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No 279, "The need for an inflation buffer in the ECB's price stability objective – the role of nominal rigidities and inflation differentials".
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Abstract

This paper analyses the implications of climate change for the conduct of monetary policy in the euro area. It first investigates macroeconomic and financial risks stemming from climate change and from policies aimed at climate mitigation and adaptation, as well as the regulatory and fiscal effects of reducing carbon emissions. In this context, it assesses the need to adapt macroeconomic models and the Eurosystem/ECB staff economic projections underlying the monetary policy decisions. It further considers the implications of climate change for the conduct of monetary policy, in particular the implications for the transmission of monetary policy, the natural rate of interest and the correct identification of shocks. Model simulations using the ECB's New Area-Wide Model (NAWM) illustrate how the interactions of climate change, financial and fiscal fragilities could significantly restrict the ability of monetary policy to respond to standard business cycle fluctuations. The paper concludes with an analysis of a set of potential monetary policy measures to address climate risks, insofar as they are in line with the ECB's mandate.

JEL classification: E52, E58, Q54.

Keywords: climate change, monetary policy, environmental economics, green finance, sustainable growth economics.

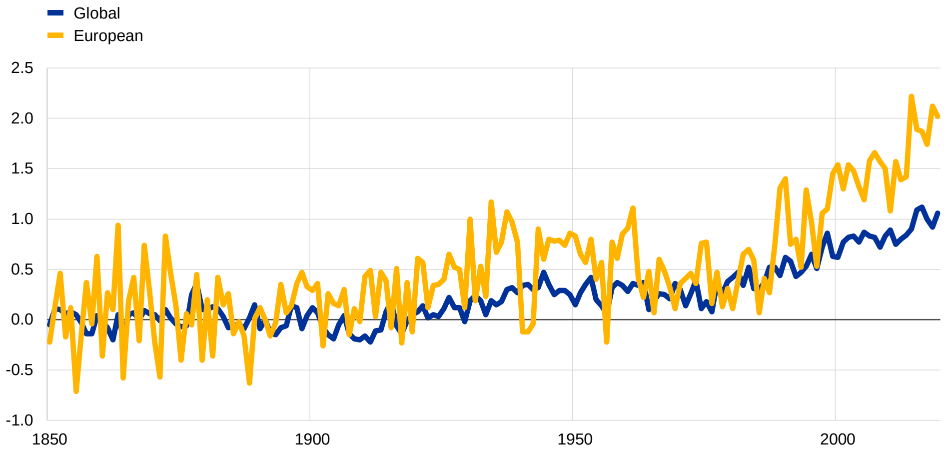
Executive summary

Climate change is one of the greatest challenges faced by humankind this century, as illustrated by measurements of global warming and the frequency of extreme weather events. European mean near-surface temperatures over the past decade (2010-19) were 1.7-1.9°C higher than pre-industrial levels, compared with a rise of around 1°C across the globe (Chart 1). 2020 was the warmest year on record in Europe.[1] The number of disasters caused by natural hazards is increasing, with extreme natural events more than doubling globally since the 1980s.[2] Climate change science attributes most of this global warming and the increased frequency of weather events to emissions of greenhouse gases (GHG) associated with human activity (Intergovernmental Panel on Climate Change (IPCC), 2014, 2018 and 2021).

Chart 1

Global and European temperatures

(degrees Celsius difference compared with pre-industrial levels)



Sources: Annual Global (Land and Ocean) temperature anomalies – HadCRUT (degrees Celsius) provided by Met Office Hadley Centre observations datasets.
Notes: Temperature anomalies are shown compared with the pre-industrial period between 1850 and 1899. The latest observation is for 2019.

The 2015 Paris Agreement marked a significant milestone in the international response to the challenge of climate change. The signatories agreed to keep the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit this increase to 1.5°C. In order to reach that target, net carbon emissions need to fall to zero by around the middle of the 21st century.[3] EU countries have jointly pledged to meet that emission target and were joined by China, Korea and Japan in the latter part of 2020, as well as by the United States and Canada in May 2021. The legislative agenda of the European Union (EU) to support the green transition is gathering momentum.

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1 See Copernicus Climate Change Service.

2 See Munich Re.

3 See IPCC (2018).

Climate change is a clear and present danger for the global economy. It differs from other risks because of its irreversible nature and the risk of non-linearities and tipping points. While subject to reasonable uncertainty, most projections confirm that there remains little time and a relatively restricted carbon budget if the Paris Agreement goals are to be met.[4] Developments to date, combined with future developments in climate and policy measures needed to combat climate change, have led to broad implications for the conduct of monetary policy across several areas of central banking.

This paper focuses on the implications of climate change for the Eurosystem's monetary policy. It studies the impact on inflation, economic activity, financial institutions and markets. These effects pose several challenges for the conduct of monetary policy, including the assessment of the appropriate monetary policy stance. The paper also considers the impact of climate change on financial risk in the Eurosystem's balance sheet and the incorporation of climate change considerations into the Eurosystem's monetary policy implementation framework, within the scope of the ECB's mandate.

Macroeconomic and financial implications of climate change

Climate change affects macroeconomic outcomes, financial markets and institutions primarily through two channels: physical risk and transition risk. Chapter 1 focuses on climate-related physical risks and their short- and long-term macroeconomic impact for the euro area. Physical risks arise from the interaction between higher average temperatures, more frequent weather extremes and the exposure and vulnerability of society and economic systems to these hazards. Physical risks can be divided into two categories: (i) gradual global warming and its associated physical changes, such as rising sea levels or changes in precipitation patterns; and (ii) natural disasters such as hurricanes, floods and heatwaves.

The projected economic loss arising from the physical risk of climate change for European countries varies significantly, depending on the study and the time horizon. Most empirical estimates indicate that climate change will likely have a limited impact on the European economy over the next few decades. The probability distribution of risks observed in historical data may, however, be a poor indication of what the future holds due to non-linearities and given that technologies and institutions evolve over time. Scenario analyses that calibrate the economic effects of climate change for alternative GHG concentration trajectories tend to find comparatively larger negative effects on the level of global GDP, particularly during the second half of this century. Table 1 summarises the channels through which climate risks could affect the European economy.

[4] See IPCC (2014).

Table 1

Possible channels of impact of climate change on the European economy

		Gradual warming	Extreme events	Transition risks
Supply shocks	**Labour supply**	Loss of hours worked due to extreme temperatures. Increased international migration.	Destruction of workplaces, need to migrate (even if temporarily).	Changes in sectoral composition of labour market could lead to higher structural unemployment.
	Food, energy and other input supply	Decline in agriculture productivity and yields.	Disruption to transport and production chains.	
	Capital stock	Diversion of resources from productive investment to adaptation capital.	Destruction due to extreme events.	Rise in stranded assets.
	Technology	Diversion of resources to reconstruction activity.	Diversion of resources to reconstruction activity.	Climate policies as a potential driver of innovation.
	Productivity	Lower labour productivity due to extreme heatwaves and lower human capital accumulation (increased health issues and mortality).	Lower capital productivity due to (possibly permanent) capital and infrastructure destruction.	Uncertain effect on productivity, as technological progress could offset underinvestment resulting from transition policies.
Demand shocks	**Energy demand**	Increased demand for electricity in summer exceeds decreased demand in winter. Policy-induced shift to renewable energy reduces demand for fossil fuels.		Higher carbon tax leading to lower demand for fossil fuels.
	Investment	Change in preferences towards more sustainable goods and services.	Uncertainty about climate events could delay investment. Investment in reconstruction increases following events.	Shift in the mix of activity towards more investment (in climate mitigation technologies) Uncertainty about climate policy may reduce investment
	Consumption	Change in preferences towards more sustainable goods and services.	If no insurance of households or firms, destruction could cause a permanent decrease in wealth and affect consumption.	Increased sustainability awareness and shift toward greener consumption.
	Trade	Disruption to trade routes due to geophysical changes (such as rising sea levels).	Change in food prices and disruption to trade flows.	Taxes, regulations and restrictions could unsettle trade routes. Risks of distortion from asymmetric or unilateral climate policies.
Aggregate impact on output and nominal variables	**Output**	Lower labour productivity, investment being diverted to mitigation and arable land loss.	Physical destruction (crop failures, destruction of facilities and infrastructure, disruption of supply chains).	Frictions resulting from distortive (fiscal) transition policies and/or (fiscal) transition policy uncertainty. Mitigated impact depends on the use of proceeds from (fiscal) transition policies.
	Wages	Downward pressures on wages from lower productivity.	Unequal effects across sectors and economies.	Unequal effects across sectors and economies (reallocation of workers from one sector to another, increased training needs).
	Inflation	Relative price changes due to shifting consumer demand or preferences and changes in comparative cost advantages.	Increased inflation volatility, particularly in food, housing and energy prices.	Prices affected by climate-related transition policies, policy uncertainty, technological changes and shifts in consumer preferences.
	Inflation expectations	Climate-related shocks, e.g. to food and energy prices, could affect inflation expectations.	Inducing more homogenous, sudden and frequent revisions to expectations.	Formation of inflation expectations affected by policies.

Sources: Adapted from Batten (2018) and the Network for Greening the Financial System (2020a).

Both empirical and theoretical studies suggest that economic losses will increase in the long term and be unevenly distributed across regions,

industries and parts of the population. Negative effects are expected to be substantially greater in southern Europe than in northern Europe. As for inflation, studies find that climate change, including the increased frequency of natural disasters, has thus far had a limited aggregate impact on advanced countries, albeit this in part reflects offsetting movements in food prices and core inflation.

The European Union has set concrete targets for the reduction in GHG emissions in line with the Paris Agreement to limit the rise in global temperature to 1.5°C. The EU has committed to reducing GHG emissions by 20% in 2020 and 55% in 2030, compared with 1990 levels. By 2050, the EU aims to achieve carbon neutrality, i.e. reduce GHG emissions to net zero. Looking ahead, tremendous policy efforts are required to achieve these targets (see, for example, European Environment Agency, 2019). Chapter 2 analyses the risks for euro area countries arising from such transition policies.

EU countries have adopted a wide range of policy instruments to support the transition to a low-carbon economy. At the European Union level, the cornerstone of climate policy is the EU Emissions Trading System (EU ETS), a "cap-and-trade" scheme which applies to roughly 50% of GDP. This is complemented by the "effort-sharing" scheme with binding national emission targets for the non-ETS sectors. The European Green Deal will increase funding for the transition through the EU budget and associated instruments (such as Next Generation EU); it aims to create a framework to facilitate sustainable investments by private investors and the public sector. Furthermore, the transition to a low-carbon economy will also need to be supported by regulatory interventions, mostly initiated at the EU level, which will restrict GHG emissions for specific products, sectors or activities.

Appropriate carbon pricing, including by various emissions trading schemes, is widely seen to be key to any successful transition strategy. A predictable path to a higher carbon price promotes a shift to lower-carbon power generation, spurs investment in green technologies and infrastructure and is considered an effective instrument to promote innovation in clean technologies. Adequate carbon pricing also reduces the risk of the green transition being accompanied by excessive investment in the wrong sectors and the accumulation of bad debt. Carbon pricing could generate significant fiscal revenues that could be used to reduce more distortionary taxes and support the groups most vulnerable to the transition. However, current carbon pricing appears far too low to achieve climate neutrality. Based on a benchmark of 60 euro per tonne of CO2 emissions, euro area economy-wide carbon prices would need to be more than double and applied more broadly across sectors (Chart 2).[5]

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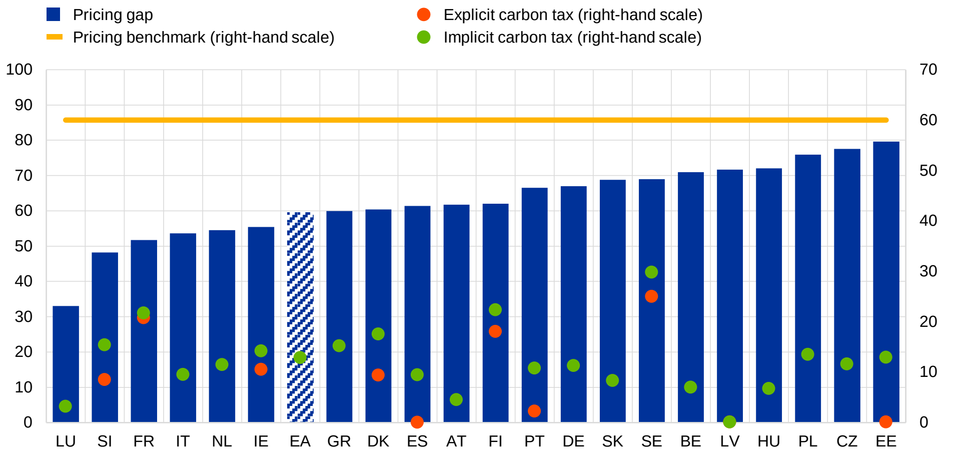
5 The OECD considers the appropriate carbon price to be around 60 EUR/tCO2, a view largely supported by the IMF (2019).

Chart 2

Carbon taxes and the pricing gap

(percentage deviation from the benchmark; EUR/tCO2, 2018)



Sources: OECD, European Energy Exchange and own calculations.
Notes: The chart shows the average explicit carbon tax (defined as carbon taxes where statutory rates are expressed in common commercial units or per unit of CO2 emissions) for 2018 (red dots), including for countries where a part of fossil fuel taxes is explicitly linked to CO2 emissions. The average implicit carbon tax (green dots) is the explicit carbon tax plus the EU ETS carbon pricing. The carbon pricing gap (blue bars) is measured as the difference between the actual effective carbon rate for every percentile of emissions and a benchmark price for which the OECD benchmark value of 60 EUR/tCO2 (yellow line) is used. A high carbon pricing gap indicates that the distribution of carbon-taxed emissions is strongly skewed towards a few sub-sectors. The carbon pricing gap for the euro area is replicated using a similar, although less granular, approach. No data are available for Lithuania. While the carbon pricing gap incorporates the EU ETS, it is based on data from before the introduction of the Market Stability Reserve.

Carbon pricing might also incorporate carbon border adjustments or an international carbon price floor. Carbon border adjustment would avoid an increase in emissions outside the EU due to higher carbon prices in the EU ("emissions leakage"). It may, however, raise several practical issues (e.g. related to the measurement of carbon in traded goods) and be politically contentious. An alternative way to reduce leakage and bring down global emissions is to introduce an international carbon price floor, at least for the largest emitting economies. Nordhaus (2015) argues that a regime with small trade penalties on non-participants – a "climate club" – could induce a large stable coalition with high levels of abatement.

Complementary structural policies play an important role in supporting the transition to a climate-neutral economy. Carbon taxes alone will contribute to the displacement of old technologies before green technological alternatives are available. The reallocation of resources from high- to low-carbon activities also requires flexible and adaptable labour and product markets, as well as efficient financial markets to support the shift away from fossil fuel energy and related physical capital to low-carbon products and production processes. In addition, efficient frameworks, such as good conditions for research, the adoption of new skills in the labour force and a favourable environment for the propagation of new technologies, including through R&D subsidies, will facilitate the structural change required to put green production practices in place. Efficient framework conditions could also help to achieve global climate targets by promoting exports of new technology (Acemoglu et al., 2012; Schnabel, 2020).

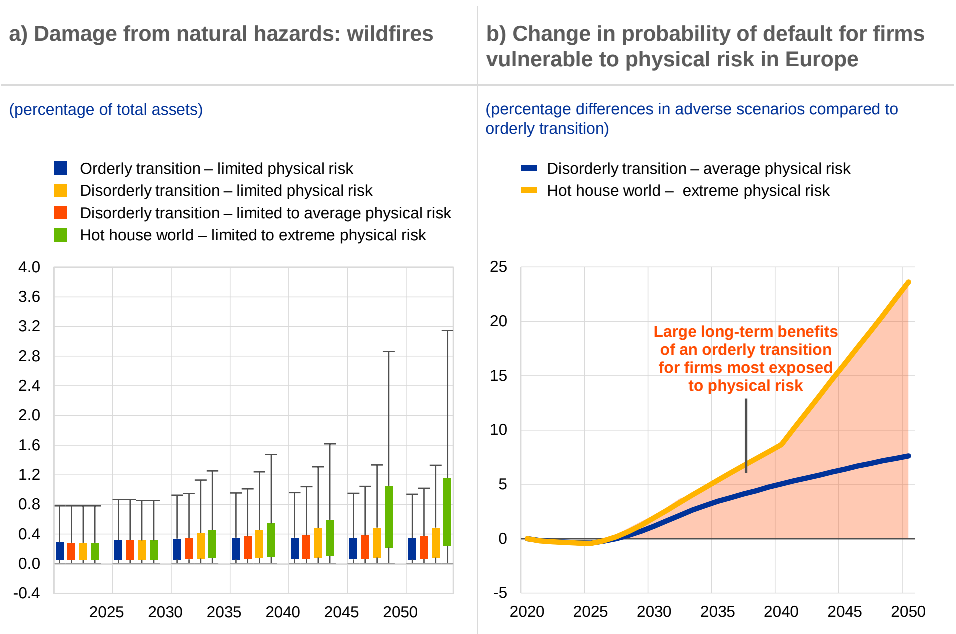
The transition towards a low-carbon economy could potentially cause large swings in asset prices and generate substantial volumes of stranded assets

(Chapter 4). Stranded assets can arise from policies put in place to penalise carbon use, from shifts in investor and consumer preferences, and from new technologies that render older technologies obsolete. Stress tests presented in this paper suggest that although asset and capital losses could be significant in scenarios involving a disorderly transition, they would remain more manageable should the transition take place earlier and in an orderly fashion.

Financial stability risks could arise from firms that are highly exposed to physical risk, as the ECB has demonstrated in its ongoing economy-wide climate stress test. The degree of exposure to extreme weather events is highly dependent on where a firm is located, but around 16% of European enterprises in the sample have at least a 1% probability of being affected by wildfires, sea level rises or river floods. Vulnerable firms are expected to sustain yearly damages from natural catastrophes of up to 3% of their total assets in the hot house world (HHW) scenario where the transition does not take place. Wildfires exhibit the highest destructive potential (Chart 3, panel a). The impact of physical risk outweighs that of transition costs, with probabilities of default in the HHW scenario rising higher than in the orderly or disorderly transition scenarios (Chart 3, panel b). For these exposed firms, the mitigating impact on physical risk of a transition to a carbon-neutral economy is particularly beneficial.

Chart 3

Expected losses from wildfires and change in probability of default for firms vulnerable to physical risk in Europe



Sources: Four Twenty Seven, Inc. (427), Orbis and ECB staff calculations (panel a) and ECB staff calculations (panel b).
Notes: Panel a: the ECB's economy-wide climate stress test estimates the one-year probability of default over a horizon of 30 years. The estimation methods follow a standard Altman Z-score, where probabilities of default are a function of corporate profitability and leverage. Profitability and leverage are shocked via a multitude of macroeconomic, supply and demand side microeconomic climate drivers (e.g. carbon prices, energy efficiency), as well as climate mitigants and amplifiers (insurance coverage and risk premia). Climate-related financial shocks are obtained using ECB calculations on NGFS scenarios.

Environmental externalities of economic activities may not be adequately priced into financial markets. Too low a carbon price, insufficient disclosures of climate-risk exposures and the lack of widespread certification of green activity remain marked impediments to efficient market pricing. Information on the sustainability of financial assets – where available – is inconsistent, incomplete, largely incomparable and at times unreliable. Research into whether transition risk is reflected in prices remains inconclusive, although there are signs of differential pricing since the Paris Agreement at the end of 2015. In general, banks appear to have been slower at pricing climate risks than institutional investors.

Emerging evidence suggests that the financial structure can affect the speed at which the economy decarbonises. Equity markets play an important role in supporting innovation. While banks may hesitate to finance green innovation without proper incentives, they can play a key role in supporting the widespread adoption of new green technology. The evidence on the extent to which green bonds have contributed to meaningful decarbonisation is scant and mixed, in part reflecting the relative immaturity of the market.

Overall, the Eurosystem needs to gain a better understanding of the impact of climate change on the macro economy and the cost of inadequate policy. As outlined in Chapter 3, a disconnect still exists between climate-specific models and central bank macroeconometric models. The climate-specific models that are currently used or integrated in economic frameworks are rich in terms of sources of climate-related risks but tend to represent the economy in a highly simplified way. Conversely, the macroeconometric models used by central banks incorporate a great deal of sectoral detail on the economy but lack climate-related forces and are operated to generate projections over horizons that are shorter than those relevant for climate analysis. In order to better capture the risks from climate change, the production structure in such models would need to account for an explicit role of the energy sector and for specific climate change policies. Moreover, models would need to deal with various sources of heterogeneity, including geographical, sectoral and household types, and would gain from incorporating more realistic expectation-formation processes than the model-consistent rational expectations that are still standard at present. A better understanding of climate risk will also require additional statistical data, including on relevant green financial instruments, the carbon footprint of financial institutions and their exposures to climate-related physical risk.

Implications of climate change for the conduct of monetary policy

Macroeconomic and financial market disruptions linked to climate change and transition policies could affect the conduct of monetary policy and the ability of the ECB to deliver on its price stability mandate through various channels. These are described in more detail in Chapter 5.

Depending on the nature and speed of the transition policy, climate risks may affect the transmission of monetary policy through financial markets and the banking sector. This happens notably via the stranding of assets and a sudden repricing of climate-related financial risk. If the financial system is weakened, the transmission of monetary policy may be impaired. The main transmission channels of monetary policy are listed in the first column of Table 2. They comprise the interest rate channel, the credit channel, which functions via bank and non-bank lending, the asset price channel, the exchange rate channel and the expectations channel. In the near future, these channels could all be increasingly exposed to climate-related risks. The discussion in Chapter 5 distinguishes between the possible impact of physical and transition risks, while only providing notional and preliminary indications given the high uncertainty about the timing, severity and trade-offs among risks.

Table 2

Monetary policy transmission: effects of climate change

	Physical risk from more common extreme weather events and persistent warming	**Transition risk** from carbon pricing and reducing emissions
Interest rate channel	Non-interest cost factors become more relevant, lowering investment and saving response to interest rate changes.	Uncertainty about timing and speed of policy response raises risk premia and volatility. Natural rate of interest affected.
Credit channel	Financial losses reduce borrower net worth, bank collateral and profitability. Non-performing loans constrain credit supply. Uncertainty reduces market funding of banks.	Financial losses reduce borrower net worth, bank collateral and profitability. Non-performing loans constrain credit supply. Uncertainty reduces market funding of banks.
Asset price channel	Physical risks destroy capital and residential property. Financial losses lower firm valuations.	Demand shifts across sectors and regions. Stranded assets.
Exchange rate channel	Devaluation incentive for short-term competitiveness gain. Higher volatility.	Carbon border adjustment may disrupt trade routes and global value chains.
Expectations channel	Monetary policy less predictable since shock persistence uncertain, blurring supply/demand.	Time-inconsistent transition policies reduce monetary policy credibility and effectiveness of forward guidance.

Several risks related to climate change may imply a dampening force on the natural rate of interest. This comes on top of the factors that have already driven its secular decline over the past few decades. At the same time, higher demand for investment for adaptation and reconstruction purposes may push up *r**, all else equal. An increase in productivity related to innovation may also exert an upward impact on the natural rate of interest. The net effect of these two opposing forces is uncertain ex ante. However, should the forces dampening the natural rate prevail, the policy rate could hit the effective lower bound (ELB) more often, limiting the monetary policy space for conventional tools.

Climate risks may further complicate the correct identification of shocks relevant for the medium-term inflation outlook. This would make it more difficult to assess the monetary policy stance and potentially increase the prevalence of output and price stabilisation trade-offs. Uncertainty about the magnitude of the effects of climate change and the horizon over which they will play out on the economy may compound these effects.

A model simulation using the ECB's New Area-Wide Model (NAWM) illustrates how physical and transition risks related to the climate could combine with financial fragilities. These themselves could be the result of the materialisation of climate risks, and could significantly restrict the ability of monetary policy to respond to standard business cycle fluctuations.

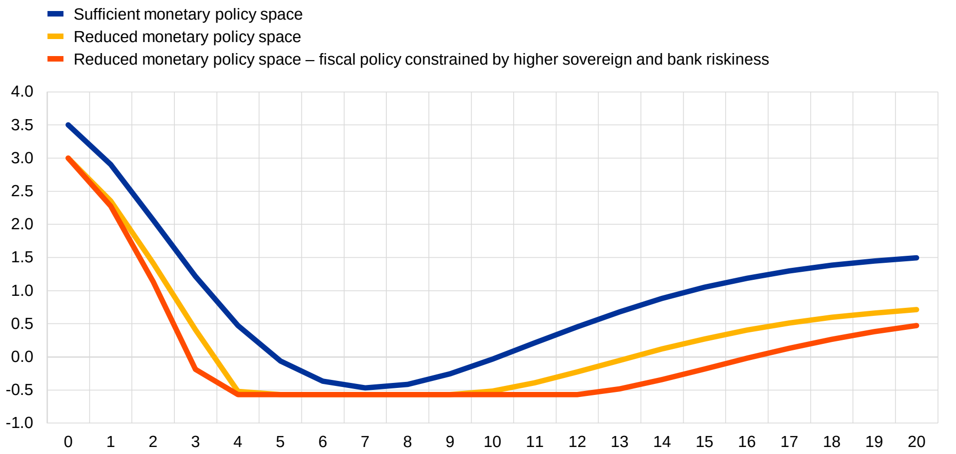
Three separate scenarios are considered.

The first looks at the challenges for monetary policy to control inflation under the changed conditions discussed above. There is a higher probability of hitting the ELB when responding to large standard demand shocks unrelated to climate change. As a result, the depth of the downturn in activity is magnified, and the time taken to return inflation to its target is increased (Chart 4).

