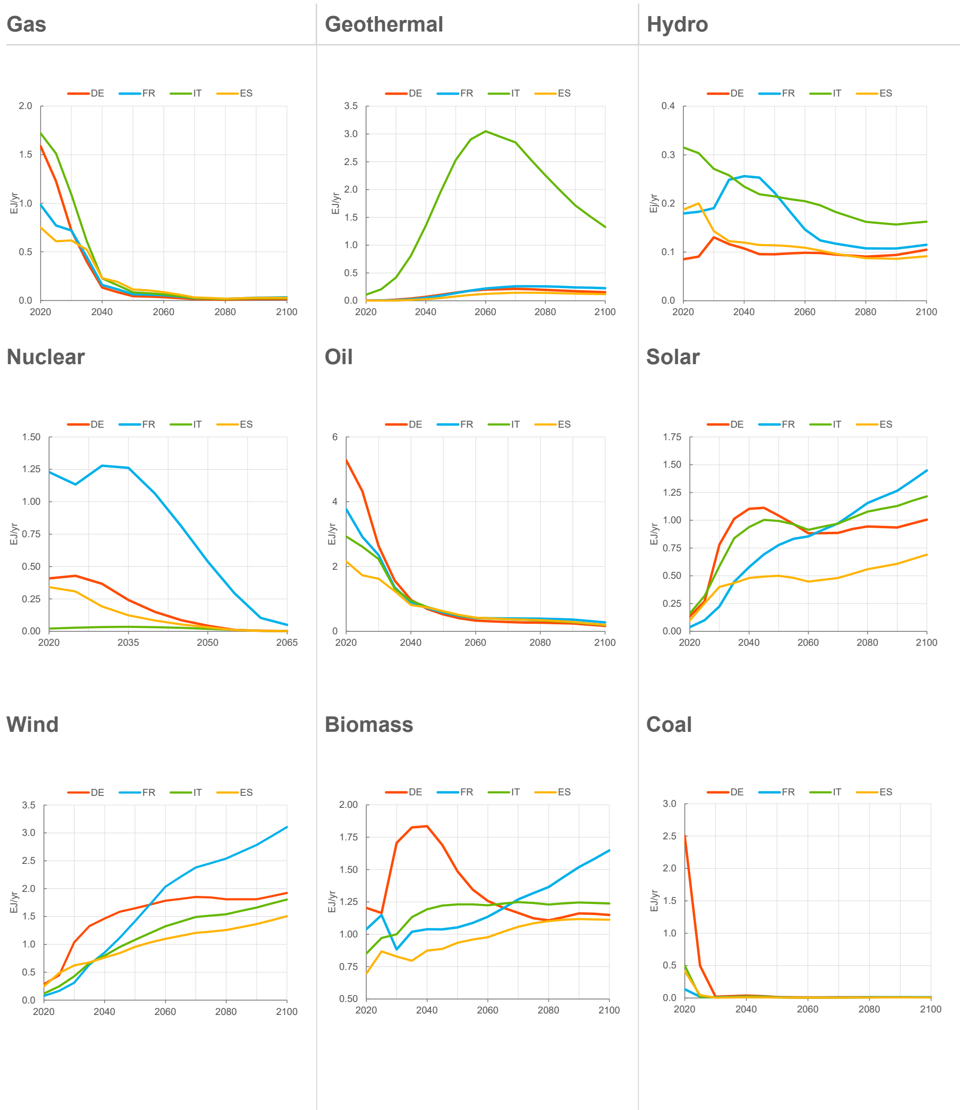
Carbon price	Carbon revenue	Energy consumption



Source: NGFS REMIND-MAgPIE 3.0-4.4.

Chart 7

Transition shocks: primary energy inputs



Source: NGFS REMIND-MAgPIE 3.0-4.4.

2.5 Main drivers of the NGFS scenarios for the euro area

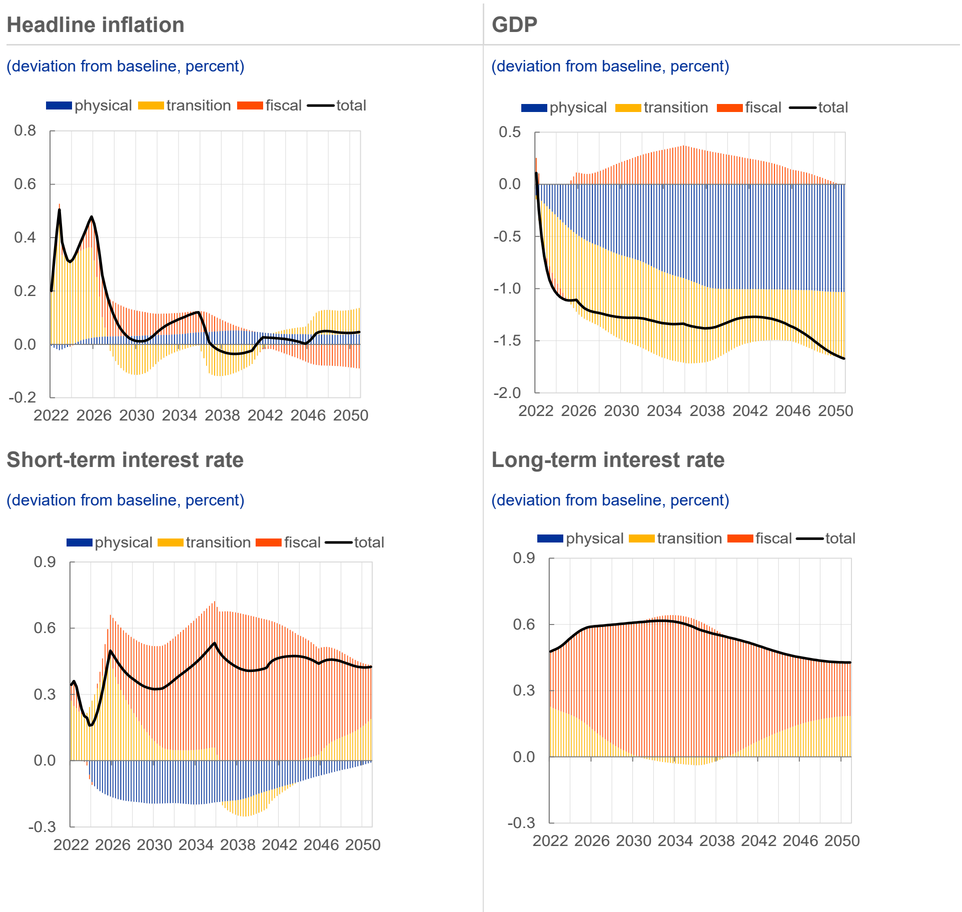
In this section we show the macroeconomic outcomes for the euro area under the NGFS Phase III net-zero 2050 scenario with a temperature rise not exceeding 1.5°C (Chart 8) and the delayed disorderly transition scenario with strong policies to keep warming to below 2°C (Chart 9). While the first climate scenario represents the best-case outcome, highly dependent on the assumptions about green innovation, the second represents the case of a disorderly transition, decisively relying on contributions from mitigation policies. We discuss the impact of the three types of shocks on real GDP growth, headline inflation and short-term and long-term interest rates in the euro area under these two alternative scenarios.

Under the net-zero scenario, transition shocks account for the strongest economic impact in the short run, while remaining important in the long run. Transition shocks push inflation upward by imposing higher costs associated with carbon emissions and reduce GDP growth as total energy input, especially fossil fuel consumption, declines. This is only partially offset by energy efficiency gains from lower productive capacity, for example. Demand exceeds supply in the short run, resulting in additional inflationary pressures.

The physical shocks have little impact on inflation throughout the horizon but a large impact on the real economy. The negative impact of physical shocks on GDP increases quickly with time until it stabilises after 2040. Fiscal shocks drive short-term and long-term interest rates strongly upward, mitigating the adverse effect on GDP to a limited extent, while their impact on inflation is positive as redistribution supports domestic demand. The additional revenues on taxable emissions collected by governments can be used in one way or another to support domestic demand and create inflationary effects.

Chart 8

Drivers of the net-zero scenario for the euro area



Sources: NGFS, NiGEM and ECB calculations.

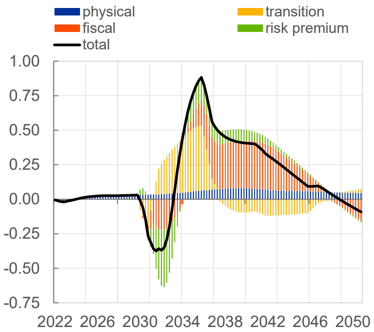
Compared with the net-zero transition, a delayed transition sees inflation rising quickly to a much higher level, driven primarily by drastic transition policies. The inflation effect in the transition period peaks around 2035 and then gradually reverts back to the steady state by 2050. On the real economy side, the damages from physical shocks reach a much more severe level until transition policies are set in motion. All three types of shocks lead to an increasingly negative impact on real GDP growth for the period considered until 2050, such that growth deviates by -3 percentage points (around twice as much as under the net-zero scenario) from its steady state. Short-term and long-term rates rise more sharply but reach similar levels in the long run as under the net-zero scenario. Under delayed scenarios an investment premium shock is additionally implemented, which acts mostly in the short run along with the launch of stringent climate policies, enhancing all effects from the other three types of shocks on inflation and growth but keeping interest rates' rise contained.

Chart 9

Drivers of the delayed scenario for the euro area

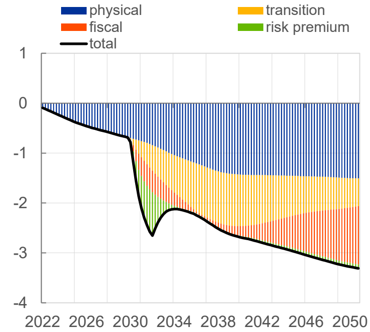
Headline inflation

(deviation from baseline, percent)



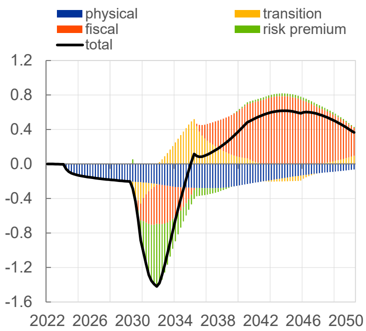
GDP

(deviation from baseline, percent)



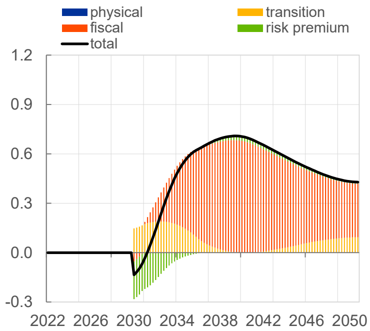
Short-term interest rate

(deviation from baseline, percent)



Long-term interest rate

(deviation from baseline, percent)



Sources: NGFS, NiGEM and ECB calculations.