Chart 4

Shrinking space for the monetary policy rate

(deviation from steady state, annual rate in percentage points)



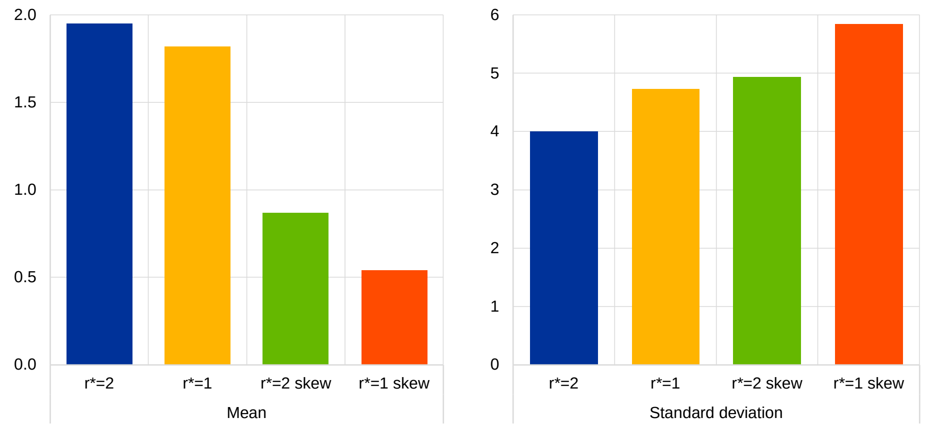
Source: ECB simulations based on the NAWM model.
Notes: The set-up is a negative demand (preference) shock hitting the economy under different assumptions for the available monetary policy space. Blue line: *r**=1.5%, low public debt, no cyclical stabilisation by fiscal policy. Yellow line: *r**=1%, low public debt, no cyclical stabilisation by fiscal policy. Red line: *r**=1%, fiscal policy constrained by active debt stabilisation + sovereign bank-nexus backlash from a highly sensitive sovereign bond default risk pricing. For the complete set of simulations, see Chapter 5.

In the second scenario, an assumed more frequent incidence of disasters caused by natural hazards – as climate change is likely to render extreme weather events more frequent and disruptive – leads to more frequent shocks. This in turn could expose the euro area and the global economy to greater volatility in output and prices. Even though these shocks are typically a combination of supply and demand shocks – such that the inferred impact on inflation is ambiguous in the short run – the simulations illustrate that the increased volatility can result in the ELB being hit more frequently, particularly if the equilibrium interest rate is also lower (Chart 5).

Chart 5

Climate-related shock volatility and inflation performance

(annual percentages)



Source: ECB simulations based on the NAWM model.
Notes: The chart depicts the mean and standard deviation of the steady-state probability distributions of annual HICP inflation obtained by carrying out stochastic simulations around the models' non-stochastic steady state under alternative values of the equilibrium annual real interest rate (*r**=2% and r*=1%), and where the annual short-term nominal rate is subject to an ELB of -60 basis points. For both *r** cases, the model is also simulated using disaster shocks, which are random combinations of negative demand, price mark-up and the permanent TFP shocks that occur with a frequency of 10%, making them, on average, more recessionary (marked with "skew" in the chart). For the complete set of simulations, see Chapter 5.

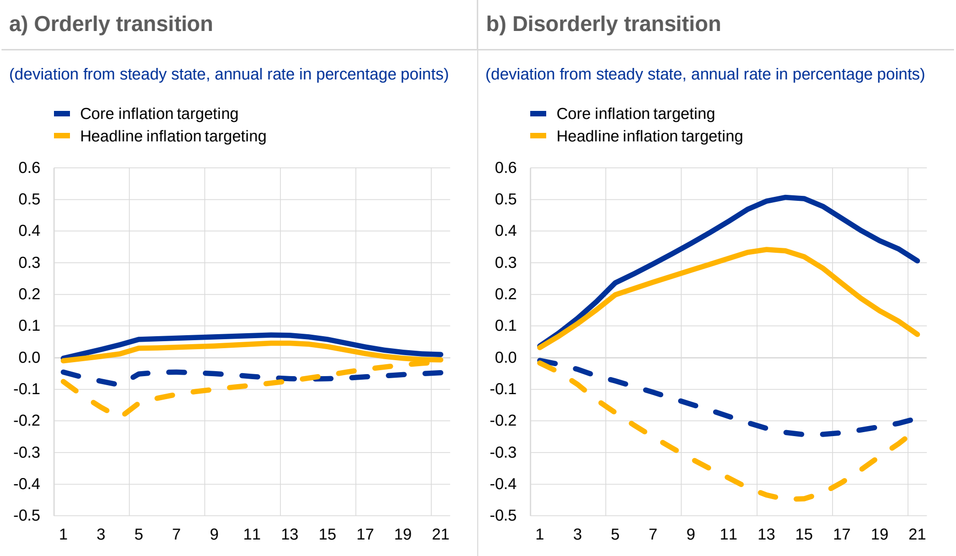
Third, the conduct of monetary policy may be affected at the business cycle frequency by the transition to a carbon-neutral economy, including through the implementation of policies and technological change (or its absence). The transition is likely to have substantial effects on economic and financial activities, relative prices and inflation, output growth and productivity, and hence on the optimal response of monetary policy, particularly if it occurs in a disorderly fashion.

Regardless of how the central bank reacts, the impact of an orderly transition is contained and poses little threat to the ability of the central bank to maintain price stability. In an orderly scenario, effective energy prices rise in a modest, but sustained fashion (3.5% per year). The policy is well-communicated – and anticipated by households and businesses. The impact on inflation and output growth depends on how the central bank reacts. Choosing to look through the impact of the relative price shift and target core inflation results in a limited impact on headline inflation and a slightly negative impact on output (Chart 6, panel a, blue lines). Targeting headline inflation results in a lower inflationary impact overall, at the expense of a greater negative impact on GDP (Chart 6, panel a, yellow lines).

By contrast, the impact of a disorderly transition is far more marked and presents the central bank with a difficult trade-off between inflation and output. In this scenario, the increase in energy prices is delayed, but then implemented suddenly, coming as a surprise to households and businesses (Chart 6, panel b). In this sudden scenario, energy prices rise by 13.5% per year. Headline inflation diverges from target for a prolonged period. If the central bank looks through the increase and targets core inflation, the impact reaches 0.5 percentage points by the fourth year. Conversely, targeting headline inflation results in a much greater reduction in GDP growth.

Chart 6

Impact of orderly and disorderly transition on inflation and GDP growth



Source: ECB simulations based on the scenarios in Allen et al. (2020).
Note: Headline inflation shown in solid lines, GDP growth in dashed lines.

These scenarios highlight how climate change risks make it necessary to carefully consider a number of design features of the ECB's monetary policy strategy. These considerations potentially include a greater emphasis on core inflation as a gauge of price pressures. A lengthening of the medium-term policy horizon could also be considered in order to take account of the impact of repeated and correlated transition shocks to price stability over several decades. At the same time, the credibility of the central bank may be compromised if the time horizon is extended too far into the future and inflation targets are missed too often. In this case, clear communication about the policy intentions of the central bank will be essential to mitigate credibility losses. That said, the challenges for monetary policy are expected to be contained if the transition is orderly and spread over decades. In addition, the medium-term formulation of the ECB monetary policy seems to equip the central bank with the requisite flexibility at the current juncture.

Moreover, if the forces dampening the natural rate prevail, the lower *r would reduce the policy space for conventional monetary policy and increase the probability of hitting the ELB, owing in part to less effective transmission.** Frequent deflationary shocks related to the materialisation of physical risk would increase the risk of reaching the ELB. This would strengthen the case for non-standard measures to become part of the ordinary monetary policy toolkit. The still limited knowledge of the possible effects and the long-term nature of climate change suggest that more precise indications regarding the impact for the strategy may only emerge over time.

The Eurosystem's mandate and climate-related actions

A number of issues need to be addressed when assessing whether the ECB can take action related to climate change in line with the its mandate under the Treaty on the Functioning of the European Union (TFEU) and the ESCB/ECB Statute.

Any action taken by the ECB must fall within the scope of its mandate, which sets the outer limits of its competences. In the area of monetary policy, these are defined by the "objectives" and "tasks" set out under Article 127 TFEU, as well as by the instruments used.[6] The ECB may take action if such action is covered by its primary objective of maintaining price stability or its secondary objective of supporting the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union. These include the objective of working towards the sustainable development of Europe based on a high level of protection and improvement of the quality of the environment.

If taking into account climate change considerations is considered necessary to maintain price stability, these considerations would fall within the remit of its primary objective. In this case, the ECB would be pursuing its primary objective of maintaining price stability rather than environmental objectives directly.

The ECB shall support the general economic policies in the Union with a view to contributing to the achievement of the Union's objectives. Pursuing the ECB's secondary objective is subject to certain limitations. First, this action must be without prejudice to the primary objective. Second, the ECB's mandate regarding the economic policies in the Union is to be supportive. This indicates that the ECB does not bear the primary responsibility for these policies and does not have the power to make policy autonomously.

A specific legal basis for ECB action may be found under Article 18.1 of the ESCB/ECB Statute, which requires the ECB and the NCBs to conduct credit operations with lending based on adequate collateral. If clear physical and transition risks related to climate change affect risks to collateral reflected in the Eurosystem's balance sheet, action taken by the ECB to mitigate these risks is within the remit of Article 18.1 of the ESCB/ECB Statute. As regards outright purchases, risk management considerations could lead the Eurosystem central banks to take similar measures with a view to protecting their balance sheets against potential losses.

In addition to the provisions of the treaties which set out the mandate of the ESCB, certain "horizontal" provisions are to be taken into account by all EU institutions – including the ECB – in their policies and activities.[7] The general provisions include the requirement under Article 11 TFEU to integrate environmental protection requirements into the definition and implementation of the Union's policies and activities, in particular with a view to promoting sustainable development. In

6 Case C-493/17, Weiss and Others, EU:C:2018:1000, para. 53; Case C-62/14, Gauweiler and Others, EU:C:2015:400, para. 46.

7 See Articles 8-13 TFEU.

addition, Article 7 TFEU requires the Union to ensure "consistency" between its policies and activities, taking all of its objectives into account and in accordance with the principle of conferral of powers. Articles 11 and 7 TFEU do not establish a legal basis for action, but rather duties with which it must comply in all policies and activities.

When taking into account climate-related considerations in the context of fulfilling its tasks, the ECB also needs to observe the general principles of EU law. This relates in particular to the principle of proportionality, institutional balance and equal treatment, as well as specific provisions of EU primary law applicable to the ECB, namely the open market economy principle and the prohibition of monetary financing.

Potential actions by the Eurosystem

The Eurosystem could step up its efforts to better understand the impact of climate-related risks and its policies on activity, inflation, financial stability and the Eurosystem's balance sheet. The Eurosystem needs to develop a better understanding of the impact of climate change on the macro economy, the implications for monetary policy, the risks to the financial system and the cost of inadequate policies from a monetary policy perspective. This could also be used as an external communication device to support the transition to a low-carbon economy.

There are also several steps that the Eurosystem could take to better incorporate climate change into its modelling framework. These include: accounting for an explicit role of the energy sector in the production structure and for specific climate change policies, which are typically country-specific; improving the ability of models to cope with various sources of asymmetry or heterogeneity; and incorporating realistic expectation-formation processes.

Overall, climate-related risks should be reflected in the Eurosystem's macroeconomic models within a suite-of-models strategy. This approach will be conscious of the limitations of a single model. Moreover, it will be crucial to find an appropriate degree of model complexity in dialogue and cooperation with climate scientists. Current models can be adapted to account for some of the above features. Semi-structural models have two advantages with respect to the dynamic stochastic general equilibrium models (DSGEs): they are typically more flexible and modular, and they can fit the data better. On the other hand, they cannot be used for welfare comparisons and typically do not allow for non-linear dynamics.

To facilitate the use of such models in the policy process, the Working Group on Forecasting (WGF) identified a roadmap with four main areas of work. These are the projection narrative, the forecasting toolbox, the medium-term analysis, as well as the scenarios and risk analysis. Five actions have already been identified to include climate change considerations in the baseline and the risk analysis of the projections. A timeline for these actions was also set out.

In order to more systematically reflect climate change considerations in the monetary policy implementation framework, the Eurosystem could consider initiatives in four areas: disclosure, risk assessment, collateral framework and the corporate sector purchase programme (CSPP) (Chapter 7). Work in these areas is already ongoing. Moreover, initiatives in these areas have the potential to be most useful for both enhancing the resilience of the Eurosystem's monetary policy implementation framework and promoting the potential catalytic role of these actions vis-à-vis financial market participants.

The Eurosystem could work with regulators to encourage disclosure and also disclose climate-related information on its own balance sheet in order to contribute to an increased general awareness and understanding of climate risk. It could introduce a new eligibility criterion or a differentiated treatment based on disclosures of private sector assets accepted as collateral and asset purchases, This could take into account EU policies and initiatives in the field of environmental sustainability disclosure and reporting. Furthermore, it could lead by example and disclose climate-related information on the CSPP and the euro-denominated non-monetary policy portfolios.

It could step up its in-house risk assessment capabilities of climate-related risk and explore how to incorporate climate change risk in its internal ratings. In particular, the ECB could start climate stress testing of the Eurosystem balance sheet to assess the Eurosystem's exposure to climate change risk. Furthermore, it could assess whether the credit rating agencies accepted under the Eurosystem Credit Assessment Framework disclose the information required to understand how they incorporate climate change risk into their credit ratings and could consider developing minimum standards for the incorporation of climate change risk into its internal ratings.

To improve the resilience of its collateral framework to emerging climate change risks, the Eurosystem could review the valuation and risk control frameworks for assets mobilised for use as collateral by counterparties in Eurosystem credit operations. This would ensure that they reflect all relevant risks, including those arising from climate change. It could also continue to monitor structural market developments in sustainability products to support innovation in the area of sustainable finance within the scope of its mandate, as done with its recent decision to accept sustainability-linked bonds as collateral.

The ECB could adjust the framework for the allocation of corporate bond purchases to incorporate climate change criteria. This might include the alignment of issuers, at a minimum, with EU legislation that implements the Paris Agreement, measured through climate -related metrics or commitments of the issuers to climate goals.

Actions regarding the implementation framework will, in some cases, require scrutiny of well-established conceptual frameworks that have previously guided the implementation of monetary policy. Defining alternative benchmarks in monetary policy operations could be examined, if it is considered that the market is not achieving an efficient allocation of resources and that alternative benchmarks may better serve the ECB in delivering on its mandate.

Where possible, the potential initiatives of the Eurosystem should take into account the EU policies and initiatives in the field of environmental sustainability disclosure and reporting. This would encompass the Corporate Sustainability Reporting Directive, the Taxonomy Regulation and the Regulation on sustainability-related disclosures in the financial services sector.

Incorporating climate change considerations into the monetary policy implementation framework requires a set of principles to assess potential policy measures and compare the resulting trade-offs between different implementation objectives and criteria. In addition, it needs to be ensured that these measures lie within the legal boundaries of the TFEU, as explained in Chapter 6 of this paper.

When assessing the implications of a given measure for price stability, its impact within the monetary policy cycle should be considered. While adjusting the implementation framework is mainly an issue of instrument design, it could also have implications for the stance which need to be addressed. In particular, it might not be possible to synchronise some measures that help to alleviate climate concerns (e.g. in the context of asset purchases or collateral eligibility) with the monetary policy cycle at all times. This would, however, depend on the specific design of the options. Thus, the opportunity to implement certain measures, taking into account their compliance with the legal framework, should be assessed on a case-by-case basis.

Appropriate and timely communication on the importance of climate change considerations for the Eurosystem's monetary policy should be duly considered. Communication with the public is crucial for a central bank to achieve its objectives. Early communication of policy measures allows for adjustments by the concerned institutions, thereby likely reducing unintended side effects on the smooth conduct of monetary policy.

1 Economic implications of the physical risks of climate change

Chapter 1 at a glance

- The physical risks of climate change arise from the interaction between, on the one hand, average temperature increases and weather extremes and, on the other hand, the exposure and vulnerability of society and natural systems to these hazards.
- Physical risks can be divided into two categories: (i) gradual global warming and the associated physical changes, such as rising sea levels or changing precipitation patterns; and (ii) natural disasters such as hurricanes and heatwaves. Though different in timing and immediate severity, both risks are dynamic, evolving over time and interacting with each other in a complex and non-linear fashion.
- Most empirical estimates indicate that climate change will likely have a limited impact on the European economy in the next few decades. However, the probability distribution of risks observed in historical data may be a poor indication in the case of climate-related risks, as it cannot be taken for granted that historical relationships will continue to hold in the future due to non-linearities and the development of new technologies. Scenario analyses that calibrate the economic effects of climate change for alternative greenhouse gas (GHG) concentration trajectories find larger negative effects on the level of global GDP, in particular as of the second half of this century (Dietz and Stern, 2015; Nordhaus, 2017).
- Both empirical and theoretical studies suggest that economic losses will increase in the long term and be unevenly distributed across regions, industries and parts of the population. Negative effects are expected to be substantially greater in southern European countries than in northern Europe. With regard to inflation, studies find that climate change, and in particular the increased frequency of natural disasters, have so far had a limited aggregate impact in advanced countries, although that in part reflects offsetting movements in food prices and core inflation.

1.1 Global warming

Continued emissions of GHGs will cause further warming. The Intergovernmental Panel on Climate Change (IPCC) has identified four possible representative concentration pathways (RCPs) for GHG concentration, relying on evidence indicating a strong relationship between cumulative CO2 emissions and projected global temperature change to the year 2100.[8] The reduced emissions related to the coronavirus (COVID-19) pandemic are expected to be temporary.[9] If the current rate of warming continues, the world is likely to see a temperature rise of 1.5°C compared to pre-industrial levels around 2040 (IPCC, 2018 and 2021). A key characteristic of the 1.5°C pathways is that they are built on the assumption of global net zero CO2 emissions around mid-century. Global warming implies rising sea levels, droughts, changes in precipitation patterns, ocean acidification and soil erosion.

Global warming affects some sectors more than others. Climate change would primarily affect the agriculture and fishing sectors by reducing agricultural yields, affecting crop production, agricultural productivity and livestock. The rise in sea levels could damage infrastructure in coastal zones and make large areas unhabitable, displacing a large share of the population. Changes in average temperatures and precipitation could lead to migration from these areas and shift tourism flows, increase energy demand and affect health through increasing mortality and morbidity rates, with implications for labour supply and labour productivity (Hsiang et al., 2017; Ciscar et al., 2018; Bamber et al., 2019).

Temperatures in Europe are projected to continue their upward trend throughout the 21st century. From 2009 to 2018, the mean annual temperature in Europe was roughly 1.7°C above that of the pre-industrial era. This already exceeds the global rise in temperature expected by the year 2040 compared to pre-industrial times, which reflects the fact that land areas in Europe are warming faster than the global average.[10] The estimated anthropogenic global warming of 0.2°C per decade in the years to come will be due primarily to the large stock of existing GHGs in the atmosphere and less to current and future emissions.

CO2 emissions generated by human activity stem from certain sectors in particular. In the EU, in 2018 electricity and heat production accounted for 33%, transport 29%, manufacturing industries 13%, residential buildings and commercial and public services 17% and other sectors 2% of the 3.15Gt of total EU CO2 emissions.[11]

Global warming has adverse supply and demand effects on the macroeconomy. In terms of **supply shocks** (Table 3), labour supply and productivity may diminish as a result of heat stress,[12] migration and a temporary

8 The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Each of the RCP scenarios has varying assumptions regarding population, economy, emissions and fossil fuel use; see IPCC (2014).

9 The impact on annual emissions in 2020 due to the COVID-19 pandemic is estimated to be a temporary 5% fall; see Le Quéré et al. (2020). The International Energy Agency (2021) estimates the fall to be around 5.8%; see also Box 2.

10 See Jacob et al. (2014).

11 See International Energy Agency (2020).

12 There is remarkable consensus about the magnitude of the causal impact of temperature shocks on labour productivity and related economic outcomes, with short-run damage estimates clustered around 2% per degree Celsius above comfort temperature; see Heal and Park (2016).

incapability to work.[13] The capital stock may be depleted and impacted by resource reallocation for adaptation purposes, and technology could be affected to the extent that resources are diverted away from innovation and R&D towards activities related to reconstruction, adaptation and protection. Lower productivity growth would push down expected future incomes, hence increasing the need to save to sustain future consumption.[14] This would result in lower marginal product of capital and thus a lower natural rate of interest r^* (see Chapter 5 for a discussion on r^*). In terms of **demand shocks**, there may be changes in energy demand related to expected variations in relative prices of energy and changes in preferences. On the one hand, weaker investment dynamics may occur related to rising uncertainty. On the other hand, reconstruction needs could temporarily boost investment. New consumption dynamics would result from changes in preferences, higher precautionary savings and permanent losses of wealth for uninsured agents.

13 For instance, Deryugina and Hsiang (2014) look at daily temperature changes in US counties over a 40-year period. The researchers estimate that productivity per individual workday declines 1.7% for each 1°C (1.8°F) rise in temperature above 15°C (59°F). A weekday above 30°C (86°F) costs a county an average of USD 20 per person in lost income. See also the wider discussion on this issue in Batten (2018), pp. 17-18.

14 Fankhauser and Tol (2005) identify two channels from climate change to long-term growth: capital accumulation and adjustments of the savings rate. Piontek et al. (2019) differentiate between climate shocks that reduce current output, shocks that depreciate capital or labour, and shocks that impair productivity. The persistence of growth effects is found to be smallest in the first case, larger for damages to production factors and largest for damages to productivity growth.

Table 3

Channels of impact

		Gradual warming	Extreme events	Transition risks
Supply shocks	**Labour supply**	Loss of hours worked due to extreme temperatures. Increased international migration.	Destruction of workplaces, need to migrate (even if temporarily).	Changes in sectoral composition of labour market could lead to higher structural unemployment.
	Food, energy and other input supply	Decline in agriculture productivity and yields.	Disruption to transport and production chains.	
	Capital stock	Diversion of resources from productive investment to adaptation capital.	Destruction due to extreme events.	Rise in stranded assets.
	Technology	Diversion of resources to reconstruction activity.	Diversion of resources to reconstruction activity.	Climate policies (carbon pricing, regulation) as a potential driver of innovation.
	Productivity	Lower labour productivity due to extreme heatwaves and lower human capital accumulation (increased health issues and mortality).	Lower capital productivity due to (possibly permanent) capital and infrastructure destruction.	Uncertain effect on productivity, as technological progress could offset underinvestment resulting from transition policies.
Demand shocks	**Energy demand**	Increased demand for electricity in summer exceeds decreased demand in winter.		Higher carbon tax leading to lower demand for fossil fuels.
	Investment	Change in preferences towards more sustainable goods and services.	Uncertainty about climate events could delay investment. Investment in reconstruction increases following events.	Shift in the mix of activity towards more investment (in climate mitigation technologies) Uncertainty about climate policy may reduce investment.
	Consumption	Change in preferences towards more sustainable goods and services.	If no insurance of household or firms, destruction could cause a permanent decrease in wealth and affect consumption.	Increased sustainability awareness and shift toward greener consumption.
	Trade	Disruption to trade routes due to geophysical changes (such as rising sea levels).	Change in food prices and disruption to trade flows.	Taxes, regulations and restrictions may unsettle trade routes. Risks of distortion from asymmetric or unilateral climate policies.
Aggregate impact on output and nominal variables	**Output**	Lower labour productivity, investment being diverted to mitigation and arable land loss.	Physical destruction (crop failures, destruction of facilities and infrastructure, disruption of supply chains).	Frictions resulting from distortive (fiscal) transition policies and/or (fiscal) transition policy uncertainty. Mitigated impact depends on the use of proceeds from (fiscal) transition policies.
	Wages	Downward pressures on wages from lower productivity.	Unequal effects across sectors and economies.	Unequal effects across sectors and economies (reallocation of workers from one sector to another, increased training needs).
	Inflation	Relative price changes due to shifting consumer demand or preferences and changes in comparative cost advantages.	Increased inflation volatility, particularly in food, housing and energy prices.	Prices affected by transition policies, policy uncertainty, technological changes and shifts in consumer preferences.
	Inflation expectations	Climate-related shocks, e.g. to food and energy prices, may affect inflation expectations.	Inducing more homogenous, sudden and frequent revisions of expectations.	Formation of inflation expectations affected by policies.

Source: Adapted from Batten (2018).
Note: Transition risks are discussed in Chapter 2 of this paper.

The real economy effects of physical risk have an impact on the financial sector. The macroeconomic effects may directly propagate to property values, corporate revenues, asset values and household wealth, which then have an impact on the financial sector. In turn, credit tightening and market losses can feed back to the real economy. Indirect effects may occur via global value chains. Climate change and supply chains are found to mutually influence each other through natural disasters and GHG emissions respectively. Faiella and Natoli (2018) show how extreme weather events may constitute a source of financial risk via the bank channel (see Chapter 4).[15]

The theoretical literature on the physical effects of climate change suggests a wide range of possible economic losses. Two benchmark studies are Nordhaus (2017) and Dietz and Stern (2015). A key distinction between the two studies is that Dietz and Stern (2015) adjust the Nordhaus Dynamic Integrated model of Climate and the Economy (DICE) (see Chapter 3) to allow climate change to affect total factor productivity (TFP) growth, which suggests strong non-linear effects. Depending on the assumptions about the various representative concentration pathways (RCPs), long-run losses in global GDP vary from 0.7% in a mild scenario to 62% of global GDP in a severe scenario (Table 4) according to Nordhaus (2017) and Dietz and Stern (2015).