3 Sensitivity to fiscal policy assumptions

The sensitivity analysis is performed on Phase III shocks under the more stringent 1.5°C net-zero scenario. In this section, we propose a sensitivity analysis according to the fiscal revenue recycling options, thereby discussing the available options within NiGEM. We first compare the impact of the various options on key macroeconomic variables before showing how such effects differ across countries.

3.1 Fiscal policy in NiGEM

3.1.1 Introduction to NiGEM's fiscal options

Full-country models feature a well-specified government sector, while a solvency rule ensures that public debt does not explode. Full-country models include a well-specified government sector, where the fiscal deficit flows into the stock of government debt. A fiscal solvency rule is introduced to ensure that the deficit and debt stock return to sustainable levels.

The fiscal solvency rule is introduced through the income tax rate. A deviation in the deficit or debt stock from their specified targets initiates an endogenous shift in the tax rate. This pulls the deficit and debt stock back towards targeted sustainable levels.

$$TAXR_t = TAXR_{t-1} + \left[\frac{0.01 * NOM_{t-1} * \{\beta_1 * (GBRT_{t-1} - GBR_{t-1}) + \beta_2 * (GDRT_{t-1} - GDR_{t-1})\}}{PI}\right]$$

TAXR: income tax rate
NOM: nominal GDP
GBRT: government deficit target (% GDP)
GBR: government deficit (% GDP)
GDRT: government debt target (% GDP)
GDR: government debt (% GDP)
PI: personal income (income tax base)

By default, the solvency rule operates through the deficit target, with β_2 set to zero. Model users can deactivate the solvency condition temporarily or permanently for specific scenario studies.

In the standard model, there are two main fiscal options that can be applied to the carbon price shock itself.

- The solvency rule is maintained such that an additional tax burden is placed on households to maintain the budget position.
- The solvency rule is deactivated, and the burden feeds into the debt position.

When reviewing the recycling of carbon tax revenue, several options are available.

- The tax burden for households can be lowered. As a result, improved real disposable income supports private consumption and hence GDP.
- Government debt stock can be reduced. Revenue from carbon taxes can therefore be used to lower fiscal deficit and hence the debt stock (including associated debt interest payments).
- Transfers to households can be increased, which has a similar effect to the lowering of taxes for consumers.
- Government investment can be increased, which has a direct positive impact on GDP as well as the economy's potential output.
- VAT can be reduced based on implicit carbon tax revenue and personal income to mitigate inflation effects, which will improve the disposable income of households and facilitate higher corporate profits. This instrument was left out of the scope of the fiscal sensitivity analysis in Section 2.
- A combination of the above options can be used.

The entire carbon tax revenue is recycled one way or another such that the solvency rule is maintained. In all cases, budget neutrality is assumed. This implies first that the entire carbon tax revenue is recycled through one of the options outlined above, and second that the solvency rule is activated, i.e. any substantial endogenous deviation from the sustainable budget path is compensated by a change in the income tax rate in order to converge again to the sustainable path. In order to better understand the impact of fiscal policy in NiGEM, we first consider standard fiscal shocks to get an idea of the magnitude of fiscal multipliers before considering the specific fiscal shocks that can be applied under the NGFS climate transition scenarios.

3.1.2 Fiscal multipliers in NiGEM

Although frequently used to analyse the impact of public policies at a macroeconomic level, NiGEM has typically delivered on effects with rather shorter horizons than those usually considered under climate scenarios. NiGEM has generally been used to assess effects over a shorter horizon (between 5 and 10 years) than that considered under climate transition scenarios (here up to 2050). In particular, over longer horizons, issues such as the interaction of fiscal and monetary policies may arise, because although monetary policy reaction may sometimes be exogenised in the short term to get a better grasp of the pure fiscal impacts, it makes less sense to fix rates for a long period of time.

Fiscal multipliers are compared for the different recycling options across horizons, depending additionally on monetary policy rate settings. To illustrate the orders of magnitude of fiscal multipliers in NiGEM depending on the simulation assumptions (types of expectations and monetary policy reaction), Table 1 presents the impact of standard fiscal shocks on euro area GDP and inflation over different horizons. The fiscal shocks, corresponding to the carbon revenue recycling schemes that will be considered later, are (i) an increase in household transfer payments, (ii) a decrease in household income taxes, (iii) an increase in government investment, and (iv) a reduction in public debt. For the sake of comparison, all shocks are of an order of magnitude of 1 point of GDP. The simulations presented are carried out first under rational expectations over the maximum horizon allowed by the model and leaving monetary policy endogenous (denoted "Fwd until 2050"), then under backward expectations with endogenous monetary policy (denoted "backward"), and finally under backward expectations but with exogenous monetary policy (denoted "backward – fixed rates").

Table 1

Impact on euro area GDP and inflation of a standard 1-point-of-GDP shock on fiscal variables

			1Q	1Y	2Y	5Y	2030	2050
EA GDP (% dev. from baseline levels)	Transfers	Fwd until 2050	0.17	0.06	0.02	-0.02	-0.16	-0.70
		Backward	0.19	0.22	0.11	0.03	-0.13	-0.69
		Backward - fixed rate:	0.19	0.29	0.33	0.30	0.21	0.03
	HH taxes	Fwd until 2040	0.24	0.19	0.20	0.19	0.13	-0.22
		Backward	0.23	0.28	0.19	0.10	-0.11	-0.85
		Backward - fixed rate:	0.26	0.42	0.50	0.60	0.67	0.20
	Govt Investment	Fwd until 2030	0.78	0.57	0.52	0.91	1.66	0.77
		Backward	0.72	0.60	0.35	0.66	1.08	0.73
		Backward - fixed rate:	0.72	0.82	0.87	1.11	1.69	0.90
	Debt reduction	Fwd until 2050	0.00	0.00	0.00	-0.02	-0.02	0.03
		Backward	0.00	0.00	-0.01	-0.01	-0.01	0.09
		Backward - fixed rate:	0.00	0.00	-0.01	-0.04	-0.05	-0.01
EA Inflation (abs. dev. from baseline levels in p.p.)	Transfers	Fwd until 2050	0.00	0.04	0.02	0.05	0.07	0.02
		Backward	0.01	0.10	0.12	0.07	0.07	0.01
		Backward - fixed rate:	0.01	0.10	0.18	0.14	0.07	-0.01
	HH taxes	Fwd until 2040	-0.23	-0.34	0.02	0.04	0.04	0.01
		Backward	0.00	0.10	0.13	0.10	0.10	-0.01
		Backward - fixed rate:	0.01	0.14	0.26	0.27	0.25	-0.04
	Govt Investment	Fwd until 2030	-0.32	-0.37	0.10	-0.01	0.12	0.04
		Backward	0.01	0.23	0.17	-0.03	-0.07	0.05
		Backward - fixed rate:	0.01	0.25	0.33	0.05	-0.04	0.07
	Debt reduction	Fwd until 2050	0.01	0.02	0.01	0.00	0.00	-0.01
		Backward	0.00	0.00	0.00	-0.01	-0.01	0.00
		Backward - fixed rate:	0.00	0.00	0.00	-0.02	-0.02	0.01

Source: Authors' calculations based on NiGEM v1.22-Climate.

In the very short term – one quarter after the initial shock – the real GDP impacts for each type of fiscal shock seem relatively similar across the various assumptions on expectations and monetary policy. The orders of magnitude for the different fiscal multipliers seem reasonable in comparison with the existing literature (around 0.2 for transfers and income tax rates, between 0.7 and 0.8 for public investment and zero for debt reduction). Indeed, among the fiscal instruments considered, government investment has the stronger output multiplier as it directly affects final expenditures and affects long-term potential output through higher capital stock (although without a direct impact on technological progress).

Over the medium to long term, macroeconomic impacts across simulation assumptions start to diverge. In general, freezing monetary policy results in the biggest GDP impact, which seems intuitive. Backward simulations yield the largest GDP impact for transfers, whatever the horizon. By contrast, for income taxes and government investment, only one year after the shock, the impacts become lower than those under rational expectations. Over the 2050 horizon, GDP impacts are always negative for transfers and income tax shocks when monetary policy is left active. Inflation effects are less clear in the short term depending on the types of expectations assumed. Though in general positive, inflation impacts are sometimes negative in forward-looking mode.

This analysis highlights the relatively high sensitivity of results depending on the assumptions made regarding expectations and monetary policy, especially in the medium to long term. In general, the positive impacts of fiscal shocks tend to fade over time and even sometimes become reversed over longer horizons due to monetary policy reaction. However, given the nature of the climate-related scenarios considered, i.e. an accumulation of supply and demand shocks, which may sometimes be very inflationary given the level of carbon taxes considered, it seems unrealistic to freeze monetary policy reaction under the transition scenarios. This calls for further research on the optimal monetary policy reaction during climate transition shocks, which is beyond the scope of this paper.

3.2 Euro area impact across alternative fiscal revenue recycling options

Four different options are considered to recycle carbon tax revenues. To correctly differentiate the impact of recycling choices, we assume in this sensitivity analysis that, for each variant, 100% of carbon tax revenues are used to finance each of the four fiscal policy choices:

- an increase in public investment;
- a cut in household income taxes;
- an increase in transfers to households;
- the reimbursement of public debt.

The policy conditionality for the simulations follows the option of an exogenous energy sector, as presented above. In particular, NiGEM is used assuming rational expectations and endogenous monetary policy. Moreover, solvency rules are activated except for public debt, which implies that the debt-to-GDP ratio may permanently deviate from its initial position.