Table 4

Representative concentration pathways and impact on the level of global GDP

	IPCC: temperature in 2081-2100 above 1850-1900	Associated long-term damage assumptions (percentage of world GDP)	
Scenario	ΔT	Nordhaus DICE 2017	Dietz/ Stern 2015
RCP2.6	$1.6°C \pm 0.4$	0.7%	0.9%
RCP4.5	$2.4°C \pm 0.5$	1.6%	4.5%
RCP6.0	$2.8°C \pm 0.5$	2.2%	9.8%
RCP8.5	$4.3°C \pm 0.7$	5.0%	61.6%

Sources: Collins et al. (2013), Dietz and Stern (2015) and Nordhaus (2017).
Notes: The required change of GHG emissions between 2010 and 2050 amounts to -72% to -41% for the RCP2.6 scenario, -38% to +24% for RCP4.5, +18% to +54% for RCP6.0 and +52% to +95% for RCP8.5. The expected temperature change (ΔT) refers to the Coupled Model Intercomparison Project Phase 5 (CMIPP5). The RCP8.5 scenario is a potential worst-case outcome and goes beyond a no-policy baseline outcome. See also Chapter 3 for further details on the underlying model structure.

Empirical estimates of the impact of physical risk on output are more limited. A meta-analysis by Tol (2018) summarises 27 published estimates of the total economic impact of climate change (measured in terms of welfare-equivalent income loss) contained in 22 studies (Chart 7). It indicates that a mean global temperature increase of 2.5°C would make the average person feel as if they had lost 1.3% of their income. Using data on 174 countries over the period from 1960 to 2014, Kahn et al. (2019) find that, in the absence of mitigation policies, a persistent increase in average global temperature of 0.04°C per year (RCP8.5 scenario) would reduce the level of world real GDP per capita by 7.2% by 2100. On the other hand, abiding by the Paris Agreement, thereby limiting the temperature increase to 0.01°C per annum, reduces the loss substantially, to 1.07%. These estimates should, however, be interpreted with caution. It is not guaranteed that historical relationships will continue to hold in the future due to non-linearities in the relationship between climate change

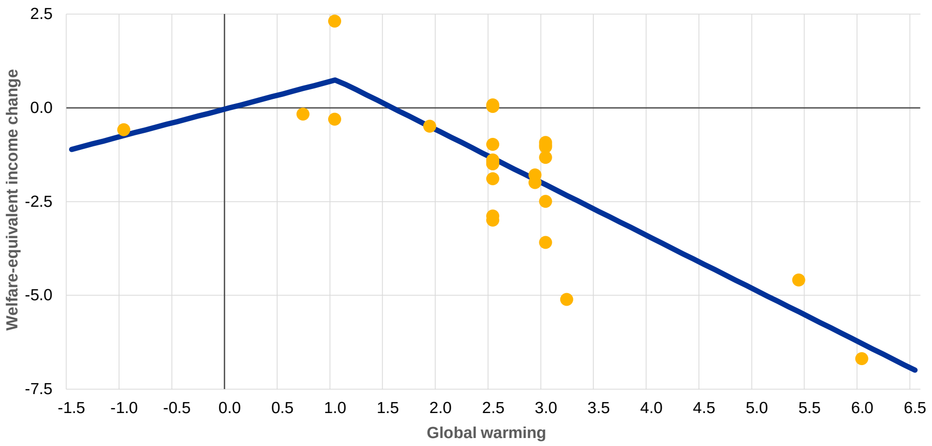
[15] The authors document a negative association between the amount of loans and the flood risk exposure of businesses. These results indicate that banks take flood risk into consideration in their loan decisions, in particular if the borrower is an SME, probably because they consider smaller firms less resilient (e.g. they are less likely to be insured against such events). This suggests that actions that mitigate flood risk might benefit SMEs' access to finance.

and the macro economy (tipping points) and uncertainty about future technological advances.

Chart 7

The impact of climate change on welfare-equivalent income

(y-axis: percentages; x-axis: degrees Celsius)



Source: Tol (2018).
Notes: The chart summarises the results of 22 studies (based on different methods). Impact is expressed in welfare-equivalent income change as a function of the increase in the global annual mean surface air temperature since pre-industrial times. The dots represent the estimates of each study and the solid line indicates the best-fit piecewise linear function.

There is a high degree of uncertainty about the impact of climate change on the EU economy. While there is consensus that the economic cost of climate change is substantially larger under an unmitigated path than under a scenario that limits global warming to the Paris Agreement targets, the projected economic losses for the European countries vary significantly from study to study. Using a climate assessment general equilibrium model, the European Commission JRC PESETA IV project finds strongly negative macroeconomic effects of climate change, suggesting that a global warming of 1.5°C would generate annual welfare losses of roughly 0.33% of GDP (Feyen et al., 2020). Restricting warming to 2°C would double the losses, while limiting warming to 3°C would incur losses of 1.4% of GDP per year. The regional distribution of losses is expected to be highly uneven, with damages in southern Europe being several times larger than in the northern Europe. These diverging effects would stem from the differing levels of water availability, as well as from differences in exposure to extreme temperatures and sectoral compositions of economies (Ciscar et al., 2018). The findings by Kahn et al. (2019) suggest that real GDP per capita losses may be contained for Europe, even under the RCP8.5 scenario (Table 5). Letta and Tol (2019) do not find a significant relationship between annual temperature shocks and total factor productivity (TFP) growth rates in advanced economies.

Table 5

Percentage loss in level of GDP per capita under the RCP2.6 and RCP8.5 scenarios

	2030	2050	2100
World			
RCP2.6	-0.01%	0.11%	1.07%
RCP8.5	0.80%	2.51%	7.22%
European Union			
RCP2.6	-0.45%	-0.80%	0.45%
RCP8.5	0.58%	1.62%	4.35%

Source: Kahn et al. (2019).
Notes: Estimates based on persistent increases in temperatures in the RCP2.6 and RCP8.5 scenarios, using 30-year moving averages for climate norms. Figures are purchasing power parity GDP-weighted. Losses are cumulative. Note also that the RCP8.5 scenario is a potential worst-case outcome, where extremely high emissions are generated by a combination of high population growth, high economic growth and strong reliance on fossil fuels. In this sense, it goes beyond a no-policy baseline outcome.

The large differences in projected economic losses stem from the fact that economic uncertainty will increase as temperatures rise and the distribution of climate shocks becomes more fat-tailed. The macroeconomic consequences of climate change involve largely unknown feedback loops and parameter values that govern the strength of those loops. This creates a distinction between temporary and permanent shocks, meaning that economic forecasting will become increasingly challenging. While empirical evidence of a strong, broad-ranging and adverse impact from climate change is increasing, it is still unclear how climate shocks are transmitted, and how factor allocation, savings and growth patterns are affected in the models used. (See Chapter 3 for a discussion on the implications of climate change for macroeconomic modelling.)

1.2 Extreme weather events

As the planet heats up, extreme weather events will become more frequent and severe. Extreme weather events are becoming increasingly frequent (Chart 8, panel a), may bring economies closer to tipping points and cause substantial damage. Climate change can be defined as a change in the weather distribution, with extreme weather events reflecting the tails of the distribution. The expected shift in the temperature distribution will therefore raise the probability of extreme weather events (Chart 8, panel b). The increase in mean and variability imply an increase in absolute and relative extremity for high temperatures (Jahn, 2015). As for quantitative assessments of the impact of natural disasters on macro variables, for instance, the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) finds a potential adverse long-term impact on global activity of up to 15 percentage points of GDP under a “hot house world scenario” (NGFS, 2020a). Regarding inflation, Parker (2018) finds that natural disasters have had a limited impact on advanced countries but have had substantial and persistent upward effects in developing economies. Faccia et al. (2020) find that very hot summers have a marked impact on prices over the medium term (Box 1).

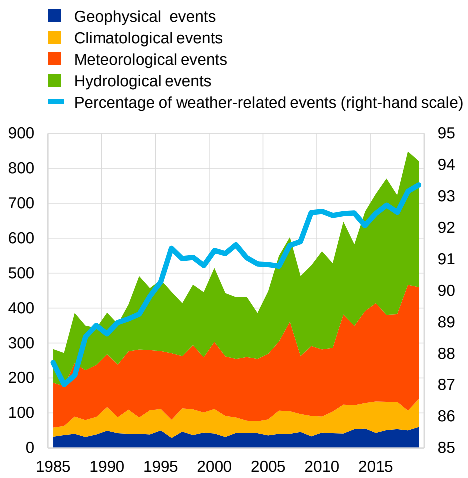
Like global warming, natural disasters affect the economy on both the supply side and the demand side. However, these effects differ in terms of timing and severity from those caused by global warming (Table 3). Extreme weather events have immediate and serious economic consequences on the supply side, as they can damage workplaces and the stock of productive capital, disrupt production processes, hinder energy supply and disrupt global value chains. Trade may also be adversely affected by disruptions to transport links and changes in relative prices. In the short term, these macroeconomic effects can be challenging for central banks, as they tend to pull output and inflation in opposite directions. In terms of demand effects, investment may be put on hold as a result of increased uncertainty, though it may also be boosted in the short term by reconstruction activity. Consumption may be hampered if there are permanent losses of agents' wealth that are not insured.

Chart 8

Extreme weather events and their probability

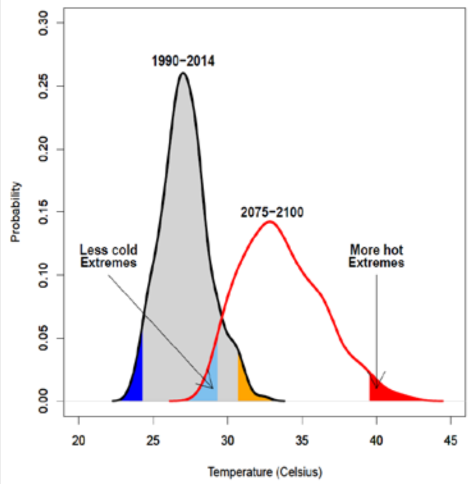
a) Extreme natural events, 1985-2019

(number and percentage of total events)



b) Probability of extreme weather events

(probability distribution)



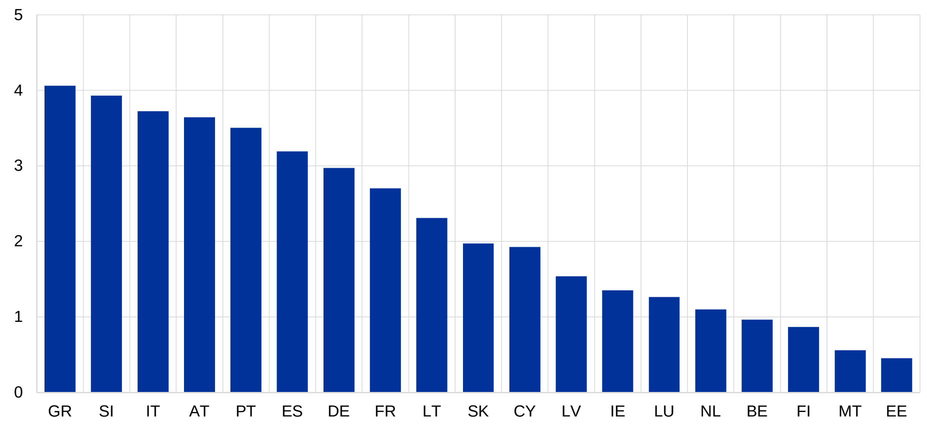
Sources: Munich Re (panel a) and IPCC (panel b).
Notes: Panel a: geophysical events: earthquakes, tsunamis, volcanic eruptions; climatological events: heatwaves, cold spells, droughts, wildfires; meteorological events: storms; hydrological events: floods. The latest observation is for 2019. Panel b: probability density functions (PDF, kernel density estimation) of the annual maximum temperature for present (black line) and future climate (red line) at a location near Frankfurt am Main. Annual maximum temperature outputs are from a set of ten Max Planck Institute Low Resolution (MPI-LR) model simulations from the Coupled Model Intercomparison Project Phase 6 (CMIPP6). Past-present data (for 1990-2014) are from the MPI-LR historical simulation, whereas future data (for 2075-2100) are outputs from the MPI-LR, forced with the ssp585 CMIPP6 scenario. The sample size is 250 (25 years x 10 runs). The simulations are forced with the ssp585 scenario; no action is taken to reduce GHGs.

Numerous extreme weather events in Europe have caused significant economic damage. For instance, the largest daily rainfall in the past 100 years was recorded in Germany in 2002 (Becker and Grünewald, 2003); the wettest summer on record since 1901 occurred in the Netherlands and Norway in 2011 (National Centers for Environmental Information, 2011); and the hottest European heatwave in the last 500 years occurred in the summer of 2003 in southern Europe (Russo et al., 2015). More recently, in the summer of 2019, Europe experienced intense heatwaves, with all-time high temperatures recorded in many locations (Naumann et al., 2020). Estimates of total cumulative GDP losses since 1980 amount, on average, to 2.5% of 2017 GDP for the countries shown in Chart 9, ranging from 1% in Finland to 4% in Greece.

Chart 9

Cumulative GDP losses due to extreme weather and climate-related events

(percentages of 2017 GDP, 1980-2017)



Sources: European Environment Agency and AMECO database.

In the medium to long term, there are three possible economic post-event dynamics following a natural disaster.

- According to the **creative destruction hypothesis**, natural disasters are followed by a period of faster growth due to the reconstruction of activity and substitution of capital by newer vintages of capital. Under this hypothesis, the economy shifts to a higher growth path than before the disaster event.

- The **recovery to trend hypothesis** postulates that natural disasters are followed by a temporary slowdown, but that income levels gradually recover to the previous trend during a post-disaster catch-up period. This hypothesis predicts that the impact of the natural disaster is only temporary.

- In the **non-recovery hypothesis**, natural disasters are thought to dampen growth by destroying productive capital and durable goods or causing a permanent loss in wealth. In this case, no rebound occurs, and the natural disaster has long-term negative consequences.

Most empirical studies support the non-recovery hypothesis, i.e. natural disasters reduce the growth rate of the economy in the long run. There is substantial evidence that disasters can lead to long-term scarring of the most heavily affected economies and disproportionately affect the poorer in society. For example, Raddatz (2009) finds that in the long run, GDP per capita is 0.6% lower because of a single climatic event, caused by heatwaves, cold spells, droughts or wildfires. Several factors are key to mitigating the aggregate impact, including the effectiveness of governance and access to finance. There is some evidence of creative destruction, whereby natural disasters provide the impetus to update the capital stock and adopt new technologies, leading to improvements in TFP (Skidmore, 2002).

Extreme weather events may put an increasing burden on public finances. The budgetary impact of extreme weather events can be direct, due to the costs associated with repairs, as well as indirect, from erosion of the revenue base due to a loss in output or from public expenditure for prevention measures (e.g. building of dikes). Empirical studies on the fiscal costs of natural disasters are scarce. The few studies available point to a rather limited budgetary effect.[16] Yet, these estimates might be somewhat outdated, as the probability of climate-related risks has been steadily increasing over time. As shown by Catalano et al. (2020), taking precautions against catastrophic events may lead to smaller economic losses than either taking no action or waiting until remedial action is necessary.[17]

Box 1

International evidence of the impact of climate change on price stability

While physical events are mostly negative for output, the simultaneous impact on both supply and demand factors makes the net effect on consumer price inflation more ambiguous. Parker (2018) investigates the impact of a range of disasters on consumer prices in a panel of 212 economies over the period 1980-2012, including – where available – the sub-components of food, energy, housing and core inflation. The analysis points to differing effects by sub-component, type of disaster and level of development.

The immediate impact of natural disasters on consumer prices tends to be modest in advanced economies but positive in developing economies. This is particularly the case for droughts and windstorms. For windstorms, the impact on food prices generally unwinds within a year but may persist for longer after droughts. By contrast, the impact on core inflation is generally negative. The increase in inflation tends to be greater in developing economies, where the weight of food in the basket is higher and inflation is generally less well anchored. For advanced economies, the overall impact on inflation has to date tended to be modest, and, if anything, has been slightly negative on balance.

Heatwaves, which are arguably a more prominent result of climate change, have received less attention in the literature, but new ECB research shows that these events can have a significant and sizeable impact on prices. Faccia et al. (2020) use temperature anomaly data from FAOSTAT to determine the impact of extreme temperatures on prices. The anomalies are calculated as the difference from each country's average between 1951-80. There has been a marked shift in these anomalies over recent decades, with the median summer anomaly in the euro area 1.3°C hotter in the 2010s than it was in the 1980s (Chart A). The authors run panel local projections for 34 advanced economies and 15 emerging and developing economies, relating a set of inflation indicators (food, energy and core CPI, plus the GDP deflator) to measures of country-specific summer temperature anomalies for the 1980-2018 period and a number of control variables

[16] Lis and Nickel (2010) quantify the direct (i.e. relief payments and financing of public disaster response) and indirect effects (i.e. lower revenue due to the fall in output) of large-scale extreme weather events on the general government budget balance. Melecky and Raddatz (2011) find that the response of fiscal variables depends on the nature of the disaster. They find that after a climatic disaster shock, public deficits increase less in countries with higher insurance penetration, as they can quickly allocate private resources to recover productive capacity rather than using public resources. Focusing on selected case studies for extreme weather events in Europe, Heipertz and Nickel (2008) use budgetary elasticities to translate the output loss into a hypothetical increase in the general government deficit ratio of the affected countries.

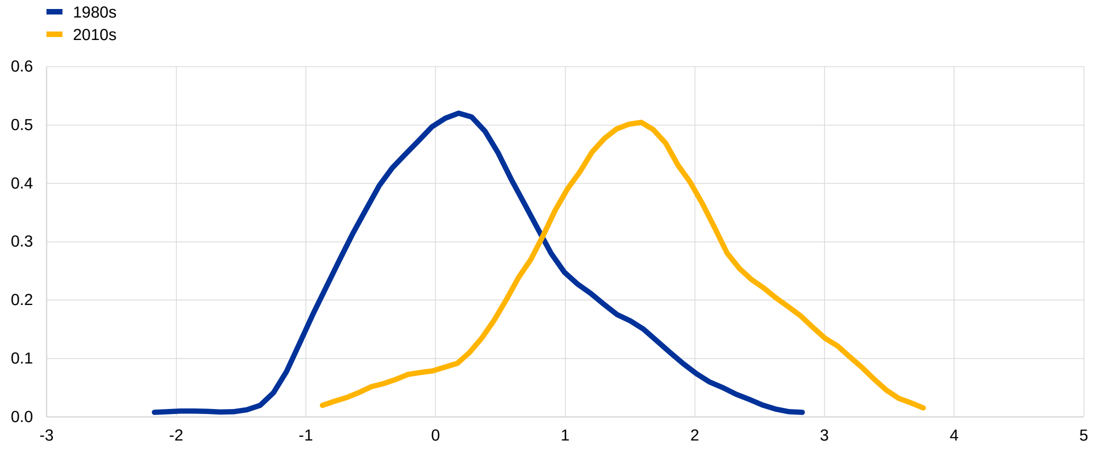
[17] See Chapter 2 for a discussion of the impact of climate change (policies) on fiscal balances.

(country fixed effects, lags of inflation, using Driscoll-Kraay standard errors to control for autocorrelation).

Chart A

Distribution of summer temperatures

(y-axis: density; x-axis: degrees Celsius compared with 1951-80 average)



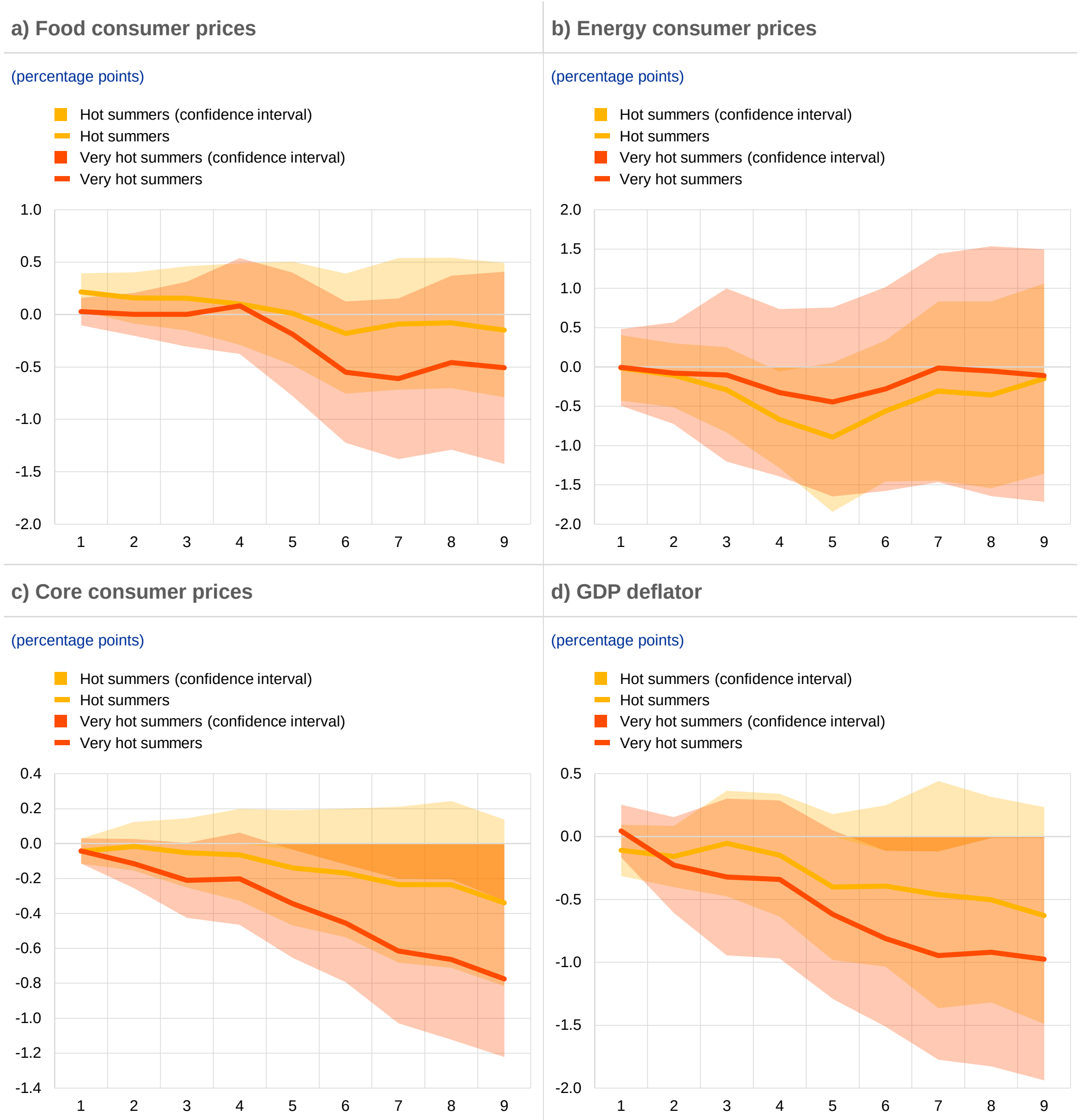
Sources: FAOSTAT and ECB calculations.
Notes: The chart shows kernel density of temperature anomalies compared with the 1951-80 average. No 1980s anomaly data for Luxembourg or Slovakia. Data for 2010s are included up to 2018.

Chart B shows the estimated impact on the level of prices for advanced economies following summer heatwaves. Hot summers – where temperatures exceed a country's long-run mean by more than 1.5°C – are associated with an increase in food prices of around 0.2 percentage points during the same summer quarter.

Very hot summers – where temperatures exceed the long-run mean by more than 2°C – have a more marked impact on prices over the medium term. France in 2003 and Germany in 2018 are two examples of such events. Core CPI fell by around 0.8 percentage points over the subsequent eight quarters, and the GDP deflator fell by 1 percentage point over the same period. Taking into account that hot summers are generally associated with a reduction in GDP growth (Colacito et al., 2019), these preliminary results suggest that heatwaves act as a short-term negative supply shock in certain sectors, by limiting crop production for example, but as a negative demand shock across sectors over the medium term.

Chart B

Estimated impact on the price level for advanced economies following summer heatwaves



Source: Faccia et al. (2020).
Notes: "Hot summers" is a dummy equal to 1 when the summer temperature exceeds a country's long-run mean by more than1.5°C. "Very hot summers" is a dummy equal to 1 if the summer temperature exceeds a country's long-run mean by more than 2°C. Shaded areas represent 90% confidence intervals.

2 Climate policies and transition risks

Chapter 2 at a glance[18]

- According to the United Nations, global emissions would need to fall by 7.6% each year between 2020 and 2030 (broadly equivalent to the pandemic-related reduction in CO_2 emissions in 2020) to limit the rise in global temperatures to 1.5°C above pre-industrial levels, as targeted under the 2015 Paris Agreement. The EU has committed to reducing greenhouse gas (GHG) emissions by 20% in 2020 and 55% by 2030, compared with 1990 levels. The EU aims to achieve carbon neutrality by 2050, meaning its GHG emissions have been reduced to net zero.

- EU countries have adopted a wide range of policy instruments to support the transition to a low-carbon economy. The objective of climate neutrality by 2050 is at the heart of the European Green Deal presented by the European Commission in December 2019. The cornerstone of EU climate policy is the EU Emissions Trading System (EU ETS), "a cap-and-trade" scheme, which applies to roughly 50% of GDP.