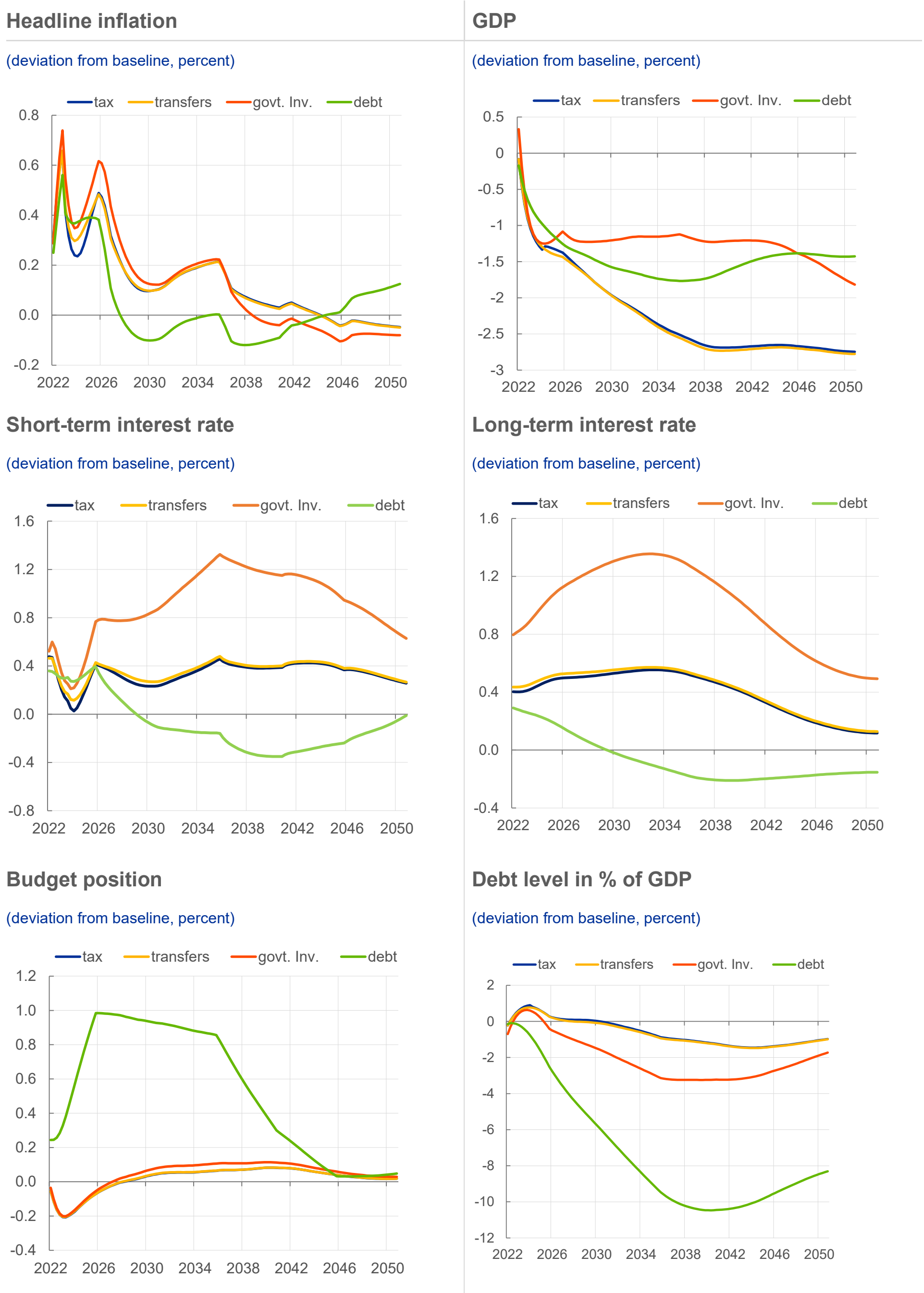
Recycling through household transfers or reduced income taxes has the most adverse impact on growth, while recycling through public investment yields the largest fiscal multiplier in the medium term. Chart 10 shows the sensitivity of the net-zero 2050 scenario to fiscal policy options for key macroeconomic variables. The results shown focus on the euro area (a comparison across the euro area is presented in Section 3.3). Overall, in the very short term (first two years of the scenario), we notice relatively limited differences across recycling options. The scenario yields negative effects on activity (GDP decreases by between -1% and -1.3% after 2 years) since neither type of fiscal stimulus is enough to compensate for the negative impact of the carbon tax and of the physical shock on GDP (see Chart 7 previously for an illustration of the contributions of the shocks to the overall GDP impact). The recycling options only become more discriminant in terms of GDP impact in the medium term, where full recycling through government investment, having the largest output multiplier, yields the least negative impact on euro GDP for the overall scenario (-1.2% after 10 years compared with around -2.1% for household transfers and income taxes). Recycling through household transfers or reduced income taxes produces the most adverse impact, having the lowest multiplier in the model.

The inflationary pattern is less discriminant across recycling options and is mostly explained by the monetary policy reaction. The inflationary impact of the scenario is strongest in the short term and slightly greater in the case of government investment. Euro area inflation increases by 0.7 percentage points after one year in the case of public investment compared with around 0.6 percentage points in the case of transfers or taxes. Headline inflation then converges gradually to the baseline after six to seven years, staying between 0.1 and 0.2 percentage points above between 2028 and 2038 before a more or less total absorption of the shock. This is mostly due to the increase in short rates, which is stronger in the case of government investment (up to 130 basis points in the middle of the horizon) compared with the transfer and tax recycling options (up to 50 basis points). Moreover, the policy stance remains relatively tight until the end of the horizon (except for the recycling-through-debt option, where there is less need for policy intervention). The pattern observed on long rates is very similar to that on short rates, since in the forward-looking mode, NiGEM simulates long-term rates as a forward convolution of short rates.

The choice of recycling options seems neutral for the budget position even in the short term, except for the debt reduction option. All options first deteriorate the government balance by around -0.2 points of GDP a year after the shock, then become more or less neutral on the budget due to the activation of the solvency rule. It is worth mentioning that the impact on the budget results both from the exogenous shock based on carbon tax revenue recycling options and from the endogenous model reaction from the deteriorating economic environment following transition shocks (automatic stabilisers).

Chart 10

Implications of alternative fiscal revenue recycling options for the euro area



Sources: NGFS, NiGEM and ECB calculations.
Notes: The results are reported in deviation from a baseline scenario, which is a combination of the NiGEM v1.22 and IAM starting values for GDP and population. It also includes IAM current policy projections for energy. No transition or physical climate risks are included in this baseline forecast. No fiscal: reference shock – carbon price only; GI: recycling through public investment; Tax: recycling through income taxes; Transfers: recycling through transfers; Debt: paying off of debt.