- Carbon pricing is widely considered essential to any successful mitigation strategy. A predictable gradual path to a higher carbon price will spur investment in low-carbon technologies and infrastructure and is considered an effective instrument to promote innovation in clean technologies. Carbon pricing would generate significant fiscal revenues that could be used to reduce more distortionary taxes and support the groups most vulnerable to the transition. Carbon pricing might also incorporate carbon border adjustments or an international carbon price floor to avoid carbon leakage, i.e. an increase in emissions outside the EU due to higher carbon prices within the EU. In addition, complementary structural policies will play an important role in supporting the transition to a climate-neutral economy. The large-scale reallocation of resources from high- to low-carbon activities requires flexible and adaptable labour and product markets, well-functioning financial markets and efficient frameworks, such as good conditions for research and the propagation of new technologies. Furthermore, the transition to a low-carbon economy will also need to be supported by regulatory interventions, mostly initiated at the EU level, which will restrict GHG emissions for specific products, sectors or activities.

- Scenario analysis illustrates the benefits of introducing appropriate carbon prices earlier rather than later. Based on high-level scenarios devised by the Network for Greening the Financial System (NGFS), simulations by the Banque de France suggest that real GDP in the EU would be some 2-6% lower by 2050 under a delayed transition scenario (where appropriate carbon prices are not

[18] Sections 2.1 and 2.2 largely draw on contributions from a team working on "Climate change and fiscal policy" under the Eurosystem Working Group on Public Finances.

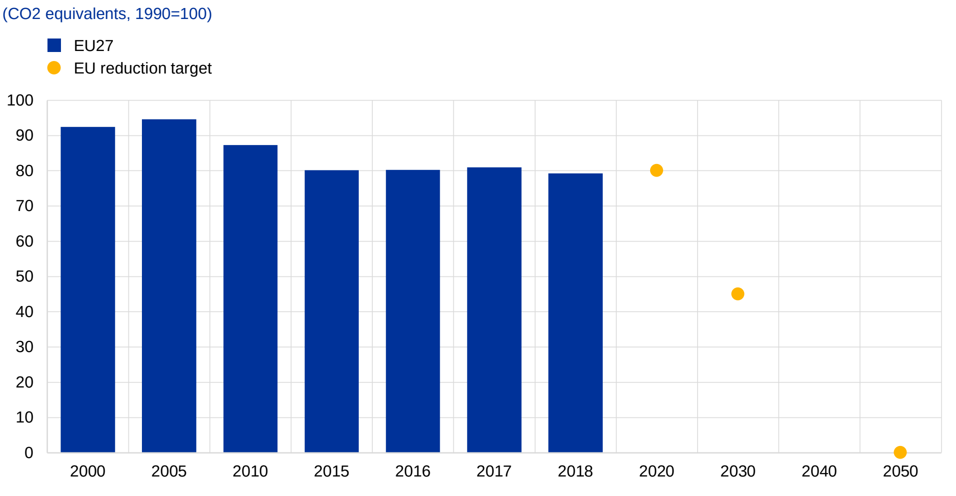
introduced before 2025) than under an orderly transition (where appropriate carbon prices are introduced as of 2020). A delayed transition also leads to higher inflationary pressure and a negative impact on public finances in the long term compared with an orderly transition. The simulated effects on the sectors exposed to delayed transition policies are substantial and could give rise to financial stability risks that are potentially much more pronounced than suggested by aggregate results.

2.1 EU climate frameworks and EU policy initiatives

The EU has set concrete targets for reducing GHG emissions in line with the Paris Agreement to limit the rise in global temperatures to 1.5°C. The EU has thus committed to reducing GHG emissions (in CO2 equivalents) by 20% in 2020 and 40% by 2030, compared with 1990 emissions. The EU aims to achieve carbon neutrality by 2050. In 2018 the reduction in GHG emissions exceeded 20% of the 1990 emission level, slightly overshooting the 2020 target. Looking ahead, however, much greater efforts will be required to achieve the targets set for 2030 and 2050, in particular as a more ambitious emission-reduction target of 55% for 2030 has recently been adopted by the European Council (Chart 10).

Chart 10

Greenhouse gas emissions and EU reduction targets



Sources: European Environment Agency and European Commission.
Note: The emission-reduction targets for 2030 and 2050 are expressed in net terms.

The EU has set up an emissions trading scheme (known as the Emissions Trading System, or EU ETS) under which CO2 emission allowances are gradually reduced so as to raise the carbon price. The EU ETS was established in 2005 and covers three sectors: energy production, manufacturing and construction, and intra-EU aviation, which together account for around 45% of total

GHG emissions in the EU.[19] [20] A significant amount of allowances continues to be allocated freely. This allows the EU to pursue its emission-reduction targets while shielding industries that compete internationally from carbon leakage.[21] Under the EU ETS, a uniform carbon price applies to all EU Member States. At the end of 2019, this stood at 24.7 EUR/tCO2. With the COVID-19 pandemic, it fell to as low as 16.3 EUR/tCO2 in April 2020, amid reduced demand for emission allowances.

The EU ETS works on the "cap-and-trade" principle. The overall volume of GHGs that can be emitted for a multi-year phase by the power plants, factories and other companies covered by the system is subject to a cap set at the EU level. Within this cap, companies receive or buy emission allowances which they can trade, if they so wish. The cap on emissions is gradually reduced, with an annual reduction of 1.74% in the period 2013-20, which will accelerate to 2.2% as of 2021.

Following the adoption of the more ambitious 2030 reduction target, in July 2021 the European Commission published its "Fit for 55" package. The package includes an in-depth review of the EU ETS, including its extension to other sectors such as road transport, building and maritime transport, and proposes the introduction of a carbon border adjustment mechanism.

In addition to the current EU ETS, an "effort-sharing" scheme was put in place with binding national emission targets for non-ETS sectors (e.g. road transport, agriculture, heating and waste) for 2020 and 2030.[22] Emission targets in the non-ETS sectors vary across EU Member States, taking into account the level of economic development as well as cost-efficiency considerations. Some countries have set themselves more ambitious targets for 2030 than foreseen under the effort-sharing scheme. Targets range from a 50% reduction from the 2005 level in Luxembourg, for example, to unchanged emissions in Bulgaria (Chart 11). Based on 2019 estimates for emissions in 2020 and 2030 by the European Environment Agency, most EU countries are expected to achieve their 2020 targets in non-ETS sectors, but will fail to meet their 2030 targets, often by far.[23]

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19 Apart from the EU ETS, international emissions trading can take place under the Kyoto Protocol mechanism.

20 Member States collected €14.1 billion revenue from the EU ETS in 2018. Revenues are channelled into national budgets mainly based on countries' historical emissions. The EU ETS Directive stipulates that at least 50% of these proceeds should be used to combat climate change in the EU or third countries. In actual fact, Member States used over 80% of the revenues between 2013 and 2017 for such purposes, though some devoted a significant share to compensate energy-intensive industries. More recently, there have been proposals to channel part of the revenue to the EU budget (Fuest and Pisani-Ferry, 2020).

21 The amount of allowances being allocated freely has been gradually reduced over time. However, in 2020 intra-EU aviation still received 82% of its allowances for free, compared with no free allowances for power generators. In the manufacturing sector, those sectors exposed to a higher risk of carbon leakage due to competitors outside the EU received a higher share of free allowances (30% in total). Under the current legislation, they will continue to do so at least until 2030.

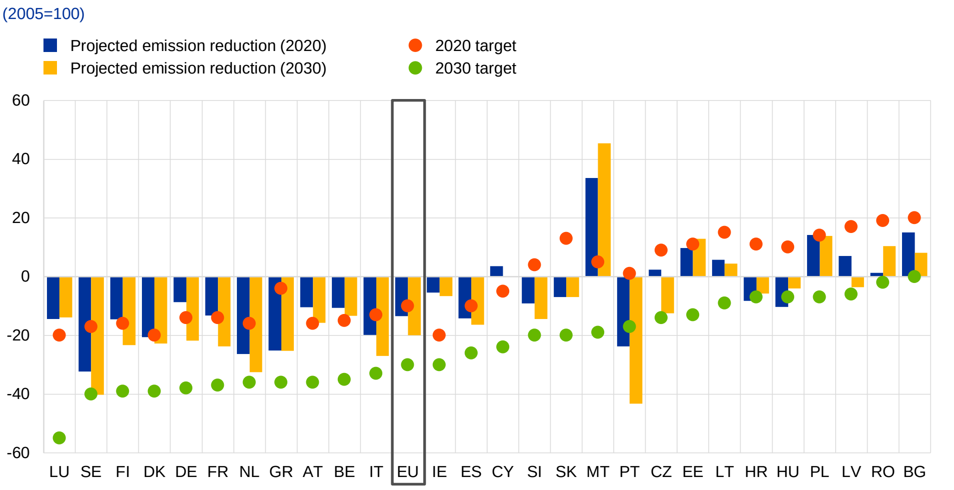
22 The "Effort Sharing Regulation" was drawn up in 2014 to complement the EU ETS by way of annual national targets for non-ETS sectors in support of the commitment for economy-wide emission reduction by 2030. Progress towards achieving the targets is assessed annually. Where there are persistent shortfalls, a penalty in the form of higher reduction obligations is applied. Broadening the coverage of the EU ETS, as suggested in the Fit for 55 package, would require a review of the "effort-sharing" scheme.

23 These estimates are based on the assumption that existing climate change policies will remain in place, while no new measures are assumed to be adopted.

These estimates do not account for the impact of COVID-19, which led to a marked decline in travel and economic activity. GHG emissions and energy consumption fell sharply amid the COVID-19 pandemic, thereby facilitating the achievement of emission targets for 2020 in the EU as a whole. However, the sharp drop in carbon emissions is likely to be temporary and may be more than offset going forward by possible changes in individual behaviour (e.g. commuters switching from public transport to private cars), and also given the experience following previous crises (OECD, 2020a) On the other hand, the pandemic provides an ideal opportunity to move towards a greener economy, in particular by fostering green public and private investment in support of the economic recovery.[24]

Chart 11

National emission reduction targets and projected emission reductions in non-ETS sectors



Sources: European Commission, Working Group on Public Finances, European Environment Agency and own calculations.
Notes: The chart shows the projected emission reductions for 2020 and 2030 by the European Environment Agency, based on the assumption of existing climate change measures. The latest available projections are from 2019 and therefore do not account for the impact of COVID-19. Positive values suggest that current policies would result in higher emission than in 2005. The national targets for 2030 take into account the more ambitious targets recently set for non-ETS sectors by some countries, namely Greece, Luxembourg, Slovenia and Slovakia. The latter are not reflected in the EU average target shown in the chart.

The emission reduction gaps suggest that greater policy efforts will be required to meet the 2030 targets for non-ETS sectors. The policies that countries have adopted to reach these targets are rather diverse and fragmented, as discussed further below. As of 2021, only Germany has applied the EU ETS to sectors it does not yet actually cover.[25] This suggests that, overall, also the impact of climate policies on output and inflation is expected to be low in the short-term.

Emission targets are complemented by targets for renewable energy and energy efficiency. To facilitate emission reduction, the EU committed to increase the share of renewables in energy consumption to 20% by 2020 and to at least 32%

[24] For a further discussion of the impact of the COVID-19 pandemic on climate change policies, see Box 2.

[25] In 2021 Germany introduced a national carbon pricing system for the transport and buildings sectors. This will start with allowances at a fixed price of 25 EUR/tCO2, which will rise to 55 EUR/tCO2 by 2025 using auctioned allowances. The corresponding government revenue from the scheme is projected to amount to €9.0 billion (0.25% of GDP) in 2021 and €10.3 billion in 2022, with the funds going into the German Energy and Climate Fund.

by 2030. The Energy Efficiency Directive underpins this effort by specifying national renewable energy targets for each country, taking into account its starting point and overall potential for renewables.

In December 2019 the European Commission announced a European Green Deal Investment Plan, which targets carbon neutrality for the EU by 2050. The plan comprises two main pillars: (i) it will increase funding for the transition using the EU budget and other tools, in particular InvestEU and, as a new element, Next Generation EU; (ii) it will create an enabling framework for private investors and the public sector to facilitate sustainable investments, in particular by leveraging and further developing sustainable finance. Part of the plan, the Just Transition Mechanism, targets a fair and just green transition to support workers and citizens of the regions most affected by the transition. Around 30% of the 2021-27 EU budget (including Next Generation EU) will contribute towards climate action and spending on the environment through multiple programmes.

The new sustainable finance strategy, published on 6 July 2021, provides a roadmap with new actions to increase private investment in sustainable projects and activities to support the European Green Deal.[26] It follows up on the 2018 Action Plan on sustainable finance, which among other things introduced:

(a) a taxonomy of sustainable economic activities, establishing a unified classification system on what can be considered environmentally sustainable economic activities. This is widely seen as a first and essential enabling step in the overall effort to channel investments into sustainable activities;

(b) a regulation on disclosures relating to sustainable investment and sustainability risks, which introduces obligations for institutional investors and asset managers to disclose how environmental, social and governance (ESG) factors are integrated at both the entity and the product level. It also requires them to incorporate these factors in investment decision-making processes, as part of their duties towards investors and beneficiaries;

(c) a regulation on sustainable benchmarks, introducing a new category of low-carbon and positive-carbon impact benchmarks to help investors better understand the relative carbon impact of their investments.

The Commission's new sustainable finance strategy includes a legislative proposal on a European green bond standard, which is complemented by a proposal for a Corporate Sustainability Reporting Directive (CSRD), thereby reviewing the Non-Financial Reporting Directive (NFRD).[27] With regard to the NFRD, the Commission proposes to (i) extend the scope of application of the NFRD to all large companies and all companies listed on regulated markets (except listed

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[26] See the comprehensive policy package on sustainable finance, published by the European Commission on 6 July 2021.

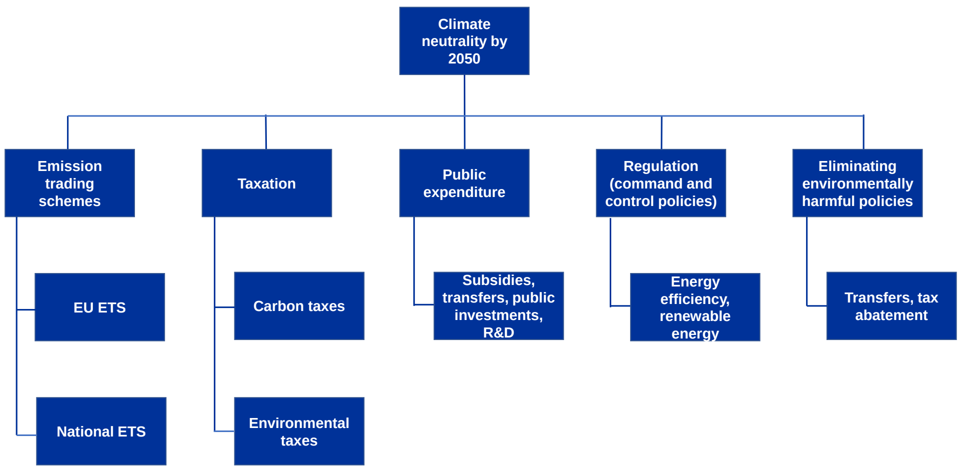
[27] See the proposal for a Regulation on a European green bond standard, published on 6 July 2021 and the proposal for a Corporate Sustainability Reporting Directive, published on 21 April 2021.

micro-enterprises); (ii) require an audit of reported information; (iii) introduce more detailed reporting requirements and a requirement to report in accordance with mandatory EU sustainability reporting standards to be developed by the European Financial Reporting Advisory Group; and (iv) require companies to digitally "tag" the reported information, to make it machine-readable and feed into the European single access point envisaged under the capital markets union action plan.

2.2 The national policy mix to achieve climate targets

This section provides an overview of the climate policy measures being taken by EU Member States. Member States are relying on a variety of tools to encourage economic agents to reduce CO2 emissions. The focus of this section is on environmental tax policies, public expenditure measures and regulatory interventions (command and control policies), which are to a large extent triggered by initiatives at the EU level. Furthermore, this section discusses the role of environmentally harmful policies.

Figure 1
Overview of fiscal policy measures to support the green transition



Source: ECB staff.

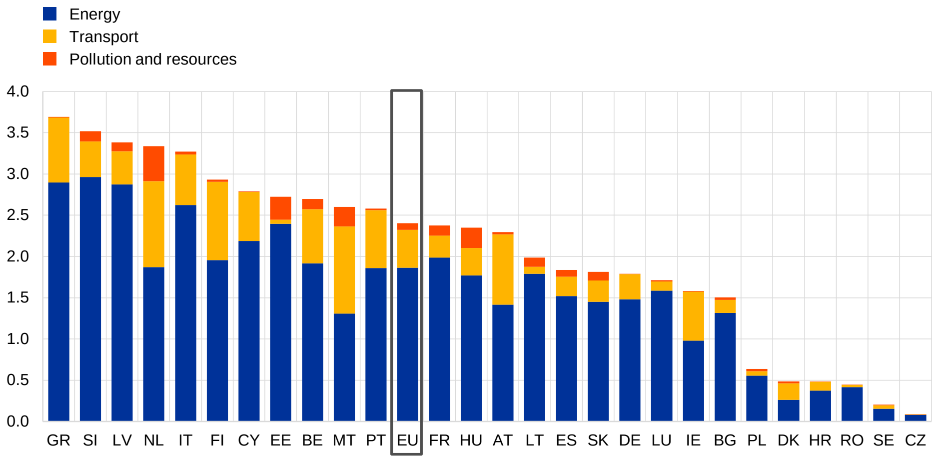
Environmental taxes and carbon taxation

All EU countries have environmental taxes in place, though often at moderate levels. Overall, environmental taxes are low compared with EU countries' total tax burden, representing only 5% of their total tax revenues (2.4% of GDP in 2018). Both their share of total tax revenues and the composition of environmental taxes have remained broadly stable since 2010. The bulk of the environmental taxes is attributable to energy taxes, which comprise carbon taxes as well as excise duties on energy products (e.g. coal, oil products, natural gas and electricity). They account for around three-quarters of environmental tax revenues in EU countries, notwithstanding large cross-country differences. Other environmental taxes (transport taxes, pollution taxes and resource taxes) account for a much lower share of tax revenues (Chart 12).

Chart 12

Environmental tax revenues across countries

(percentage of GDP, 2018)



Sources: Eurostat and own calculations.
Note: Estimates shown for Spain, France, Croatia and Portugal.

Only a few EU Member States have an explicit carbon tax in place. These include Denmark, Estonia, Spain, Ireland, Portugal, Sweden and Slovenia, while in some countries, such as France, Finland and Latvia, taxes on fossil fuels are at least partly explicitly based on CO2 emissions.[28] [29] In 2018 the average explicit carbon tax across all sectors of the economy – weighted by the sector's share in total emissions – varied across countries ranging from 0.1 EUR/tCO2 in Estonia and Spain to around 20 EUR/tCO2 in Finland and France and 25 EUR/tCO2 in Sweden (Chart 13). The implicit carbon tax combines the explicit carbon tax with the EU ETS carbon pricing, weighted by the sector's share in total emissions.

The gap between the minimum carbon prices that are needed to reach the targets under the Paris Agreement and those currently observed remains large. The average explicit and implicit carbon taxes might be overestimated when accounting for the cumulative distribution of carbon taxes, which tends to be strongly skewed if only a small fraction of emissions in an economy is highly taxed, such as liquid fuel. To account for this, the OECD devised a "carbon pricing gap", which compares the percentile distribution of the actual carbon rate with a benchmark, for which the carbon benchmark of 60EUR/tCO2 is used.[30] A high value for the carbon pricing gap points towards only a low proportion of emissions being taxed. Taking Finland, for example, although fossil fuels and biofuels are highly taxed, most other CO2 emissions are only lightly taxed. For the economy as a whole, this results in a

[28] Based on OECD Tax Energy Use 2019 Country Notes and national sources (see Working Group on Public Finances).

[29] In Spain, the carbon tax is only applied to fluorinated gases. Furthermore, in the Czech Republic, although there is no explicit carbon tax, several legislative proposals for carbon taxation have been put forward in recent years.

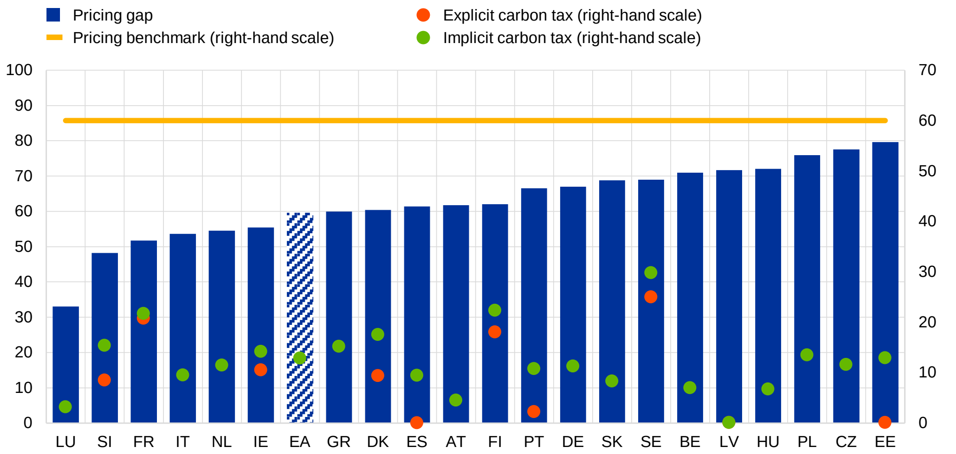
[30] See OECD (2018) and OECD (2019) for a more detailed discussion of the carbon pricing gap and the benchmark. The OECD also replicated the exercise using a less strict benchmark of 30 EUR/tCO2.

carbon pricing gap of 62 percentage points against the benchmark of 60 EUR/tCO2 (Chart 13). More generally, the picture is confirmed by very low explicit carbon tax revenues in the EU, ranging in 2018 from 0.01% of GDP in Estonia and Latvia to 0.3-0.4% of GDP in Slovenia and France (Chart 14).

Chart 13

Carbon taxes and the pricing gap

(percentage deviation from the benchmark; EUR/tCO2, 2018)

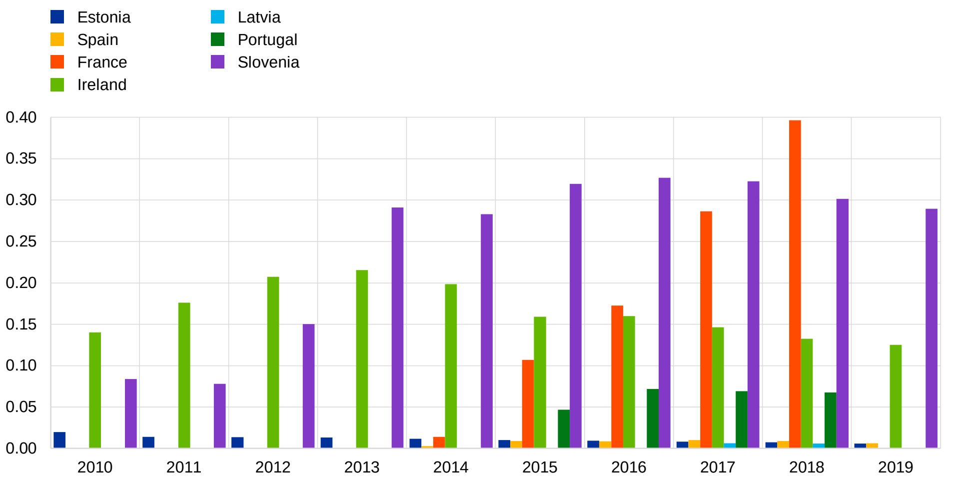


Sources: OECD, European Energy Exchange and own calculations.
Notes: The average explicit carbon tax for 2018 is shown (yellow line), including for countries where a part of fossil fuel taxes is explicitly linked to CO2 emissions. The average implicit carbon tax (red lines) is the explicit carbon tax plus the EU ETS carbon pricing. The carbon pricing gap (blue bars) is measured as the difference between the actual effective carbon rate for every percentile of emissions and a benchmark value for which the OECD benchmark value of 60 EUR/tCO2 (yellow line) is used. A high carbon pricing gap indicates that the distribution of carbon-taxed emissions is strongly skewed towards a few sub-sectors. The carbon pricing gap for the euro area is replicated using a similar, although less granular, approach. No data are available for Lithuania. While the carbon pricing gap incorporates the EU ETS, it is based on data from before the introduction of the Market Stability Reserve.

Chart 14

Explicit carbon tax revenue over time

(percentage of GDP, 2010-19)



Sources: Eurosystem Working Group on Public Finances and own calculations.
Note: The chart shows available data for the EU Member States that have explicit carbon taxes in place.

The sizeable carbon pricing gaps suggest that carbon taxation in the EU is far too low and fragmented to achieve the emission-reduction targets. Deriving an optimal level of carbon taxation is far from trivial, given the high uncertainty regarding the social costs of carbon emissions.[31] Also, this would depend on the underlying assumptions and the efficiency of the other policies in place. Yet, several international organisations, such as the OECD, suggested a rough benchmark of 60 EUR/tCO2 as being reasonable and politically still feasible. The IMF (2019) proposed that a carbon price of 75 USD/tCO2 would be required globally to ensure meeting the Paris Agreement targets (IMF Fiscal Monitor, 2019). More recently, the European Commission simulated the carbon price required in order to achieve the more ambitious EU emission-reduction target of 55% by 2030 under different policy scenarios. Under the scenario that assumes an extension of the EU ETS to cover the buildings, road transport and intra-EU maritime navigation sectors, a carbon price of 60 EUR/tCO2 would be required to meet the 55% target.[32]

The design of a carbon tax has important implications for its environmental and macroeconomic impact. The definition of the tax base (CO2 emissions, or at the source of them), the sectors covered and the use of the funds raised, among other things, can make a substantial difference in terms of correcting the externality and affecting the income of the agents from an aggregate perspective (Box 3). In a recent empirical study, Metcalf and Stock (2020) analysed the macroeconomic effects of carbon taxation for 31 European countries over the past three decades, in which they did not find any negative effects on GDP and employment. In the same vein, Osterloh (2020) illustrates that the impact of existing climate measures on euro area GDP and prices in 2020-22 is expected to be low (see also Box 4).

One important aspect for climate change mitigation relates to the level of and change in energy efficiency and how this determines the energy intensity of certain sectors across countries. To this end, it is useful to look at the implicit tax rate on energy, which sets energy tax revenues in relation to energy consumption, and to compare it with an overall measure of energy intensity by country. Chart 15 reveals a negative correlation between the implicit tax rate of energy and energy intensity. This suggests that higher taxes on energy can encourage a lower energy intensity of GDP, notwithstanding sectoral differences across countries. At the same time, higher energy taxes can also have adverse effects on international competitiveness (Box 3), which provides a case for the introduction of a carbon border adjustment mechanism, also with a view to reducing the risk of carbon leakage (European Commission, 2020).

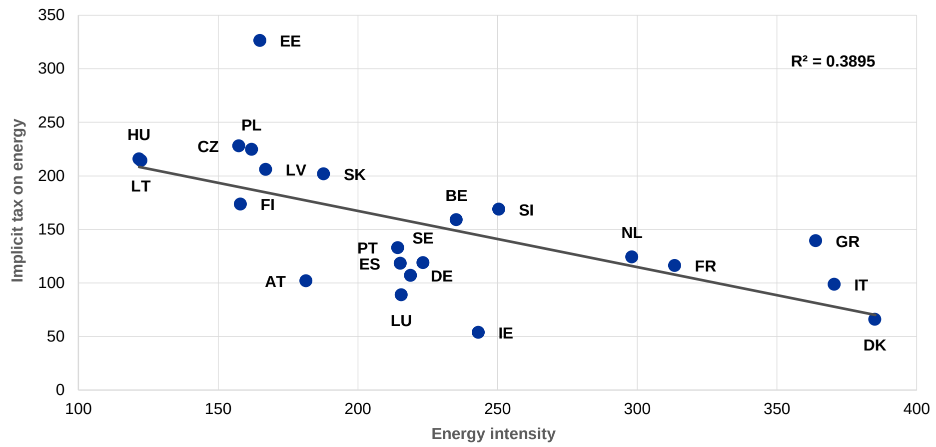
31 For a discussion of various estimates of the social cost of carbon emissions, see Gillingham and Stock (2018) and Wang et al. (2019).

32 In the various scenarios set out by the European Commission (SWD, 2020, p. 176), which differ in the importance of the policy instruments, including regulatory policies, the required EU ETS carbon price varies between 32-65 EUR/tCO2.

Chart 15

Energy intensity and implicit tax on energy

(y-axis: EUR per tonne of oil equivalent, 2018; x-axis: kg of oil equivalent per thousand EUR)



Sources: Eurostat and own calculations.
Note: The implicit tax rate on energy is the energy tax revenues in relation to the corresponding energy consumption, expressed in oil equivalent.

Climate policies on the expenditure side

The expenditure measures adopted by various countries to combat climate change are many and varied. Policies range from transfers to households and subsidies to firms to incentivise emission reduction – mainly through the use of cleaner technologies, electricity generation from renewable energy sources and energy-efficient activities – public expenditure for environmental purposes and public R&D spending to promote cleaner technologies and climate change mitigation. Next Generation EU, with its focus on green transition, has provided further impetus to climate policy measures on the expenditure side, including through measures to increase the energy efficiency of buildings, foster renewable energy sources in electricity generation and provide targeted support schemes, by promoting public transport, for instance.

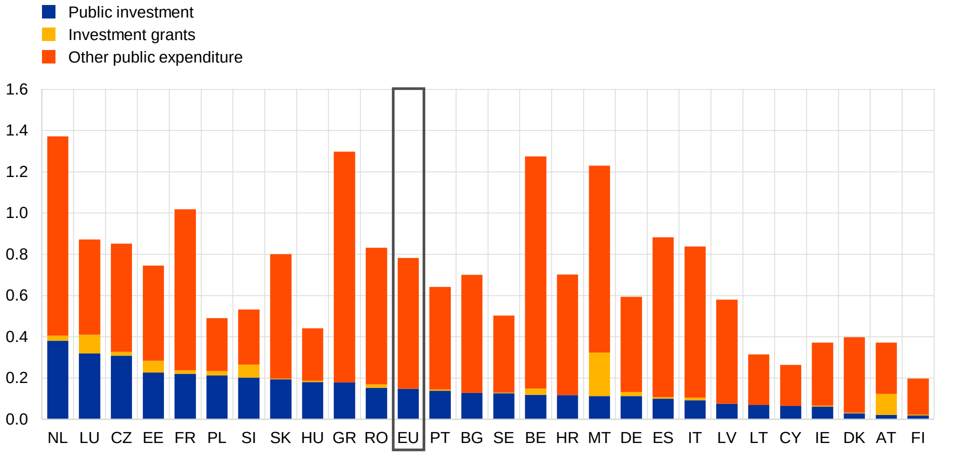
As regards public investment expenditure on environmental protection, EU Member States spent, on average, 0.15% of GDP in 2018, ranging from 0.02% in Finland to 0.38% in the Netherlands (Chart 16). These shares have remained broadly unchanged over time. Investment grants related to environmental protection seem less significant, with the exception of Malta (0.2% of GDP) and Austria (0.1% of GDP). Based on information from the Eurosystem Working Group on Public Finances, funds have mostly been invested in energy efficiency and clean energy usage in public buildings (e.g. renovations, installation of renewable energy systems), public transport (e.g. in Latvia and Lithuania), the electric car charging infrastructure and e-mobility research, as well as in “cleaner” electricity generation (e.g. in Greece). Although public investment in environmental protection accounts for only a small fraction of total related public expenditure, it can be expected to have a relatively high multiplier effect compared to other climate change measures.

As regards R&D expenditure on environmental protection, EU Member States spent, on average, only 0.03% of GDP in 2018. At the country level, it ranged between close to 0% in Cyprus, Greece, Lithuania and Romania and 0.08% in Italy.

Chart 16

Public expenditure on environmental protection

(percentage of GDP, 2018)



Sources: Eurostat and own calculations.
Notes: Total public expenditure on environmental protection is the sum of public investment in environmental protection (blue), investment grants (orange) and other public expenditure (yellow). Estimated data are shown for Portugal. Decomposition including investment grants is not available for Bulgaria, Croatia, Lithuania or the EU.

Regulatory policies

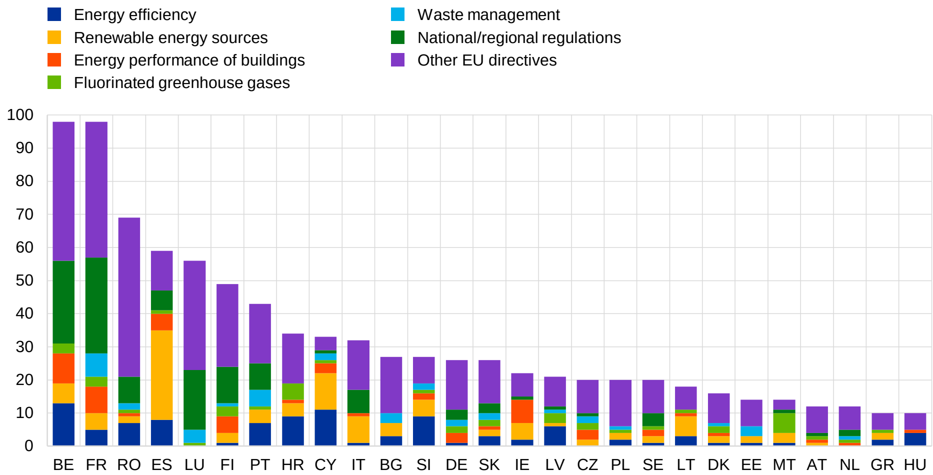
To foster climate change mitigation, several different regulatory policies have been adopted at both the national and the EU level.[33] These command-and-control policies take the form of regulations (i.e. permission, prohibition, standard-setting and enforcement), in contrast to economic instruments which rely on financial incentives. The number of national regulations to mitigate climate change has increased considerably over the past two decades, as they reflect, to a large extent, the national implementation of regulatory initiatives at the EU level. The numerous regulatory policies in place today cover a wide variety of areas, ranging from standards on the energy performance of buildings to regulations on energy efficiency more broadly and the use of renewable energy sources. Overall, most regulations focus on energy efficiency and renewable energy sources in line with the respective EU targets, but the number of regulations does vary considerably across countries (Chart 17). For example, Belgium and France have ten times more regulations in place than the Netherlands, Greece or Hungary. That said, the number of regulations itself does not necessarily provide a good indication of their effectiveness and may simply reflect other factors, such as the different degree of federalism across countries.

33 This overview of different climate change policies does not assess their effectiveness. For a further discussion, see, for example, IMF (2019b).

Chart 17

Regulatory policies on environmental protection

(number of policies, 2019)



Sources: European Environment Agency and own calculations.
Notes: The chart shows the cross-country distribution of different regulatory policies for environmental protection at the EU and the national level. While many of the regulations are directly linked to climate change mitigation, the chart also covers regulations related more broadly to environmental protection (e.g. waste management). The category "Other EU directives" covers a variety of regulations, including standards on CO2 emissions, from cars to vans, promotion of energy efficiency in the agricultural sector and promotion of clean and energy-efficient road transport. The category "National/regional regulations" covers those standards that are not linked to an EU regulation.

Eliminating environmentally harmful policies

Besides active climate change mitigation policies, cutting environmentally harmful policies is also expected to be beneficial for the environment, in addition to the positive budgetary effects. Environmentally harmful policies mainly comprise transfers and tax abatements (such as tax exemptions or tax credits) to households and firms. Often these policies were originally designed for other purposes, such as distribution and competitiveness, and their potentially damaging impact on the environment was ignored.

Among the environmentally harmful policies, tax expenditure on energy taxes plays a larger role than budgetary transfers. This can be measured by the differences in the effective tax rate, expressed in tonnes of CO2 emissions, across fossil fuel products and sectors. If there were no environmentally harmful tax expenditures, CO2 emissions from energy use would be taxed uniformly, at least when abstracting from other instruments such as the EU ETS. Chart 18 shows the effective carbon tax rate by energy source and across different sectors. This varies considerably across energy sources, albeit at varying degrees across countries. It is generally higher for fuels, due to relatively high fuel excise duties, than for heating oil, natural gas or coal.[34] Moreover, even within the group of fuels used for transport purposes, diesel enjoys a tax privilege over petrol. Several countries try to partly

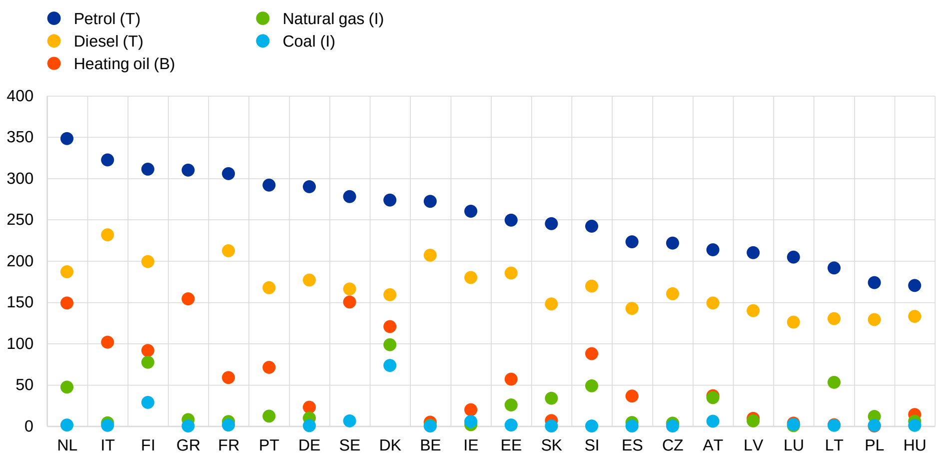
34 The low effective tax rate for coal reflects its coverage by the EU ETS.

offset this privilege by higher vehicle or registration taxes, which do not, however, affect the marginal cost of using a car.[35]

Chart 18

Effective carbon tax rates by energy source across different sectors

(EUR/tCO2, 2018)



Sources: OECD and own calculations.
Notes: The chart shows the effective carbon tax for various energy sources, based on the tax rates applicable in July 2018. The energy sources represent different sectors of the economy: transport sector (T); the buildings sector (B); and the industry sector (I) (excluding the sectors covered by the EU ETS). No data are available for Bulgaria, Cyprus, Croatia, Malta or Romania. The data are sorted by the effective carbon tax rate for petrol. No effective carbon tax rate reported for coal for Latvia or Portugal or natural gas for Sweden.

Examples of environmentally harmful tax credits include favourable company car taxation. Several countries (Belgium, Bulgaria, Germany, Greece, France, Italy, Latvia, Lithuania, Hungary, Malta, Portugal, Poland and Finland) apply a favourable tax rate for private use of company cars or offer fuel vouchers, thus distorting the price signals for the cost of car ownership and fuel consumption and affecting ownership and model choice as well as driving habits.[36] Another example are tax abatements for commuters where granted solely on the basis of the distance between work and home, irrespective of the means of transport used, as is the case in Germany and Austria. Such tax credits might not only disincentivise the use of public transport, but also affect location choices, fostering urban sprawl. Moreover, international and domestic aviation enjoys tax abatements (e.g. tax exemption for kerosene, VAT exemption for international flights), despite intra-EU flights being covered by the EU ETS.

Furthermore, several countries provide tax reductions or tax rebates for energy-intense industries, partly to compensate for higher costs related to the EU ETS. In Germany, for example, the manufacturing, agricultural and forest sectors benefit from electricity and energy tax reductions of up to 60% of standard tax rates for electricity and heating fuels (natural gas and liquefied gas) and up to 73% of the

35 See European Commission (2015), "Tax reforms in EU Member States - 2015 Report", *Taxation Papers,* No 58.

36 See European Commission (2015), op. cit.

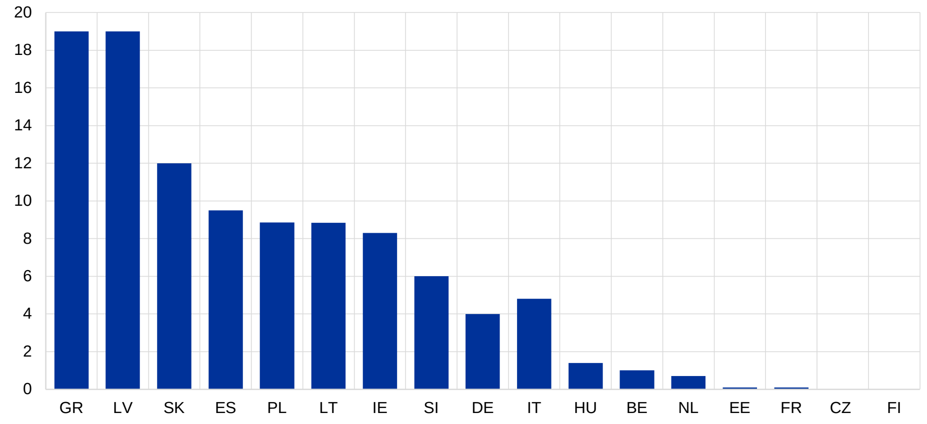
standard rate for heating oil.[37] Austria provides energy tax rebates for the manufacturing sector amounting to 0.1% of GDP.

Comparable cross-country data on environmentally harmful expenditure policies are in short supply.[38] The OECD collects information on public transfers to promote fossil fuel production and/or consumption, which shows large differences across countries and time. Although direct budgetary outlays have declined since 2010 in many EU Member States, notably in Belgium, the Czech Republic, Hungary, Estonia and France, environmentally harmful subsidies still remain in several countries.[39] In 2019 transfers in support of fossil fuels amounted to almost 0.2% of GDP in Greece and Latvia (Chart 19).

Chart 19

Public transfers in support of fossil fuel production and/or consumption

(percentage of GDP, 2019)



Sources: OECD and own calculations.

Public expenditure measures in support of fossil fuels are environmentally harmful, as they can incentivise higher emissions and/or higher levels of resource extraction. Such measures can also reduce incentives to invest in environmentally friendly alternative products or technologies, thereby giving rise to implicit environmental costs. Budgetary transfers in support of fossil fuels across EU Member States are mainly focused on:[40]

(i) supporting energy consumption by (low-income) households and/or in remote areas (e.g. Belgium, Cyprus, France, Greece, Hungary, Ireland and Italy). In Belgium, for example, the heating social welfare fund provides grants to low-income and indebted households to support the consumption of heating oil. In Greece, oil companies

37 See European Commission (2013).

38 While the examples given provide an indication of the importance of environmentally harmful expenditure, they do not meet the criteria for a fully fledged database to assess and compare the order of magnitude across countries.

39 According to the OECD, these support measures are considerably larger than those given to renewable energy.

40 Based on information provided by the Eurosystem Working Group on Public Finances and the OECD database on public transfers in support of fossil fuels.

receive a subsidy for supplying petroleum products to remote areas. In Slovakia and Poland, in-kind benefits for miners include the provision of free coal for heating purposes;

(ii) research, development and demonstration (RD&D) funding related to the production, storage, transport and distribution of fossil fuels (e.g. France, Italy);

(iii) providing State aid to energy-intensive industries to compensate for indirect carbon costs. In the Netherlands and Finland, energy-intensive industries are compensated for the increased costs and loss in competitiveness that result from higher energy prices due to the EU ETS.[41] In Slovakia, electricity produced from domestic coal has been subsidised since 2005, while at the same time a State aid scheme exists to facilitate the closure of uncompetitive coal mines.[42]

2.3 Towards an enhanced policy mix

Among the various policy measures available, appropriate carbon pricing is widely seen to be most important for any successful mitigation strategy. By internalising the externalities associated with carbon emissions, carbon pricing gives economic agents an incentive to find ways to conserve energy and switch from high- to low-carbon activities (Akerlof et al., 2019; Farid et al., 2016; Parry et al., 2012; Parry et al., 2015). A predictable gradual path to a higher carbon price will spur investment in green technologies and infrastructure and is considered an effective instrument to promote innovation in clean technologies (Aghion et al., 2015). Adequate carbon pricing would also ensure that the composition of capital spending is consistent with decarbonisation and reduce the risk that the transition is accompanied by excessive investment in the wrong sectors and the accumulation of bad debt. Incentives can be strengthened further by reducing environmentally harmful policies such as distorting levies and surcharges.

Carbon pricing would generate significant fiscal revenues that could be used to reduce more distortionary taxes and support the groups most vulnerable to transition (Krogstrup and Oman, 2019; IMF, 2019a, 2019b, 2020). One concern over carbon pricing is that the implied increase in energy prices not only has the potential to suppress labour demand in energy-intensive sectors but also to disproportionally reduce the purchasing power of low-income households, which spend a larger share of their income on heating and mobility. At the same time, carbon pricing increases government revenues. For instance, the OECD (2017) estimates that a carbon price set at €30 per tonne would generate revenues – on average across G20 countries and considering current emission levels – of almost 1% of GDP. This additional revenue could be recycled to ease the impact of the transition on low-income households. Carbon pricing could even generate a “double

41 In Finland, Treasury data show that the compensation for EU ETS indirect costs for energy-intensive industries was €29.1 million in 2019.

42 Based on information provided by the Working Group on Public Finances (Národná banka Slovenska).

dividend" (Botta, 2018), i.e. the efficiency costs of a revenue-neutral environmental tax reform would be lower if the additional revenues generated from carbon pricing were recycled through a reduction in other more distortionary taxes (e.g. taxes on labour or capital income) that affect the economy by discouraging investment and labour force participation.

Carbon pricing and emissions trading are the most prominent carbon pricing models. Both carbon pricing systems reduce emissions wherever it is most cost-effective, can achieve the same carbon prices and can raise the same amount of revenue. Nevertheless, there are important differences. Carbon taxes provide more certainty about future prices and can be easily complemented by other supplementary policies, while emission reduction is achieved only indirectly via price incentives. Given uncertainty about future technologies and abatement costs, the actual emission reduction can therefore deviate significantly from the desired path. On the other hand, an emissions trading scheme provides more certainty about the quantity of emissions but implies higher price volatility (IMF, 2020).

Carbon pricing might also incorporate carbon border adjustments or an international carbon price floor to reduce emission leakage. In the absence of international coordination, carbon pricing may lead to carbon leakage, a flight of polluting companies to other countries where such a tax does not exist.[43] According to the IMF (2019b), a uniform carbon tax that cuts emissions by 50% in the EU would increase emissions by 15% in the rest of the world for each unit of EU emissions avoided, as the EU would turn to importing or outsourcing energy-intensive goods instead of producing them domestically. One way of mitigating this drawback is through a carbon border adjustment – a levy charged on imports and exports to ensure a level playing field given carbon prices levied elsewhere. However, measuring embodied carbon in traded goods can be contentious and carbon border adjustments risk retaliation (Keen and Kotsogiannis, 2014). An alternative way of reducing leakage and bringing down global emissions is to introduce an international carbon price floor, at least for the largest emitting economies, including the European Union, China, India and the United States (IMF, 2019b). Nordhaus (2015) argues that a regime with low trade penalties on non-participants, a "climate club", can induce a large stable coalition with high levels of abatement.

An appropriate design for carbon pricing is key. The IMF (2019a) presents several elements of an appropriate carbon pricing mechanism. First, wide-ranging coverage of emissions is crucial. Carbon prices should incorporate not only the environmental costs of emissions associated with climate change but also local air pollution, traffic congestion, road damage and accidents. Co-benefits in terms of innovation and productivity growth, among other things, should also be reflected in carbon prices (Aghion et al., 2009). Second, carbon prices should be aligned with

[43] The relevance of energy prices for international competitiveness is documented in Faiella and Mistretta (2020). The authors show that unit energy costs (UEC), defined as total energy costs as a percentage of the value of production, have become progressively more relevant: UECs increased from 3.1% in 2000 to 4.7% in 2015. Also compared with unit labour costs, energy costs have been constantly increasing. Modelling the relationship between firms' foreign sales and the UEC in a gravity model set-up, the study finds that an increase in energy costs reduces bilateral exports, with euro area countries showing the largest negative effects. These results suggest the need for specific policies to limit the effects of the European climate strategies on industrial competitiveness.

mitigation objectives, implying a predictable steady increase in carbon prices over time to help mobilise low-carbon technology investment. Third, efficient use of the additional fiscal funds generated is essential.

Complementary structural policies have an important role to play in supporting the transition to a climate-neutral economy. The transition to a carbon-neutral economy will imply a massive structural transformation of the European economy. Beyond appropriate carbon pricing, the large-scale reallocation of resources from high- to low-carbon activities requires flexible and adaptable labour and product markets, as well as well-functioning financial markets. In addition, efficient frameworks, such as good conditions for research and the adoption of new skills in the labour force and a favourable environment for the propagation of new technologies, make an important contribution to a successful transition by facilitating the structural change required to put green production practices in place (German Council of Economic Experts, 2020).

The transition to a low-carbon economy requires large-scale public and private investment in new technology which, through exports of new technology, could also help to achieve global climate targets. Achieving climate neutrality will require scaled-up public investment in low-emission and climate-resilient infrastructure (for example in local public transport, or in the grid and electricity storage infrastructure) together with measures to incentivise the search for innovation and new business models. The use of government funding can accelerate the introduction of new technologies in the areas of research funding, workforce training and infrastructure investment. Public expenditure measures, such as low-carbon investment subsidies or outright public investment, are particularly relevant since they can lock in the type of energy mix used for a long time and help resolve the chicken and egg dilemma in public transport and urban infrastructures, for example. Government support is needed to address the knowledge spillovers from research and development that may prevent their full social benefit being captured. In addition, technology barriers are particularly acute in the clean energy sector, as energy technologies often require networks and have long lifetimes and high upfront costs, and face uncertain returns (Smulders and Zhou, 2020). Such policy measures would increase the options for replacing carbon-intensive goods with low-carbon alternatives. For a given carbon price, this would then lead to a stronger adjustment response from high- to low-carbon options. At the same time, government support measures should be carefully designed to mitigate the risk of wasteful spending and avoid negative side effects caused, for example, by promoting new technologies irrespective of their future costs and preventing open competition between new technologies (IMF, 2019b, 2020; German Economic Council, 2020).

2.4 The macroeconomic impact of mitigation policies

This section assesses the macroeconomic impact of transition policies using a number of scenarios. The NGFS has set out a set of scenarios that can be used for macro-financial analysis, relying primarily on existing IPCC mitigation and adaptation pathways (Network for Greening the Financial System, 2020a). The

Banque de France has used some of these scenarios to assess transition risks and quantify their macroeconomic, sectoral and financial effects. These are used as input into a bottom-up stress-testing exercise conducted by the French Prudential Supervision and Resolution Authority (see Allen et al., 2020). The use of scenarios in climate science is motivated by the uncertainty associated with climate change. Unlike usual quantitative risk assessments, the probability distribution of risks observed in historical data is a poor guide in the case of climate-related risks, as most of them have not been observed to date. The comparison of different possible outcomes therefore provides an illustration of the variety of plausible outcomes. The following discussion provides further details on the approach and the economic findings.

Building on the NGFS (2020b), Allen et al. (2020) proposed different transition scenarios, including a baseline scenario – based on an orderly transition scenario – and two adverse scenarios, spanning the period from 2020 to 2050. In terms of narrative, the orderly transition is broadly-speaking a roadmap designed to outline how EU countries can meet their Paris Agreement commitments to achieve net zero emissions by 2050. The two scenarios reflect different assumptions about the likelihood and timing of government action, as well as technological developments and their spillover effects on productivity. Each scenario combines assumptions related to (i) the introduction of a public policy measure (a higher carbon tax); (ii) productivity shocks resulting from the insufficient maturity of technological innovations (higher energy prices, including for low-carbon sources of energy that may not meet expectations); and (iii) the crowding-out effects on investment in non-energy sectors (lower productivity gains than expected in the orderly scenario). Figure 2 presents the three stylised scenarios in terms of their implied CO_2 emission profiles.