4 Sensitivity to monetary policy assumptions

As in the previous section, we analyse sensitivity to monetary policy settings for the Phase III shocks under the more stringent 1.5°C net-zero scenario in comparison with a delayed scenario. The sensitivity analysis considers three alternative monetary policy interest rate rules under each scenario. The standard two-pillar rule is compared with the Taylor rule and price level targeting.

4.1 Monetary policy rules: specification design

The monetary policy authority in the model operates predominantly through the setting of the short-term nominal interest rate. This is done with reference to simple policy feedback rules that depend on targets such as inflation, the output gap, the price level and/or nominal output. The interest rate reaction function responds to "gaps" between observed and target values of inflation, etc. The target values are set to the baseline values of the relevant variable, so that a shock producing a deviation in GDP, inflation or the price level from baseline values will initiate an endogenous reaction in interest rates, depending on the rule selected. All rules include a lagged interest rate, which allows for a degree of inertia in interest rate setting. In the following we present the three different interest rate reaction functions in turn.

The two-pillar monetary policy rule targets both nominal GDP and inflation, and the policy rate reacts to deviations from either of the targets. The two-pillar strategy sets the short-term interest rate as a function of the ratio of the nominal GDP target to nominal GDP and the difference between inflation expectations and the inflation target. This policy brings current nominal GDP back to its target level.

$$INT_t = \gamma * INT_{t-1} + (1-\gamma) * \left[\alpha * ln\left(\frac{NOMT_t}{NOM_t}\right) + \beta * (INFL_{t+i} - INFTS_{t+i})\right]$$

INT: nominal short-term rate
NOM: nominal GDP, defined with the GDP deflator by default
NOMT: nominal GDP target
INFL: expected inflation, defined with the consumer expenditure deflator
INFTS: inflation target

The Taylor rule varies short-term interest rates in order to respond to variations in output gap and inflation:

$$INT_t = \gamma * INT_{t-1}(1-\gamma) * \left[\alpha + \beta\,(INFL_{t+1} - INFTS^*_{t+1}) + \delta * ln\left(\frac{GDP}{GDPcap}\right)_t\right]$$

GDP : GDP
GDPcap: trend output for capacity utilisation

Following the price level-targeting approach, interest rates are set in response to variations in price level and inflation targets:

$$INT_t = \gamma * INT_{t-1} + (1-\gamma) * \left[\alpha * ln\left({}^{CED}/_{CED^*}\right)_t + \beta\, (INFL_{t+1} - INFL^*_{t+1})\right]$$

CED: consumer expenditure deflator
CED:* consumer expenditure deflator target

4.2 Euro area impact across various monetary policy rules

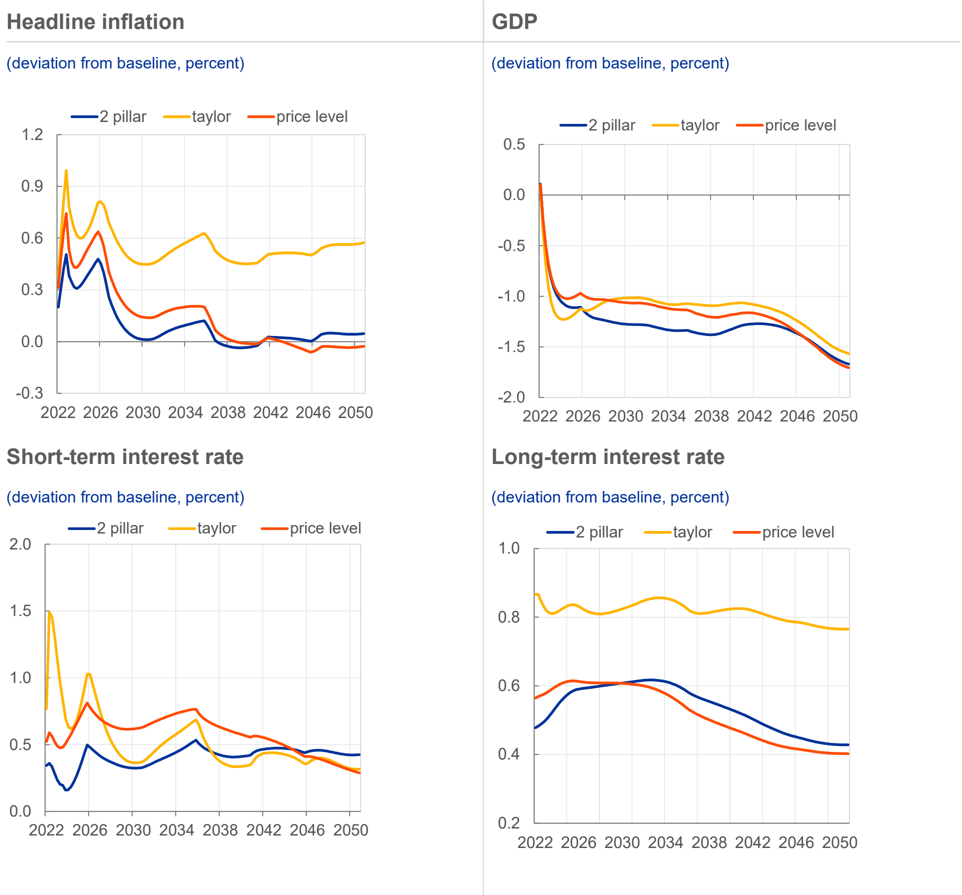
Comparing the net-zero scenario with the delayed scenario clearly shows that costs are higher in terms of GDP growth decline if transition policies are delayed, whereas inflation abates after an initial rise back to its baseline level, with the exception of the Taylor rule. The monetary policy rule implies interest rate changes to counteract the economic impact from physical shocks and transition shocks, such as higher carbon prices, as well as from the fiscal intervention of carbon tax revenue recycling. NiGEM allows users to experiment with different types of expectation formation in a range of markets. Rational expectations are assumed by default in simulations for monetary policy rules and financial markets, including exchange rates, long-term interest rates and equity prices. Wage bargains are also assumed to be settled based on a country-specific degree of rational expectations. By default, consumers are assumed to be myopic, as the evidence of forward-looking behaviour is less clear, but react to changes in their forward-looking financial wealth. The housing market is also treated as adaptive by default. However, users can modify the defaults to run any scenario with forward-looking or adaptive expectations in any of these markets.