The orderly transition scenario assumes climate policies are introduced early and become gradually more stringent. Net zero CO_2 emissions are achieved by 2050, giving a 67% chance of limiting global warming to below 2°C. It is assumed that carbon neutrality will be reached by a combination of a gradual increase in carbon prices (54 USD/tCO_2 in 2025 and 181 USD/tCO_2 in 2050) and ambitious objectives in terms of energy efficiency, GHG reductions and developments in renewable energy. This leads to an increase in the oil price (including tax) of 2.5% per year.

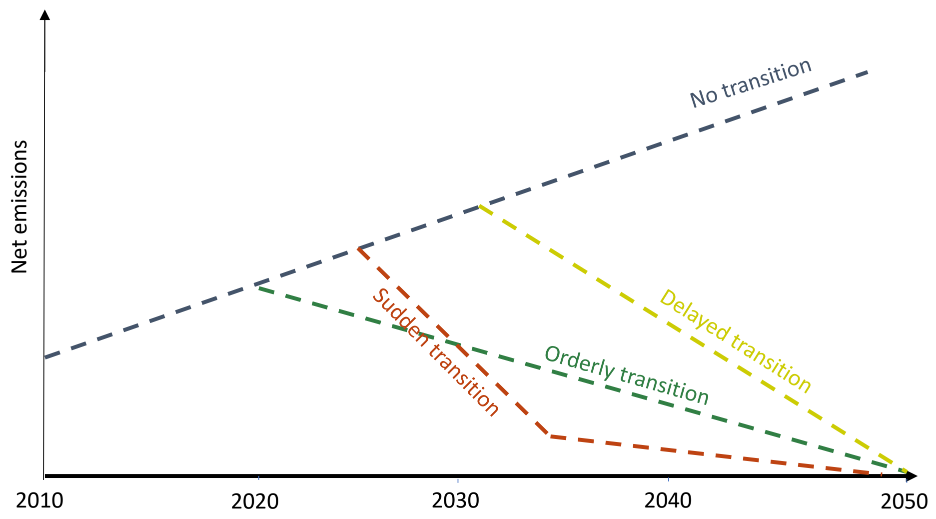
The two adverse scenarios are based on delayed policy action, requiring a steeper increase in carbon prices. Under these scenarios, climate policies are not introduced before 2025 (sudden transition) and 2030 (delayed transition). Since action is taken relatively late and limited by available technologies, emission reductions need to be sharper than under the orderly scenario to limit warming to the same target. The stronger increase in the carbon price leads to higher production costs for firms and losses in purchasing power for households, as the redistribution of the proceeds of the carbon tax is not sufficient to offset the effect of the increase in consumer prices on real income over the entire horizon. This results in higher transition risk.

The first adverse scenario implies delayed policy action and the late introduction of a carbon tax. This scenario relies on a strong revaluation of carbon prices in 2030 in order to maintain the carbon neutrality target in 2050. The carbon price at the global level rises from 14 USD/tCO2 in 2030 to 704 USD/tCO2 in 2050. This results in an increase of 4.5% in the oil price each year. No other measure (beyond those already included in the orderly simulation) is considered in this first adverse scenario.

The second adverse scenario, a swift and abrupt transition, combines a revision in carbon prices with a negative productivity shock (compared with the orderly transition scenario) from 2025. Under this scenario, it is assumed that renewable energy production technologies are not as mature as expected under the orderly scenario, which translates into higher energy prices requiring new investment. The increase in the cost of energy and the necessary redirection of both public and private investment towards renewable and/or carbon-free energy consequently trigger negative effects on aggregate productivity. The trajectory of carbon prices is unexpectedly revised at the same time to reach 3 USD/tCO2 by 2025 and 917 USD/tCO2 by 2050. The oil price rises by 5.5% per year.

Figure 2

CO2 emission profiles of alternative scenarios

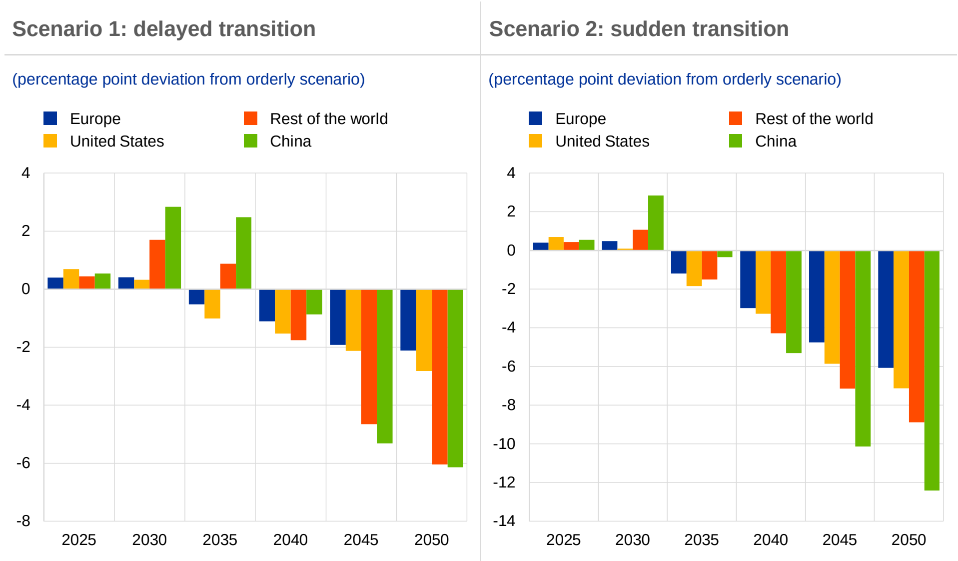


Source: Allen et al. (2020).

To process these narratives, the simulations combine three main modelling blocks. Although the NGFS high-level scenarios provide information about transition policies, emissions, temperatures and GDP for major economic areas, the economic and financial assessment of climate change additionally requires more detailed information on current and future key macro-financial variables at more granular levels. First, the effects of these scenarios on key macroeconomic and financial variables were examined using the National Institute’s Global Econometric Model (NiGEM). The second block consists of the junction with a static multi-country, multi-sector general equilibrium model, including the key features for modelling the effects of carbon price shocks and changes on productivity levels. Finally, a financial block is added to estimate a number of financial variables at the appropriate level of granularity (Allen et al., 2020).

Chart 20 shows the impact on GDP effects of an adverse transition compared with the orderly scenario for the main economic areas. The growth effects are negative by the end of the simulation horizon (2050) under all scenarios. In Europe and the United States, results indicate that real GDP would be some 2% lower under the delayed transition scenario (Scenario 1) than under the orderly transition. This difference would rise to around 6% under the sudden transition scenario (Scenario 2). In the rest of the world, economic activity is expected to be more severely affected by the structural changes embedded in the transition narratives, with the effects varying greatly across countries. In particular, China experiences the largest losses to GDP (around 6% by 2050 under the delayed transition scenario and 12% under the sudden transition scenario). These effects are mainly explained by greater energy consumption and lower energy efficiency compared with advanced economies such as the United States or European countries. In all cases, however, the GDP losses are rather slow to materialise and GDP remains broadly unaffected until 2035-40.

Chart 20
Impact of adverse transition on real GDP level

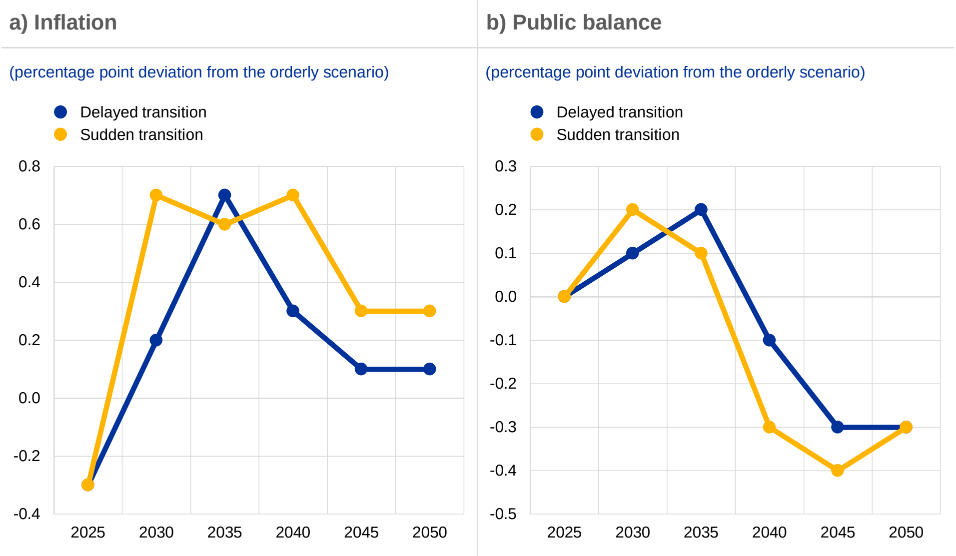


Source: Allen et al. (2020).

In the euro area, adverse transitions are associated with higher inflationary pressure in the long term than under the orderly transition scenario. The inflation response under the adverse transition scenario is negative in the short term (until 2025) but positive thereafter (2030 and beyond) due to the delayed, but more rapid increase in carbon pricing compared with the gradual trajectory of an orderly transition. From 2030 to 2050, the annual inflation rate in the delayed transition scenario is, on average, between 0.1 and 0.7 percentage points higher than the rate under the orderly transition (Chart 21). At the end of the projection horizon, the inflationary effect of the increase in energy prices is limited since it is offset by the disinflationary pressures stemming from the decrease in economic activity. Under the sudden transition scenario, the effect on inflation is relatively stronger than under the previous scenario, as early as 2030, with a 0.5 percentage point increase compared with the rate under the orderly scenario. In addition to a swifter and sharper rise in carbon prices, this scenario includes a decrease in productivity. This negative supply shock causes an additional decrease in activity while maintaining higher price levels. Thus, in 2050, the inflation rate remains higher than in the orderly scenario (by 0.2 percentage points). It is important to note that these simulations were conducted under monetary policy rules that include a certain degree of tolerance of inflation following supply shocks such as carbon price increases, thus allowing for a prolonged deviation of inflation from the aim of close to 2%.

Chart 21

Impact of disorderly transition scenarios on euro area inflation and public finances



Source: Allen et al. (2020).
Notes: Panel a: deviations from orderly scenario of euro area average annual inflation rate in percentage points; panel b): deviations from orderly scenario of euro area public balance as a percentage of GDP.

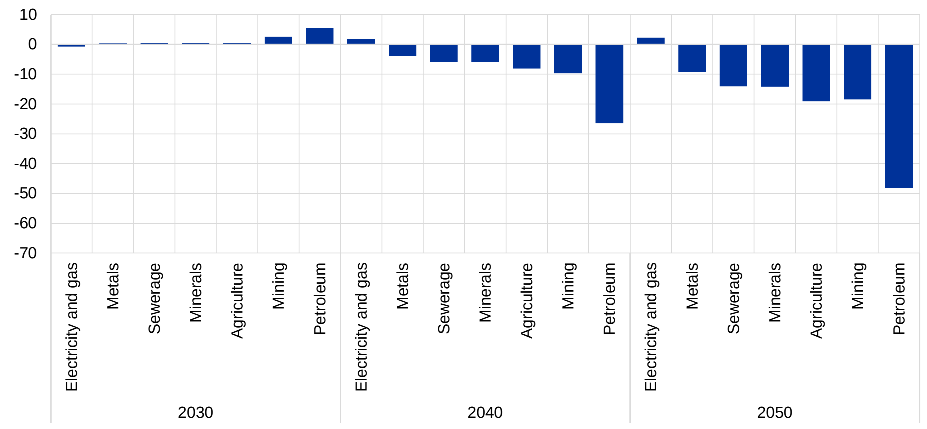
A delayed or sudden transition also has a negative impact on public finances in the long term compared with an orderly transition. The decline in production and employment amid an adverse transition reduces public revenue, whereas the increase in the unemployment rate causes an increase in public expenditure in terms of welfare benefits. The net effect is a deterioration in government fiscal balances in the long term. Ex ante, the carbon tax should provide additional revenue to the government yet, in the assumptions of Allen et al. (2020), these are entirely redistributed to households in the form of lump sums payments. Moreover, fiscal variables are left endogenous and react to the macroeconomic developments following stabiliser mechanisms. No additional fiscal rules (e.g. to limit public indebtedness) are enacted. Due to the deterioration in activity compared with the orderly scenario, government fiscal balances therefore deteriorate by around 0.3% of GDP at the end of the period under both scenarios (Chart 21).

Although the macroeconomic costs of the simulated shocks are fairly mild, the impact by sector can vary significantly and be more substantial. Several studies have quantified the effects of transition policies at sectoral levels. Devulder and Lisack (2020) show that while the most affected sectors are generally those that pollute the most, a carbon taxation policy could propagate to other sectors via their intermediate input consumption. The network structure tends to affect upstream sectors relatively more than downstream ones, given their taxation levels: some sectors, such as mining or chemical products, are disproportionately affected, whereas relatively high-polluting sectors such as motor vehicle repair are affected little.

Chart 22

Sectoral impact of delayed transition on real value added across EU countries

(percentage point deviation from orderly scenario)



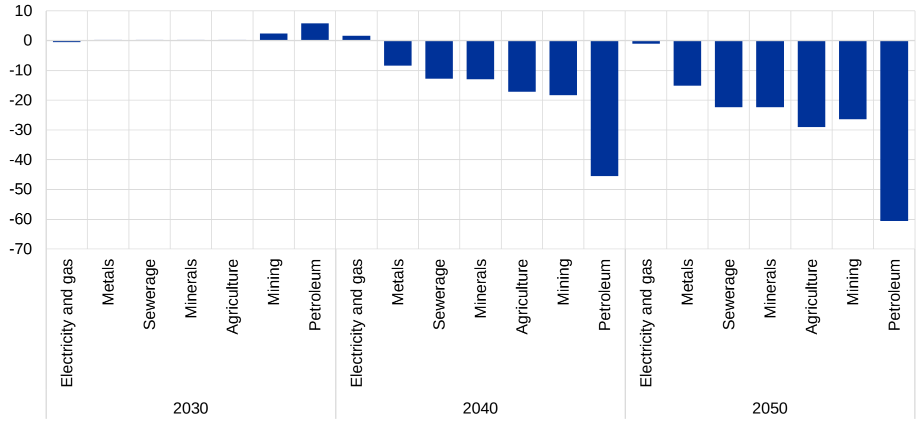
Source: Allen et al. (2020).

There is significant sectoral heterogeneity across the scenarios. Chart 22 shows the sectoral impact of the delayed transition scenario (Scenario 1). A country-wide carbon price may have differentiated, non-linear effects on sectoral outputs, depending on sectoral emissions, substitution possibilities and the sector's upstream or downstream position within the production network. Overall, the extraction and industry sectors are more affected than the service sectors, with the largest losses in the refined petroleum and coke ("petroleum"), agriculture and mining sectors. The former experience a fall in output of close to 50% in 2050 compared with the orderly scenario. In the sudden transition scenario (Scenario 2), the output effects are even stronger, reaching a decline of some 60% in the petroleum sector in 2050 compared with the orderly scenario for the EU (Chart 23). Unsurprisingly, petroleum, agriculture and mining are the sectors most affected. In the EU, their sectoral value-added losses reach 61%, 29% and 26% respectively.

Chart 23

Sectoral impact of sudden transition on real value added across EU countries

(percentage point deviation from orderly scenario)



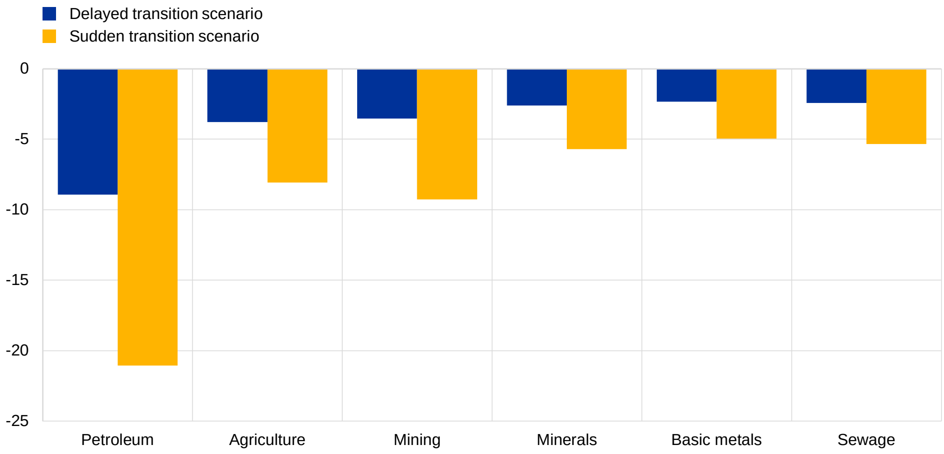
Source: Allen et al. (2020).

Based on the macroeconomic and sectoral results, the impact on equity prices is assessed by discounting scenario-based dividend streams using a dividend discount model. In other words, the simulations assess the relative stock price variation as of 2020 if investors were to re-evaluate their anticipated dividend stream, taking into account the new information from the two adverse scenarios (compared with the orderly scenario). Chart 24 shows the elasticities for climate-relevant economic sectors in the euro area. In the case of the petroleum sector, we observe that a shift today in investors' expectations about the sudden transition scenario (Scenario 2) dividend stream would imply a negative price variation of 20%.

Chart 24

Impact of alternative transition scenarios on equity prices across EU countries

(percentage deviation from baseline)



Source: Allen et al. (2020).

Overall, the results show that the negative economic impact of disorderly transitions in terms of a low-carbon economy is quite tangible. Although the effects at macroeconomic levels remain somewhat limited, the simulated effects on the sectors exposed to the transition policies are substantial. The magnitude of these sectoral effects gives rise to financial stability risks that are potentially much more pronounced than suggested by aggregate results. The disorderly transition scenarios also result in a series of disruptive structural changes across and within sectors, with associated stock market price shocks at sectoral level, increases in credit spreads and differentiated effects on firms' financial stability and probability of default.

While scenario analyses provide useful indications about risks related to certain types of transition, modelling the economic costs is nevertheless subject to significant uncertainty. The effects reflect differences not only in the assumptions made in the transition scenario but also in the modelling approach used. Moreover, the literature is still in its infancy and owing to significant remaining gaps, the level of uncertainty is likely greater than the range provided. These gaps include the feedback uncertainty effects from transition to physical risks, as well as changing consumption preferences or migration. Another important limitation of the model estimates is the lack of interaction between the real economy and the financial sector. These interactions could significantly amplify the overall economic impact, however, as with transition to a low-carbon economy, difficulties may arise in the financial sector due to a loss of profitability in some sectors. This would lead to losses on financial assets, owing notably to asset stranding. These difficulties could then spill over into the real economy and be a significant drag on economic activity.

Moreover, the transition to a low-carbon economy generates costs that may trigger unfairness within the labour force and across countries. The transition to a low-carbon economy requires a gradual transformation of carbon-intensive industries, such as steel production, chemical production or petroleum extraction. The challenge of an orderly transition is to deal with the cost of structural adjustment and address concerns over short-term trade-offs, for example with regard to job losses induced by transition policies. The net effect of decarbonisation policies on jobs also depends on how many new jobs are created in low-carbon activities, in the energy sector (such as solar and wind power generation) and in the economy more broadly. The literature suggests that the net aggregate employment impact of moving towards a low-carbon economy is limited, with 0.3% of jobs affected in OECD countries and 0.8% of jobs affected in non-OECD countries (Château et al., 2018). However, these numbers depend on the sectors and countries in which the transition takes place. For example, the mining and fossil fuel electricity sectors could see an estimated 8% job reduction (Botta, 2018). In general, the job effects depend on the extent of substitution between high- and low-emission activities.

These results provide an illustration of what has been named the "tragedy of the horizon" by Mark Carney, former Governor of the Bank of England (Carney, 2015). The short-term economic costs of transition policies need to be assessed in relation to the positive economic impact of limiting GHG emissions. Any transition scenario should therefore be compared with a "business-as-usual" (BAU) scenario, which includes the physical implications of no policy action. Alestra et al. (2020) illustrate such a trade-off with a long-term growth model. At the 2060 horizon, the net GDP impact is more detrimental under the transition scenarios than under the BAU scenario, as losses from climate policies are higher than the avoided damage at this horizon. At the longer 2100 horizon, however, the net GDP negative impact is lower under the transition scenarios than under the BAU scenario. Over this period, the losses from climate policies are lower than the damage avoided.

The heterogenous impact of climate change at the country level poses additional challenges. Alestra et al. (2020) also show that countries and regions that benefit the most from the implementation of an ambitious climate policy would be those which are most harmed under the BAU scenario. By contrast, the gain is insignificant for numerous developed countries. This illustrates what is usually called the “tragedy of the commons”, i.e. to avoid high losses from global warming in some countries, mainly developing ones, climate policies need to be implemented in all countries, including countries where the gain from these policies could be small. This implies that efficient climate policies need coordination between countries.

Box 2
Implications of the COVID-19 pandemic for EU climate policy

The coronavirus (COVID-19) pandemic led to a sharp decline in CO2 emissions in 2020, which is broadly in line with the annual emission reduction needed to meet the target under the Paris Agreement. The lockdown measures and the decline in economic activity had a marked impact on CO2 emissions. The International Energy Agency estimates that global CO2 emissions declined by 5.8% in 2020 compared with 2019.[44] Le Quéré et al. (2020) estimate an annual decrease of between 4.2% and 7.5% which, they argue, is comparable to the annual rates of decrease needed over the next few decades to limit global warming to 1.5°C. Even limiting global warming to just below 2°C, using the IPCC estimates for a needed 25% decline in CO2 emissions by 2030, would require a 3% annual fall in emissions.

The pandemic-related fall in carbon emissions is likely to be temporary and may not alter the long-term challenges. Emissions will rebound with economic recovery unless policy choices support the transition to a green, sustainable economy. The lessons learnt from past crises, including the 2008 global financial crisis, suggest that crisis-related emission reductions are temporary and are more than offset globally by stronger growth rates in emissions in the subsequent years (Chart A).[45] However, this was not the case for the EU, particularly after the 2008 global financial crisis. In response to the 2008 crisis, the EU and many of its Member States introduced green stimulus programmes and strengthened market-based mechanisms,[46] which helped to reverse the trend of rising CO2 emissions.

The economic impact of the pandemic makes it more challenging to enact the mitigation policies needed to achieve the climate targets in a sustainable manner. The global economic recession in 2020 may make it more challenging to implement the policies needed for mitigation. In addition, the fluctuation in oil prices, such as the sharp decline observed in 2020, may alter the incentives for firms to switch from fossil fuels to low-carbon, energy-efficient technologies; therefore, climate policies play a significant role in stabilising climate-related investment.[47] The fallout from the

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[44] See International Energy Agency (2021).

[45] See OECD (2020a).

[46] See International Energy Agency (2020).

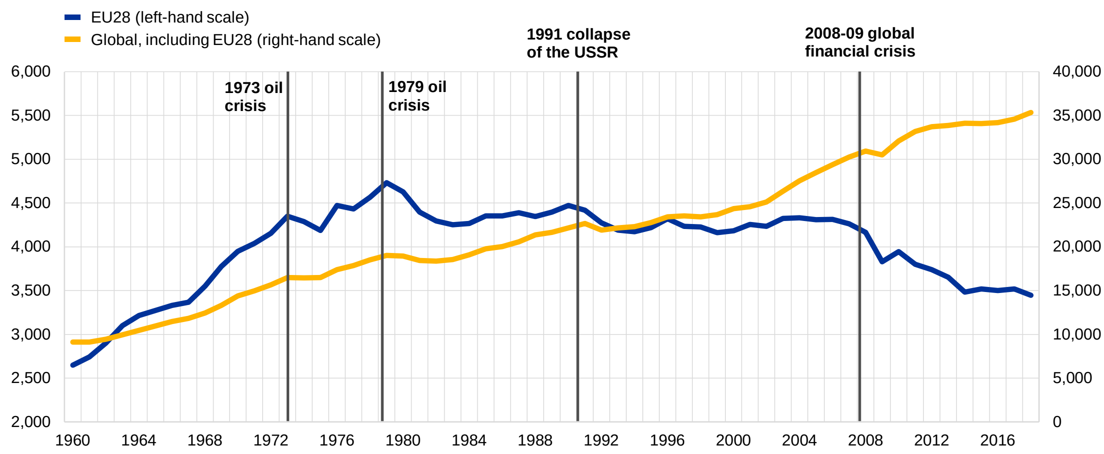
[47] See OECD (2020a) and Dechezleprêtre et al. (2011).

crisis also increases the urgency of understanding how climate mitigation can be achieved in an employment- and growth-friendly way and with protection for the more vulnerable groups of society (IMF, 2020). At the same time, the crisis also provides an opportunity to accelerate the transition to a low-carbon economy. At least 37% of the EU's Recovery and Resilience Facility (RRF) allocation should support the green transition. This could help to achieve a faster reduction in emissions, provided that policies are geared towards green investments and encouraging the private sector to invest in clean technologies.

In order to achieve the envisaged targets, Next Generation EU spending to spur the green transition would need to be accompanied by revised climate targets to make them more ambitious. With the existing cap on emissions, RRF spending on sectors covered by the EU Emissions Trading System (EU ETS) will lower the price of EU ETS emission certificates but without achieving a faster transition to a low-carbon economy. In non-ETS sectors, RRF spending will facilitate compliance with national targets. This implies that the additional resources for green investment under the RRF need to be accompanied by more ambitious targets in order to have a meaningful impact on emission reduction.[48]

Chart A
Greenhouse gas emissions

(million tonnes CO2)



Sources: Global Carbon Project,[49] OECD and own calculations.

Box 3
Economic and environmental impact of introducing a carbon tax in Spain

Estrada and Santabárbara (2021) develop a model and define a set of scenarios to assess the environmental and economic impact of introducing a carbon tax in Spain. The scenarios cover (i) different levels of the carbon tax; (ii) the possibility of a carbon border adjustment; and (iii) different uses of the tax revenues generated (lowering public debt, reducing social contributions or subsidising electricity bills).

48 See Gros (2020).

49 See Gilfillan et al. (2019), United Nations Framework Convention on Climate Change (2019) and BP plc (2019).

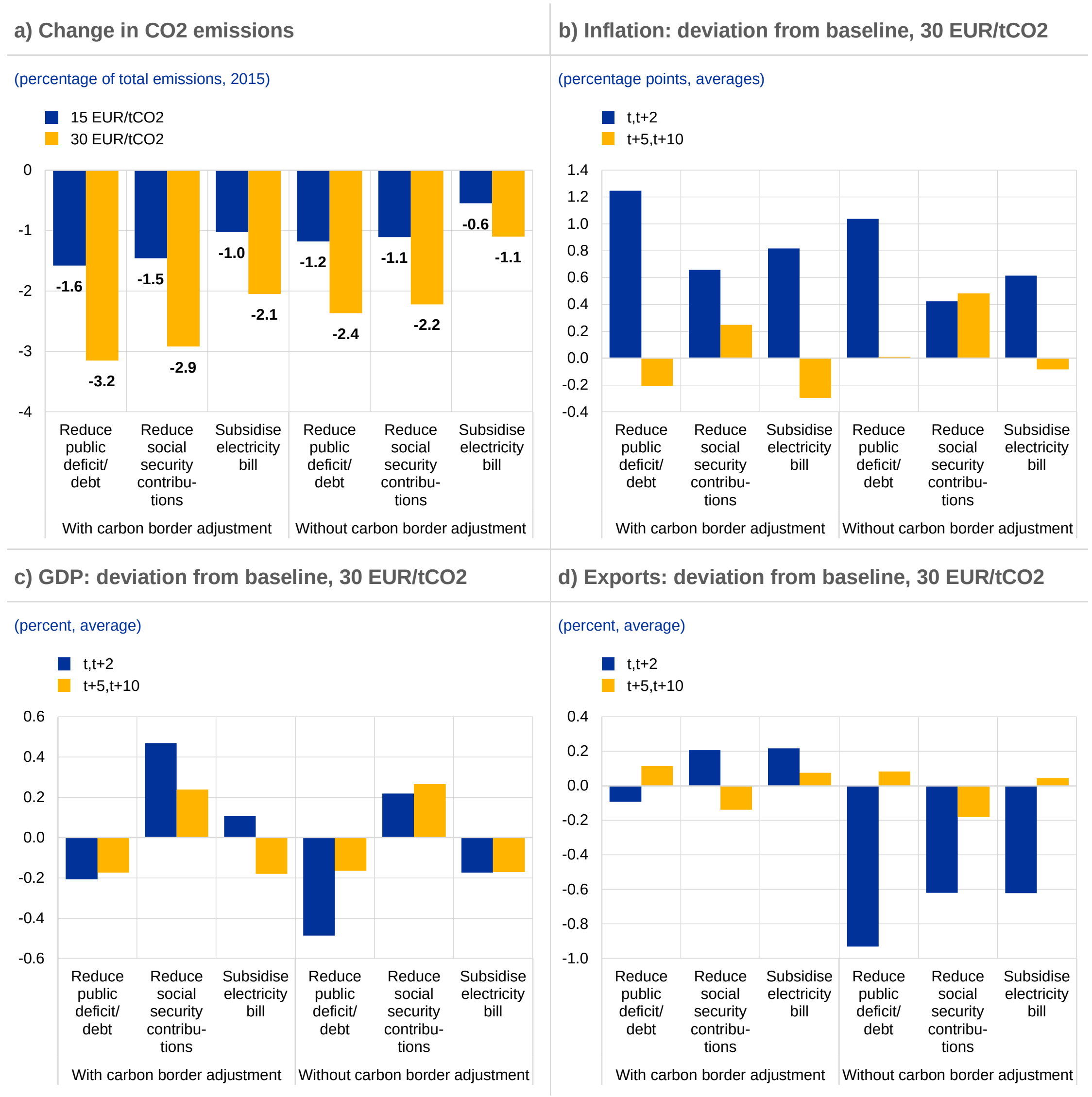
The model consists of two modules that combine sectoral information with a general equilibrium approach. The sectoral module is made up of a static partial equilibrium model for the Spanish economy that combines information from input-output tables, sectoral CO2 emissions, a demand system for households and a demand system for clean and polluting energy inputs. This module obtains results on CO2 emissions disaggregated at the sectoral level. The second module is based on a general equilibrium approach that serves to simulate a parametric tax reform.

The results show that carbon tax designs with carbon border adjustment are more effective for lowering emissions in Spain than those without such an adjustment. The difference is non-negligible and stems from the tax on imports (Chart A, panel a). The introduction of the carbon tax translates into an increase in inflation for households (Chart A, panel b), which reduces their consumption, resulting in a drop in GDP (Chart A, panel c). Exports fall due to the loss of competitiveness (Chart A, panel d) and national production is substituted for imports, as relative import prices fall. Under the scenario with a carbon border adjustment, the reduction in emissions is higher and the decline in GDP is less pronounced than under the scenario without a carbon border adjustment, since the fall in GDP is cushioned by higher domestic absorption.

The results also suggest that carbon taxes can boost economic activity if the revenues are used to reduce more distortionary taxes. When the funds are used to reduce social contributions, labour costs are reduced and employment increases. This raises household income and leads to higher consumption, providing a permanent boost to production (Chart A, panel d). Obviously, the increase in activity will cushion the initial reduction in emissions, but the net effect continues to be positive from an environmental perspective. If the funds are used to subsidise electricity costs, this encourages agents to consume energy, which steers towards a smaller reduction in emissions. The tax increase has an immediate effect on the price of energy inputs, which is transferred to consumer prices and company costs partly offset by the lower electricity bill. The increase in inflation leads households to reduce consumption and, in the case of firms, labour costs increase substantially, since higher wage demands of workers are not compensated by the reduction in social contributions, as in previous simulations. Consequently, the change in GDP is less favourable than when the fiscal revenues are used to reduce social contributions.

Chart A

Environmental and economic impact of introducing a carbon tax in Spain



Source: Estrada and Santabárbara (2021).

Box 4

The impact of a carbon tax on production costs across EU countries

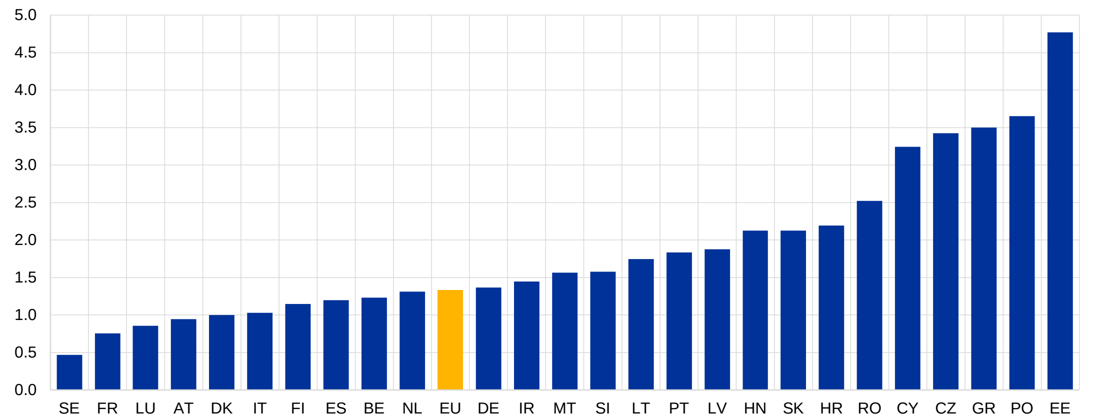
This box discusses the impact of a carbon tax in the EU on production costs and competitiveness. Hebbink et al. (2018) use an input-output model database that includes data on carbon emissions (EXIOBASE, 2015) to calculate the impact of introducing a carbon tax on production costs by country at the sectoral level. They assume that the same carbon tax of €50 per tonne of carbon is introduced across the EU on carbon emissions (including other greenhouse gases) by all sectors. This carbon tax is imposed in addition to the existing taxes on energy and the carbon tax levied as part of the EU Emissions Trading System (EU ETS).[50] The carbon tax is implemented in the EU alone, not the rest of the world. The authors allow for production factor substitution between capital, labour and energy at the sectoral level. However, the dampening effect of this assumption about the increases in calculated cost stemming from the carbon tax is very minor due to low substitution elasticity.

Chart A shows the impact of a €50 per tonne of carbon tax on total production costs (defined as the increase in the GDP deflator) across individual EU countries. The carbon tax increases production costs directly as well as indirectly through higher costs of intermediate inputs used in the production process. In the EU, a carbon tax of €50 per tonne will increase production costs by an estimated 1.3% on average. There are large differences across countries, however. Production cost increases are significantly higher in central and eastern European (CEE) countries than in northwestern Europe. In CEE countries, most cost increases are between 2% and 4%, compared with roughly 1% in most other countries. This is partly a result of the relatively high carbon intensity of energy sectors in CEE countries. Also, the carbon-intensive manufacturing sector often makes up a relatively large part of their economies.

Chart A

Effect of €50 per tonne carbon tax on production costs across EU countries

(percentage change)



Source: Hebbink et al. (2018).

A higher carbon tax also affects international competitiveness. Exporting companies compete in various ways, including in their sales prices, which predominantly reflect production costs. The change in the production costs of a country’s exports relative to the change in costs of exports from other countries it competes with gives a measure of the effect of the carbon tax on price competitiveness. Chart B shows this effect for the different EU countries. Again, there are large differences across countries, mostly due to the differing effects on production costs discussed above. Furthermore, competitiveness is affected by the share of extra-EU exports. In countries such as Greece and Cyprus, the estimated effect of the EU carbon tax on competitiveness is relatively big, because a relatively large share of exports goes to non-EU countries where the carbon tax is not implemented.

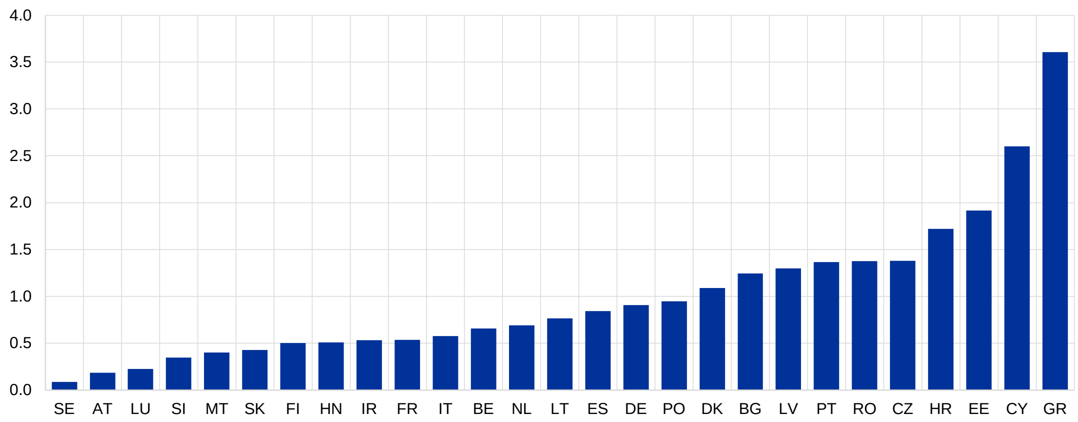
[50] The input-output model is from the international EXIOBASE dataset, based on 2015 data, when the average EU ETS price was relatively low. This implies that the effect of existing carbon taxes on production costs is also relatively small.

This analysis shows that the average impact in the EU of a €50 per tonne of carbon tax on production costs and price competitiveness is relatively modest. However, for around one-third of EU countries, the estimated impact of a carbon tax is considerably more significant. Also, there are large differences across sectors. The carbon tax could have a profound impact on a number of carbon-intensive industry sectors (Hebbink et al., 2018). In practice, the effects of the carbon tax will likely be less pronounced than these estimates, because for some firms it will be cheaper to reduce their emissions than to pay the carbon tax. Furthermore, these estimates are based on production structure data from 2015, while the carbon intensity of production has decreased significantly over the past five years and would likely continue to decrease in response to such a tax, further reducing the impact of any such tax. Finally, the adverse economic impact is much less pronounced when implemented at the EU level than at the individual country level. In addition, it shows the importance of a coordinated effort at the global level to avoid negative repercussions as a result of a loss in competitiveness.

Chart B

Effect of a €50 per tonne carbon tax on competitiveness across EU countries

(percentage changes)



Source: Hebbink et al. (2018).

3 Challenges for macroeconomic modelling

Chapter 3 at a glance[51]

- Climate change poses challenges for the macroeconomic models used by central banks for forecasting and policy analysis. There is a disconnect between climate and central bank macroeconometric models. To better account for climate-related risk, macroeconomic models will need to deal with various sources of asymmetry or heterogeneity, by sector, region, country and types of household, and include a realistic expectation-formation process.

- The complex transmission channels of climate change to the economy suggest that the integration of climate factors into the ECB's economic analysis is best addressed by relying on a combination of macroeconomic models and scenarios. Two main approaches are feasible: (i) a satellite approach, which uses climate models as satellites for the main macro models and reproduces scenario-type analyses by feeding the main macro models with shocks and future paths generated outside the model; and (ii) a modification of the main workhorse models, typically the dynamic stochastic general equilibrium (DSGE) model, which changes the structure of the economy and introduces features pertinent to climate change and mitigation policies.

- The Eurosystem will take several steps to incorporate climate risk into its analytical framework. To take account of climate change considerations in the macroeconomic forecasting process, the Eurosystem Working Group on Forecasting (WGF) first identified a roadmap with four main areas of work (projection narrative, forecasting toolbox, medium-term analysis, scenarios and risk analysis) and five actions to be able to include climate change in the baseline scenario and the risk analysis of the Eurosystem macroeconomic projections. A second part of the modelling strategy will entail the development of new climate-specific models to assess the implications of climate change for the transmission of monetary policy and related macro-financial interactions. Beyond the adaptation of existing models, new climate satellite models will be built to conduct policy and scenario analyses.

3.1 Climate models and their use in economic frameworks

A number of quantitative models, known as climate-related integrated assessment models (IAMs), have been developed to support the research interests of economists, policymakers and, more recently, central banks. Climate-related IAMs typically couple different strands of science to describe how

[51] This chapter largely draws on contributions from the Eurosystem Working Group on Economic Modelling (WGEM) and the Eurosystem Working Group on Forecasting (WGF).

societal or economic developments and the Earth system affect each other.[52] This literature has grown significantly in recent years, covering a variety of models that analyse how climate policies interact with energy-economic systems (Kriegler et al., 2015). In addition, shared socio-economic pathway scenarios are a key ingredient, as population and GDP drive energy demand. A commonality across all models is the key role of carbon and energy prices in control emissions. Within such an IAM framework, it is useful to distinguish between two model categories where the climate system is treated in different ways. While in cost-effectiveness models, a global warming target and a corresponding carbon budget is taken as a given, there is no such constraint under the category of cost-benefit models. Cost-benefit models thus involve an additional factor of uncertainty – namely the uncertainty about the right specification of climate damage – such that a high degree of caution seems to be justified. From a central bank's perspective, climate targets are typically assumed to be exogenous, which suggests that cost-effectiveness models are more relevant.

3.1.1 Integrated assessment models for cost-benefit analyses

The most prominent example of a neoclassical climate-economy growth model is the Dynamic Integrated model of Climate and the Economy (DICE) (Nordhaus, 2008 and 2017). This Ramsey-type model simultaneously solves the trajectory of CO2 emissions and the temperature path for an optimal pathway of consumption. (See Box 5 for the linkage between emissions, temperature, and output.) The models are designed to compare the costs and benefits of limiting global warming to certain temperature levels, but they do not illustrate processes and relationships between the economy, energy systems and the Earth system in a detailed manner. By internalising climate damage from greenhouse gas (GHG) emissions and maximising a social welfare function (often boiled down to the maximisation of the discounted consumption utility of economic agents), such simple IAMs can identify an optimal climate policy – i.e. an optimal level of climate change mitigation.

DICE has become popular for exploring channels through which global warming affects economic growth, though its assumptions about the damage function have been challenged. An important advantage of the DICE model is that modifications to the damage functions or refinements of the climate module can easily be implemented. At the same time, Nordhaus' assumptions about damages and discounting have been criticised.[53] For example, the standard quadratic damage function has come in for criticism, as it yields implausibly low damage at high temperatures. Dietz and Stern (2015) highlight severe economic effects that could result from a significantly higher GDP response to temperature increases, while

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52 Climate models are applied under different model classes, such as economic growth models, overlapping generation models and environmental DSGEs. Even though not all classes are "standard IAMs" (with infinitely-lived agents), many of them can be categorised as IAMs in a broader sense.

53 For a discussion, see Weitzman (2012), Wagner and Weitzman (2015), Dietz and Stern (2015), Fankhauser and Tol (2005) and Glanemann et al. (2020). Dietz and Stern (2015) incorporate several impact channels through which temperature impairs economic growth. Fankhauser and Tol (2005) identify two channels from climate change to long-term growth: capital accumulation and savings rate adjustments. Growth effects are stronger in a model with endogenous technological change.

Weitzman (2012) emphasises the risk of catastrophic outcomes due to fat tails of the damage distribution.[54] Moreover, recent studies suggest that detrimental effects are stronger and last longer when production factors and productivity growth are affected.[55]

Simplifying assumptions about the climate system constitute a second factor of uncertainty. Dietz et al. (2020) gauge the spectrum of possible misspecifications by using the economic framework of DICE. They combine it with selected climate models and find a substantial variation in outcomes for economically optimal carbon prices across models.[56] The outcomes depend critically on whether positive carbon cycle feedbacks are omitted and on the prescribed delay between an emission impulse and the temperature response. These results are in line with Lowe and Bernie (2018), who estimate much lower carbon budgets to meet the Paris Agreement targets when Earth system feedbacks are accounted for. Accordingly, the goodness of IAMs in simulating climate change depends on the assumptions made about the carbon cycle and atmosphere-ocean circulation. Given the uncertainties and possible inaccuracies surrounding the modelling of future climate damage and how to simplify the representation of the climate system, a high degree of caution is warranted with respect to cost-benefit analyses in IAMs.

3.1.2 The cost-effectiveness mode in IAMs

Cost-effectiveness models aim to find a cost-effective solution for economic variables to meet an exogenous policy objective. Cost-effectiveness models are not applied to determine an economically optimal temperature pathway or an optimal level of climate change mitigation. A damage function therefore does not have to be specified. Instead, a social welfare function is maximised under the constraint of limiting warming to a prescribed target (e.g. for the global mean surface temperature). The resulting efficient strategy comprises shifts in regional energy systems and equilibrium pathways for consumption, carbon prices, GHG emissions and energy prices necessary not to exceed these emissions. Depending on the setting, there may be different trajectories for the optimal carbon price at which a climate target can be achieved. Unlike cost-benefit IAMs which rely on very simple climate models, sophisticated multiregional IAMs can embed more complex, process-based representations of the climate system, such as energy balance

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54 According to Weitzman (2012), damage functions are a notoriously weak link in the economics of climate change.

55 See, for example, Piontek et al. (2019), who differentiate between climate shocks that reduce current output, shocks that depreciate capital or labour and shocks that impair productivity. The persistence of climate effects is found to be smallest in the first case, larger for damage to production factors and largest for damage to productivity growth.

56 In a controlled setting, using the DICE economic framework, Dietz et al. (2020) use reduced-form representations of 16 carbon cycle models and 16 atmosphere-ocean general circulation models. Each of the resulting sets of 256 climate models maps cumulative CO2 emissions to a global temperature response. It is shown that different climate model structures and parametrisations cause significant differences in CO2 impulse responses. Dietz et al. (2020) find wide variations in welfare-maximising emissions, temperatures, and optimal carbon prices: optimal warming in 2100 ranges from 2°C to 4°C – solely driven by variations in the formulations of climate models. This warming differential is mirrored in global emissions, ranging from close to zero to 50 GtCO2 per year. To meet a 2°C target in 2100, emission pathways vary considerably across models.

models.[57] A well-known IAM deployed to identify cost-effective pathways is the Regional Model of Investments and Development (REMIND) model developed by the Potsdam Institute for Climate Impact Research. Along with scenario projections from two other large-scale multiregional IAMs (the Global Change Assessment Model and the Model of Energy Supply Systems and their General Environmental Impact), the REMIND projections form the basis on which the NGFS baseline (orderly) scenarios are constructed (Network for Greening the Financial System, 2020a). In turn, the NGFS baseline scenarios are made available to the central bank community to prepare the ground for a macroeconomic impact analysis.[58]

Linking climate models to existing macroeconomic models

Most central banks currently do not have frameworks that comprehensively integrate macroeconomic and climate models in a single tool. For macroeconomic models to make sense of the impact of climate-related shocks, they must contain the basic mechanisms to account for the several transmission channels through which physical and transition risks affect the macro economy (as described in Chapters 1 and 2). Climate models such as the IAMs illustrated in this section include some macroeconomic variables. However, they tend to have highly simplified representations of the economy, most of the transmission channels are absent, and the feedback between the climate and the macroeconomic blocks is limited. Moreover, these models tend to model physical and transition risk channels independently and do not provide an account of the macroeconomic implications at the level of detail necessary for central banks. On the other hand, the traditional macroeconometric models that central banks develop and use for forecasting and policy analysis usually include a wide range of economic mechanisms and can be easily modified to assess some of the channels affected by climate risks, such as a change in commodity prices or supply-side weather shocks. However, such models have several limitations that make them inappropriate for studying the macro-financial effects of climate risks in a comprehensive manner. This includes their limited representation of energy and agricultural systems, the lack of sectoral granularity and their modelling horizon, which is usually limited to the business cycle.

With the climate agenda also becoming prominent for financial institutions, the effort to develop comprehensive frameworks is increasing. Some central banks and financial institutions have started to develop tools to better understand the macroeconomic effects of climate risks (for example, the NGFS with its sub-group on scenario analysis; see also the Task Force on Climate-related Financial Disclosures (TCFD), 2017, and the Bank of England, 2017). Some institutions, such as the Bank of Canada, have adapted available climate-economy models, which have then been

[57] For example, the Model for the Assessment of Greenhouse-Gas Induced Climate Change is an elaborated reduced-form climate model that is able to emulate complex Earth system models in terms of global temperature and reproduces the declining uptake of carbon sinks. The latter refers to the fact that the less CO2 removed from the atmosphere, the more CO2 the carbon sink has already removed cumulatively, and the higher the temperature is. Other climate models are Hector v2.0 (three-part carbon cycle: 1-pool atmosphere; 3-pool land; 4-pool ocean). More complex climate models, such as Earth system models or Earth system models of intermediate complexity, are rarely used in IAMs.

[58] See Chapter 2 for a stress-testing exercise by the Banque de France and Allen et al. (2020) building on the NGFS scenarios. The relevant scenario data can also be found in this link.

applied to other contexts in order to examine macroeconomic, sectoral and technological changes (e.g. the MIT Economic Projection and Policy Analysis 6 model in Ens and Johnston, 2020). Others, such as De Nederlandsche Bank (DNB) or the Banque de France, have translated climate scenarios designed with climate models into a set of macroeconomic effects by using standard multi-country macroeconometric models, such as the National Institute's Global Econometric Model (NiGEM) (see Vermeulen et al., 2018; Allen et al., 2020; and Chapter 2).

A satellite approach seems to be a good starting point for integrating the two agendas. Macroeconometric models are not well-designed to simulate the large structural economic shifts that will follow from the transition to a low-carbon economy. Building a comprehensive tool which is able to provide paths of variables at such a level of detail could prove to be challenging. Therefore, a link using more disaggregated models appears necessary to account for sectoral implications. In fact, the approach recommended by the NGFS relies on a suite of models that translate climate-related scenarios obtained from climate models into macroeconomic, sectoral and financial variables (see, for instance, Allen et al., 2020).

Scenario analysis is a useful tool to assess the macroeconomic implications of climate-related risks. The development and use of scenarios in climate science stems from acknowledging the limits of projections and the deep uncertainty associated with climate change. Unlike usual quantitative risk assessments, the probability distribution of risks observed in historical data is a poor guide for climate-related risks, as most of the risks have not yet been observed. Typically, climate scenarios either describe the socio-economic and policy pathways compatible with a given GHG concentration trajectory, or they illustrate the change in climate implied by such a trajectory. As a result, instead of proposing the best predictions of future outcomes, central banks have thus far worked on scenario analyses through the comparison of different possible outcomes, considering uncertainty through a set of assumptions that can be changed in order to assess the variety of plausible outcomes. The climate-related scenario drivers can relate to environmental conditions, longer-term physical effects, transition policies, technology or consumer preferences. They are translated into shocks related to capital destruction, different levels of carbon taxation, changes in energy and food prices, technological progress or energy demand. As illustrated in Chapter 2, the NGFS proposed a set of scenarios that can be used for macro-financial analysis, including a standardised set of transition risk, physical risk and macroeconomic variables, relying primarily on existing IPCC mitigation and adaptation pathways (Network for Greening the Financial System , 2020a; Allen et al., 2020). Some practical considerations for how to use these climate scenarios to assess macroeconomic and financial risks were also presented in a guide (Network for Greening the Financial System, 2020b).