Under the net-zero scenario, differences in GDP growth for the different monetary policy reaction functions remain marginal overall, but inflation can remain persistently higher if the Taylor rule is applied. Chart 12 shows the implications of alternative monetary policy rules for the euro area under the net-zero scenario. In the net-zero transition euro area economy, GDP growth declines and remains permanently below the baseline by around 1 to 1.7 percent. In Phase III, this result is driven by greatly reduced productive capacity on the supply side (K&W 2020 estimates) on top of overall lower domestic demand, regardless of the monetary policy rule in place. Headline inflation rises in the short term, mostly due to higher energy costs following the implementation of carbon prices, counteracted by lower demand. Over time, inflation tends to return to prior trends, with the exception of the Taylor rule. In fact, the impact on inflation and GDP growth is strongest for the Taylor rule, leading to the strongest short-term interest reaction, almost three times the reaction of price targeting. As the long-term interest rate in NiGEM is the convolution of expected short-term interest rates, the long-term rate remains at a higher level after an initial jump in short-term interest rates.

In the medium to long run, real macroeconomic outcomes display similar dynamics and converge to similar levels regardless of the monetary policy rule applied, with the exception that inflation settles at a persistently higher level when the Taylor rule is applied. The Taylor rule suggests raising short-term interest rates when inflation is above the target and the output gap is positive. As the climate shocks replicated with productivity shocks significantly reduce productive capacity and thus the potential output, they create a positive output gap such that monetary policy reacts more strongly in addition to higher inflation.

Chart 12

Implications of alternative monetary policy rules for the euro area under the net-zero scenario

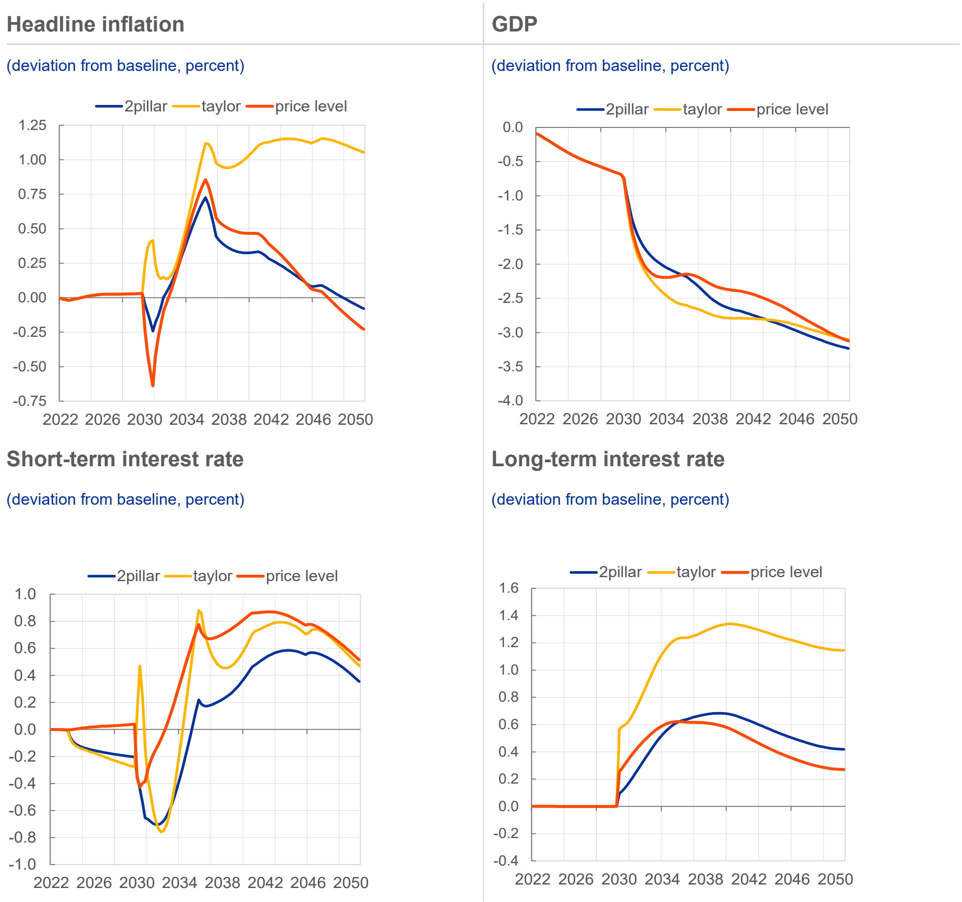


Sources: NGFS, NiGEM and ECB calculations.

Under the delayed scenario, the resulting macroeconomic impacts are much more pronounced compared with the net-zero scenario. Chart 13 shows the implications of alternative monetary policy rules under the delayed scenario. The overall patterns across the policy rules are amplified if preserved as under the net-zero scenario. For instance, GDP drops more suddenly and drastically as soon as transition policies are implemented. By contrast, inflation drops initially as much lower demand effects induced by carbon prices outweigh the feed-through of higher energy costs. Subsequently, it picks up as the impact reverses, but it tends to revert to the baseline level quickly. Short-term interest rates decline in reaction to lower inflation, with the exception of the Taylor rule. Over time, the short-term interest rates under the Taylor rule settle at around the same level as under the other rules. As a distinct feature for the Taylor rule, which reacts to the large changes in the output gap more sensitively, inflation and long-term interest rates end up permanently higher relative to the baseline.

Chart 13

Implications of alternative monetary policy rules for the euro area under the delayed scenario



Sources: NGFS, NiGEM and ECB calculations.

5 Conclusion and areas for future development

The NGFS scenarios have become an increasingly accessible tool to help policymakers, central banks and private institutions assess the costs and opportunities of a green transition. As confirmed by the FSB-NGFS report and the recent NGFS general feedback survey, a wide range of users have adopted the NGFS scenarios rather than alternative models to inform their business strategy, monitor financial risks and guide policy decisions. The NGFS feedback survey also recorded widespread satisfaction with the macroeconomic modelling of climate risks combined with the transition and physical risk modules, the scenarios and narratives explored as well as the geographical coverage of the NGFS scenarios. These three features underline the strength of the NGFS framework as an available public good for analysing climate risks and their impact on the economy and financial system.

At the same time, the user community has identified important areas of improvement where further work is needed to increase the usability and range of applications of the NGFS framework. Respondents to the NGFS general feedback survey identified three clear priorities to improve the scenarios at the technical level: (a) increase sectoral and geographical granularity, (b) introduce short-term scenarios, and (c) better represent acute physical risk. Furthermore, the survey highlighted three common obstacles in terms of usability of the NGFS scenarios: (a) understanding the underlying model assumptions and levels of uncertainty, (b) finding guidance on how to apply the NGFS scenarios and translate them into financial risk metrics, and (c) accessing the relevant data and identifying key outputs.

To account for users' feedback and better support them going forward, the NGFS has developed a multi-year work program centred around a few strategic priorities. First, the NGFS scenarios will be updated to account for changes in the broad geopolitical and climate policy situation, including the war in Ukraine and lock-in of fossil fuel technologies in many jurisdictions. The scenario framework will also be expanded to explore possible adverse disruptions in both transition and physical risk terms coming from lack of policy coordination and decreased net-zero ambitions, which could result in a too-little-too-late scenario. Second, the physical risk modelling will be enhanced further to account for more physical hazards, to produce specific country-hazard impacts on countries' GDP and to better align the modelling between transition and physical risk as well as their interactions. These developments should limit the current underestimation of the impacts of unfettered climate change and support further ambition actions to limit global warming.

Importantly, the NGFS long-term scenarios developed so far will be complemented by short-term scenarios to capture the implications of transition policies and natural disasters in the near future. The short-term scenarios will jointly analyse climate change mitigation stringency and related business cycle shocks, based on a set of possible narratives that can range from a strong introduction of climate policies with consequent turmoil in financial markets to climate policy divergence and bottlenecks in the trade of critical minerals. These shocks would then be translated into demand-side and supply-side impacts, with final implications for key macro-financial indicators.

The fourth strategic priority relates to the improvement of NGFS scenarios' sectoral granularity, which is expected to be enhanced within the suite-of-models approach developed so far rather than via alternative models. Especially in consideration of the increased model complexity and the divergency of results across different modelling approaches (see, for example, G-Cubed), it has been deemed useful to improve the sectoral granularity of the macro-financial output at the IAM and NiGEM levels. The fifth and final strategic priority refers to improving communication and engagement with NGFS scenario users and stakeholders to ensure the NGFS scenarios remain a global public good.

The NGFS scenarios and their future development will remain an important tool to continue and operationalise the Eurosystem action plan to include climate change considerations in its monetary policy strategy. As published in July 2021, the ECB's Governing Council is strongly committed to expanding its analytical capacity in macroeconomic modelling, statistics and monetary policy with regard to climate change. To this end, it has decided on a comprehensive action plan with an ambitious roadmap to further incorporate climate change considerations into its policy framework. In particular, the ECB will accelerate the development of new models and will conduct theoretical and empirical analyses to monitor the implications of climate change and related policies for the economy, the financial system and the transmission of monetary policy through financial markets and the banking system to households and firms.

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Matthieu Darracq Pariès
European Central Bank, Frankfurt am Main, Germany, email: matthieu.darracq_paries@ecb.europa.eu

Stéphane Dées
Banque de France, Paris, France, email: Stephane.DEES@banque-france.fr

Annabelle De Gaye
Banque de France, Paris, France, email: Annabelle.DEGAYE@banque-france.fr

Laura Parisi
European Central Bank, Frankfurt am Main, Germany, email: laura.parisi@ecb.europa.eu

Yiqiao Sun
European Central Bank, Frankfurt am Main, Germany, email: yiqiao.sun@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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