3.2 Integrating climate risks into central bank workhorse models

Although satellite-based scenario analyses are an excellent short-term solution, macro models and tools need to be adapted somewhat over the medium to long term. While scenario analysis should be part of central banks' forward-looking toolboxes to assess the economic and financial effects of climate change, climate-related risks should also be included in central bank workhorse models to account for their interactions with other, more standard risks within the usual monetary policy horizon (short to medium term). This section briefly outlines how macro and climate tools can be integrated into the main areas of the typical modelling arsenal of a central bank for forecasting and policy analysis, namely time series (nowcasting), semi-structural and structural models. Many of the tools would also benefit from improved statistical data for climate change risk analyses (Box 6).

3.2.1 Nowcasting and short-term forecasting models

Central banks can make beneficial use of nowcasting and short-term forecasting models to forecast the effect of disruptions created by climate change on the output gap and inflation. Weather events have become an increasing source of uncertainty in forecasting real and nominal variables. As a result, the influence of weather events has already been introduced into a few central bank nowcasting models in order to better understand and forecast price dynamics (Batten et al., 2019).

There are several ways to introduce climate-related factors into nowcasting models, depending on the channels through which nominal and real variables are affected. First, extreme weather events primarily affect food prices, and it may be possible to incorporate seasonal and climatic forecast data to better account for expected weather patterns. With a better assessment of deviations from temperature and precipitation norms, central banks may be better prepared to understand possible food price changes. Second, weather events will also affect energy demand and supply, and hence prices. Weather conditions are already included in electricity price forecasting in some economies (see, for instance, a survey by Weron, 2014). There is empirical evidence that models augmented with weather forecasts statistically outperform specifications that ignore this information in the density forecasting of electricity prices (Huurman et al., 2012). Finally, the forecasting benefits of integrating weather variables in models extends beyond food and energy prices and can affect the dynamics of many other macroeconomic variables. Weather significantly weighs on economic activity in the short term, mainly because the outputs of some sectors, such as utilities, construction and retail, are particularly exposed to extreme conditions (Bloesch and Gourio, 2015; Bell et al., 2014).

Also, climate policies need to be adequately reflected in short-term forecasting tools. Forecasting models should also be expanded to account for transition policies and risks – linked to climate policy announcements – because they will affect not only fiscal variables (such as taxes) but also the sectoral composition of the economy, and, depending on the policy design, energy prices.

3.2.2 Semi-structural models

Semi-structural models, the main workhorse models used by ESCB members to inform the projection process, are typically modular and flexible by design and can include new blocks to account for climate change. An attractive feature of semi-structural models in terms of analysing the economic impact of transition risks is their flexibility in accounting for market imperfections (Network for Greening the Financial System, 2019a). In addition, semi-structural models are typically estimated using an error-correction framework, which isolates the short-run dynamics of each variable from their long-run equilibrium value or target. Transition risks and policies can generate large fluctuations in macro-financial volatility in the short run but can also cause structural changes that affect an economy's long-run growth path (Cambridge Institute for Sustainability Leadership (CISL), 2015; Alestra et al., 2020). Accordingly, the ability of semi-structural models to incorporate the differential temporal impact of different shocks is particularly useful when analysing climate change issues over different horizons.

Enhancing mechanisms for semi-structural models

To better reflect climate-related risks, semi-structural models will need to be equipped with key mechanisms. Besides specific instruments for climate change mitigation, these will include the international macro-financial channel and a production structure with an explicit role for the impact of the energy sector on potential output.

International and sectoral dimensions

Existing semi-structural models which have integrated climate considerations are generally multi-country models that explicitly incorporate the international spillovers of climate policies. Models such as the NiGEM (National Institute for Economic and Social Research (NIESR), 2020) are not only well suited to modelling the international macro-financial spillovers of various transition policies or of incorporating transition policy coordination. Under the NiGEM, countries that have implemented carbon taxes can form a "green club" that imposes a carbon border adjustment tax on imports from non-members (NIESR, 2020). Technically, this tax is equivalent to a tariff that increases the relative price of imports. The model also allows for different assumptions about how revenue from the tax is recycled. The cross-country dimension is particularly important in long-horizon models, such as the Advanced Climate Change Long-term (ACCL) model, which incorporate a damage function (Alestra et al., 2020). As it is global emissions that matter for mitigating rising temperatures, it is the joint impact of transition policies on reducing those emissions that will determine their feedback to higher, long-term economic growth and welfare in each country. In addition, these models can capture the international spillovers that arise from the heterogeneous impact of transition policies due to differences in both economic structure and exposure to physical risks.

Global semi-structural models also contain detailed macro-financial linkages that make them particularly suitable for generating stress-test scenarios for financial firms and investment portfolios under different transition risks. The CISL uses the output of the mitigation scenarios from the general equilibrium model (GEM) to analyse the impact on the returns of hypothetical portfolios which vary according to their risk profile, equity/fixed income share and country weights. They show that as transition policies can generate both systematic and non-systematic risk, only some risks are “hedgeable” (CISL, 2015). Vermeulen et al. (2018) and Allen et al. (2020) use the NiGEM to generate several scenarios in order to test the resilience of the financial sector to transition risks related to government transition policies, technological change, and consumer and investor confidence. The results are then used to assess the exposure of financial institutions to industries that are vulnerable to these risks.

Expectations and sentiments are an important transmission channel of the international macro-financial linkages. The relatively detailed treatment of both domestic and international macro-financial linkages in semi-structural models can also be suitable for analysing the impact of transition risks that arise due to a sudden change in the expectations of consumers, firms or financial market participants. This uncertainty about future risks related to climate policies, asset stranding or technological change may generate a significant increase in macro-financial volatility in the short run (Vermeulen et al., 2018). CISL (2015) uses the GEM to examine the impact of shifts in consumer and investor sentiment in response to different transition policies. The short-term effects of a strong mitigation scenario, including lower growth due to high volatility, stranded assets and higher uncertainty about long-term investments, gradually dissipate in the medium term.

Energy sector, transition policies and the long run

A multi-sector model that explicitly includes energy can facilitate a granular analysis of the impact of transition policies. Policy instruments such as carbon taxes affect the economy through their impact on relative energy prices and resemble a typical supply shock. There are at least three ways of incorporating the impact of changes in energy prices on potential output in semi-structural models. The first approach is used by the Yoda model and the GEM; it allows carbon taxes, and hence energy prices, to affect total factor productivity (TFP) in a Cobb-Douglas production function with capital and labour. The second approach includes energy directly as a separate factor of production. Under the NiGEM, potential output takes the form of a constant in which a constant elasticity of substitution bundle of capital and labour is nested in a Cobb-Douglas function with energy and labour-augmenting productivity. The energy component is further decomposed into the output intensity of fossil fuels and renewables (NIESR, 2020). Modelling production in this way allows disorderly transition scenarios to be generated in which the share of renewables rises abruptly due, for example, to an improvement in technology. The third approach to modelling long-run output is more empirically determined and does not impose a theoretical structure on the relation between output and inputs. This allows greater detail to be incorporated for the output determination, particularly in relation to various energy inputs and energy technologies, such as in the Energy-Environment-Economy Macroeconometric Model (E3ME) (Pollitt et al., 2019). In these models, carbon taxes also affect TFP through their impact on relative energy prices. However, the equation for TFP can also include other policy and structural factors that may interact with transition policies over time, such as in the ACCL model, which integrates climate damage functions that are particularly important for assessing the impact of transition policies over long-term horizons (Alestra et al., 2020).

Existing evidence from semi-structural models shows that fiscal and structural policies can be important in supporting the transition pathway. A recent report by the OECD (2017) augments potential output in the Yoda model to incorporate the impact of public capital and lower product market regulation on productivity. A "decisive transition" scenario is simulated in which carbon taxes are calibrated so that there is a 50% probability that the increase in global temperatures is below 2°C by 2050. The study shows that complementing this climate policy with a reduction in product market regulation and an increase in public investment of 0.5% of GDP could raise long-run output in G20 economies by almost 3%, relative to a baseline of no-policy change.

Weaknesses of semi-structural models

Welfare computation, structural changes and non-linear dynamics are often absent from semi-structural models. One potential weakness of the semi-structural approach is that it does not incorporate a well-defined measure of welfare and so provides less guidance on "optimal" transition policies. In addition, these models are estimated, which means that they reflect historical statistical relationships. If the transition to a low-carbon economy leads to significant structural change, these relationships may no longer be stable. Finally, semi-structural models are essentially linear and, accordingly, may not incorporate the non-linear mechanisms to amplify the impact of transition risks (Network for Greening the Financial System, 2019a).

3.2.3 Dynamic stochastic general equilibrium models

The economics profession has started adapting dynamic stochastic general equilibrium (DSGE) models to incorporate both physical and transition risks of climate change. DSGE models can be adapted to include both physical and transition risks. Physical risks are typically modelled by including a climate disaster process in the production sector or an aggregate consumption process or by using temperature shocks as a proxy for climate change. Transition risks are introduced by implementing technological changes or economic policies to arrive at a lower-carbon economy.

The inclusion of physical risk mostly follows the pattern of IAMs. As discussed in Section 3.1, IAMs pioneered the idea that climate change affects economic outcomes. Higher emissions or higher temperatures caused by emissions that are a by-product of economic activities lead to lower production by means of a damage function. DSGE models with endogenous temperature and/or pollution dynamics mostly follow the same approach (Angelopoulos et al., 2013; Cai et al., 2012; Heutel, 2012; Economides and Xepapadeas, 2018; Hambel et al., 2018). There are also exceptions which typically model the temperature process as exogenous (Bansal and Ochoa, 2011; Donadelli et al., 2017; Karydas and Xepapadeas, 2019). A number of models have extended the production side of the economy to a multi-sector set-up, where only one subset of polluting industries produces emissions (Bukowski and Kowal, 2010; Golosov et al., 2014; Traeger, 2015; Donadelli et al., 2019). Some studies (Angelopoulos et al., 2013; Donadelli et al., 2019) also include environmental quality as a public good in the utility function of households to capture the climate change externality.

Various economic policies and technological changes are implemented to analyse transition risks. Among the economic policies simulated using DSGE models are carbon taxes, emission caps with trading-of-pollution permits, and emission intensity targets. Box 5 contains references to an expanding DGSE literature that takes these policies into account.

The way that monetary policy is conducted can influence the effectiveness of climate change policy. The literature that combines climate change (policy) with monetary policy is still quite scarce. Annicchiarico and Di Dio (2015) find that the monetary policy reaction shapes the optimal policy response to climate change in their model. Economides and Xepapadeas (2018) also develop a model including both climate change and monetary policy and point out that climate change gives rise to additional economic shocks that will affect the optimal conduct of monetary policy. Economides and Xepapadeas (2019) incorporate climate change into a New Keynesian model of a small open economy for Greece and find that the loss of monetary policy independence does not matter for the long-run implications of climate change.

DSGE models that include environmental aspects have the potential to become the new workhorse models of central banks, although the literature still needs to evolve. To date, there are no estimated DSGE models with climate change elements in use in central banks. While Gallic and Vermandel (2020) incorporate weather shocks into a DSGE model for New Zealand, their model does not feature monetary policy and has not been developed by central bank researchers. Box 5 provides a review of common modelling approaches and recent applications of environmental dynamic stochastic general equilibrium (E-DSGE) models and their wide range of set-ups. Box 7 applies a macro-financial DSGE model for the transition period from a low-carbon tax to the optimal carbon tax level.

3.3 Implications for Eurosystem projections

This final section complements what has been discussed above from the practical perspective of the Eurosystem/ECB staff economic projection. The Working Group on Forecasting (WGF) reviewed the current status and extent to which issues related to climate change had been included in the staff projections by EU NCBs. Actions to be taken within the scope of the staff projections and processes were also identified to ensure that the impact of climate change and related policies were better captured in the baseline and risk analyses. We report the conclusions and action points of this review in the following section.

3.3.1 Current status of climate-related issues in the projections

The review shows a high degree of homogeneity in the current practices and discussions within the ESCB. A significant number of NCBs emphasise that the forecasting frameworks already take into account some of the most relevant effects over a three-year horizon – namely transition policy measures. This is mainly done using fiscal assumptions. Fiscal measures that comply with the usual rules for inclusion in the fiscal assumptions of the staff projections are taken on board, while policy intentions, which are not yet well-specified or legislated, are treated as risks surrounding the baseline projections. Regulatory changes and structural shifts in the behaviour of consumers and firms are generally not considered, even if they may influence the projections indirectly through macroeconomic data outturns, model re-estimations or expert judgements. Short-term physical risks, such as extreme weather events, are by nature not foreseeable and thus treated on an ad hoc basis as and when they occur, while longer-term physical risks, such as gradual increases in global temperatures or rising sea levels, are considered insignificant for the normal three-year projection horizon.

Only a few NCBs explicitly include climate-related issues in their forecasting toolkits beyond taking on board the impact of government policies in the form of domestic carbon taxes and/or investment plans. Some NCBs have experience in including weather-related variables in nowcasting tools or projecting energy prices at a detailed level, directly or indirectly incorporating factors such as the prices of allowances under the EU Emissions Trading System (EU ETS). While most NCBs do acknowledge the increasing importance of climate-related issues, they have thus far considered the relatively short forecast horizon, the great uncertainties and the absence of an undisputed methodology to be an obstacle to integrating those issues more comprehensively in their forecasts.

3.3.2 Actions to improve the forecasting tools and processes

Macroeconomic projections, in general, and inflation projections, in particular, should attempt to consider the effects of climate change, as well as related policies enacted to mitigate its effects. The stocktaking exercise among forecasters, as well as the analyses in other parts of the Monetary Policy Committee

(MPC) report show, however, that experience is scarce. With this in mind, the WGF identified four areas of work (projection narrative, forecasting toolbox, medium-term analysis, scenarios and risk analysis) and five actions that will be implemented in the near future. Further work could also be undertaken, if regarded necessary.

Improving the projection baseline

The first work stream concerns the baseline Eurosystem/ECB staff economic projections. The general objective of the WGF is to elaborate how to integrate climate-related policies into the projections. To this end, it will extend the scope of the common technical assumption in order to include EU ETS allowance prices (Action 1). Future developments in EU ETS prices are very uncertain, in particular as EU climate policy and 2030 emission targets evolve over time. This means that it is very difficult to forecast such prices. Nevertheless, the Eurosystem forecasting process would benefit from a common assumption being set for EU ETS prices in order to be explicit about what is being assumed, thereby enabling alternative scenarios to be considered. Short-term inflation forecasts would also be improved by enhancing the monitoring of these prices and their pass-through to consumer prices, thereby ensuring greater consistency across countries.

Beyond the EU ETS, it is important to monitor and quantify the effects of other climate-related policies, for both ETS sectors and non-ETS sectors covered by the "effort-sharing" regulation, which are set at the national level. The WGF will regularly evaluate the macroeconomic impact of climate-related policies, for both inflation and GDP (Action 2). The main challenge will be to identify the measures in a comparable manner. First, it could prove difficult to disentangle environmental motives of given policies within a broader set of policy objectives. Second, even if the impact of certain specific climate-related mitigation policies can be quantified (for example, as percentage points to headline inflation brought about because of higher indirect taxation), not enough information may be available to quantify the effects on growth and inflation from other broader government measures or policies, such as control and command regulations. However, even if the WGF recognises limitations in assessing the impact of climate-related policies and the risk of uncertain or inconsistent estimates, it is still important to start gathering information on this topic.

Developing the WGF's toolbox

The second area of work identified by the WGF concerns the toolbox used by forecasters at the forecasting horizon and in particular for nowcasting. The WGF intends to make sure that best practices are consistently used within the ESCB. To this end, in line with the recommendations outlined above in the section on nowcasting, the group will organise a regular discussion on GDP nowcasting and short-term inflation forecasting using climate-related factors. It will also reflect on methodological lessons learnt from projection exercises during the COVID-19 crisis (Action 3).

Although it is widely acknowledged that unusual weather conditions affect economic activity, few central banks across the Eurosystem have attempted to include climate-related data in their forecasting models. Existing models suggest that there are some accuracy gains but that these may be small.[59] A significant number of NCBs often incorporate climate factors into the forecasting exercises based on judgement. With regard to inflation, the focus will be on methods used to project energy prices and food price inflation. With regard to energy, the positive experience of some NCBs in using wholesale electricity data could be followed by other central banks, and the provision of assumptions about carbon prices could be used to develop short-term inflation models incorporating this information. In the case of food prices, climate change is expected to increasingly lead to greater volatility. This may be seen in high frequency commodity price data (such as EU farm gate prices), which are typically included in narrow inflation projection exercise models. Nevertheless, the scope for directly including climate variables could be investigated more systematically.

Changes in the composition of domestic demand are another important characteristic of the potential implications of climate change. However, fully taking into account the implications for private consumption would require a much more detailed level of analysis than is currently done for staff projections. Given the considerable uncertainties, the costs would probably largely outweigh the benefits. Public demand (and infrastructure investment) can be included somehow, either as factors related to the baseline, as fiscal assumptions related to public planning, or those related to output, which are covered by our action below (see Action 4).

The recent pandemic shock and the experience gained in dealing with it in the projection exercises can also be useful for dealing with the inclusion of climate-related shocks in projections. From the point of view of modelling and forecasting, the pandemic was an exogenous shock not unlike natural disasters. Therefore, when thinking about climate change and the forecasting processes, some lessons may also be learnt from it, in terms of both alternative forecasting methodologies and the policy impact.

Medium-term analysis

The third area of work concerns the medium-term analysis beyond the three-year horizon. The WGF will establish a set of principles for analysing the longer-term impact of climate change on output (Action 4). The approach should take into account country heterogeneity (e.g. degree of the impact, country's plans to curb GHG emissions, etc.). Given the standard rules for including fiscal measures in the projections (i.e. only measures which are well specified and very likely to be regulated are included), the baseline medium-term projections currently implicitly assume a (practically) no policy change scenario, even if this may conflict with ambitions to tackle climate change expressed by governments. Under such assumptions, the materialisation of physical risk becomes increasingly likely at

59 See, for example, Pinkwart (2018).

longer horizons and consequently should be included in the baseline scenario with a higher probability. On the other hand, the greater the damage from the materialisation of physical risk, the more mitigation policies could be expected to be implemented.

Alternative projections of output over the longer horizon could thus aim at describing scenarios in which physical risks, such as an increased frequency of extreme weather events, gradual warming and other climate-related events (e.g. sea level rises), would materialise. Extreme weather events and climate-related factors could influence output via productivity, capital accumulation, migration flows and so on.

While the focus, together with the actions proposed for the projection exercise process, would primarily be on mitigation policies, the primary focus of this medium-term analysis would be on physical risk and its impact on output. No NCB has thus far developed longer-term estimates of output that explicitly incorporate the impact of climate change. There are indeed significant uncertainties about the link between output and climate change, however it seems feasible to elaborate a set of proposed principles.

Scenario and risk analysis

The fourth area of work identified by the WGF concerns scenario and risk analysis. Scenario analyses are based on expanding the Basic Model Elasticities, which describe the reaction of national economies to standardised shocks (oil prices, interest rates, exchange rates, confidence shocks, etc.) over a four-year horizon. They are routinely used in the forecasting process to assess the impact of changes in assumptions. They are also employed as the main macroeconomic tool to develop the adverse scenario in the context of the regular European Banking Authority's stress-testing exercises.[60] Expanding the set of Basic Model Elasticities to include additional shocks, such as carbon taxes or new technology, would first require further developments in macro models, as outlined in Section 3.2 above.

For risks analyses, the relatively short horizon of the macroeconomic projections inevitably limits the choice among climate-related risks solely to transition risk, due mainly to changes in public policies or financial disruptions. Further tail events with a large economic impact over the short to medium term, such as extreme weather events, may also need to be taken into account in the risk assessment. Given their unpredictability, however, these "high-impact, low-probability" events should only be considered on an ad hoc basis. Their economic impact may be assessed in specific scenario analyses using different models and tools from those used in the forecasting process. The WGF will include climate-related factors in the risk assessment of the staff projections (Action 5).

60 See, for example, EBA (2020).

Box 5

Environmental dynamic stochastic general equilibrium models: specifications and selected applications

Dynamic stochastic general equilibrium (DSGE) models have become a standard workhorse tool for quantitative policy analysis in macroeconomics. While monetary and fiscal policy issues are regularly addressed within this framework, DSGE models have recently also been adopted to analyse environmental policies and simulate the effects of climate change. Environmental dynamic stochastic general equilibrium (E-DSGE) models range from slightly modified standard frameworks, ignoring the presence of direct adverse pollution effects, to integrated assessment type models, which explicitly include the economy and the climate in a unified framework in order to assess the macroeconomic implications of anthropogenic emissions.[61] E-DSGE models usually feature environmental externalities in a highly reduced form by assuming that pollution – as a by-product of the production process – either negatively affects social welfare directly or the efficiency of production.[62] [63]

One prime example of the latter are the models of Heutel (2012) and Golosov et al. (2014), where the negative effects of pollution are captured by a damage function, implying that a fraction of total output is negatively affected by emissions. As regards the damage function, various specifications are applied in the literature, typically with the intention of capturing the effects of a specific type of emission externality. Popular modelling choices include quadratic damage functions, as in Heutel (2012), or exponential specification, as in Golosov et al. (2014).

An alternative conventional modelling approach assumes that pollution has a negative effect on the utility of households. While some studies simply assume that negative externalities of production directly reduce household utility (see, for example, Chang et al., 2009), others take a more indirect approach by modelling the effects of pollution on environmental quality which, in turn, affects households' utility (see, for example, Angelopoulos et al., 2013).[64]

As pointed out by Weitzman (2012), however, the modelling of damage or welfare losses represents a notoriously weak link in assessing the economic effects of climate change. This is due to both the difficulty of specifying a functional form a priori and the sensitivity of the model results with respect to a particular specification. Various strategies have been employed to specify pollution-induced damage or loss, of which two prominent examples are the "bottom-up" approach and the "top-down" approach (Hassler et al., 2016). In the bottom-up approach, explicit damage to particular regions and economic sectors is defined and aggregated in order to derive a functional representation of pollution-induced damage or losses. By contrast, the top-down approach is

61 As outlined in Cai and Lontzek (2019), the term "integrated assessment models" generally refers to a broad class of analytical frameworks which incorporate models of both the climate and the economy and how they interact.

62 In prototypical E-DSGE models, emissions at the firm level are modelled as a constant fraction of output. While allowing for costly abatement and some form of natural decay, the aggregate stock of pollution usually evolves according to a linear law of motion encompassing domestic pollution, as well as aggregate emissions from the rest of the world.

63 Although, in principle, climate change can also be modelled as having a negative impact on physical capital (see, for example, Dietz and Stern, 2015), pollution-induced output and utility losses appear to be the preferred approach in the E-DSGE literature to capture the macroeconomic consequences of anthropogenic emissions.

64 Instead of postulating a direct relationship between anthropogenic emissions and production or welfare, some studies choose a more disaggregated modelling approach by, first, mapping the pollution level to climate (usually represented by global mean temperature) and, second, mapping climate changes to damages or welfare losses (see, for example, Cai et al., 2012; Cai et al., 2013; Cai and Lontzek, 2019).

designed to estimate a reduced-form relation between aggregate measures such as GDP, consumption and investment on the one hand and climate on the other. As a further caveat, E-DSGE models usually focus on small fluctuations around the steady state. As discussed in Heutel (2012), this may be regarded as a difficult assumption, given that the economy is not likely to be on a steady-state growth path when it comes to emissions.

One typical application for E-DSGE models is the (qualitative) assessment of the short to medium-run effects of different environmental policy regimes. Fischer and Springborn (2011), for example, explore the macroeconomic performance of an emissions tax, an emissions cap and an intensity target, given unexpected changes in productivity. They use a flexible price model of the business cycle and abstract from explicitly modelled adverse pollution externalities, simply postulating the presence of an emission constraint instead. They show that an emissions cap regime is capable of reducing the volatility of most macroeconomic variables considered in the model. Also employing a flexible price model which, however, features production damage from the stock pollutant carbon dioxide, Heutel (2012) concludes that an optimal environmental policy allows carbon emissions to be procyclical (i.e. increasing during expansions and decreasing during recessions). Assuming disutility from pollution, Angelopoulos et al. (2013) compare the second-best optimal environmental tax policy and the resulting allocation to the first-best allocation in a flexible price environment. Allowing for both unexpected economic changes (technology shocks) and environmental disturbances (pollution shocks), among other things they find the Ramsey-optimal environmental tax to be procyclical when there is an economic shock, while it is countercyclical when there is an environmental shock.

While early work in this research area was based on flexible-price models, Annicchiarico and Di Dio (2015) point out the importance of the price stickiness assumption in carbon policy analysis. Specifically, they compare four different environmental policy scenarios (no policy, an emissions tax, an emissions cap and permit trading system, and an intensity target) assuming that the model economy is driven by three temporary exogenous disturbances: a technology shock, a government consumption shock and a monetary policy shock. In their analysis, price stickiness is a decisive factor in shaping the effects of emissions regulations. In particular, an emissions intensity target regime, which sets firms' emission targets relative to their output, is likely to generate a higher degree of macroeconomic volatility when the degree of price rigidity is high. Moreover, they show that welfare is less volatile under a cap-and-trade scheme, while its mean value tends to be slightly higher with a tax policy if the degree of price stickiness is not too high (otherwise, mean welfare appears to be higher under a cap-and-trade policy).

Besides nominal rigidities, other established building blocks from the DSGE literature have also been utilised in E-DSGE model analysis. Annicchiarico et al. (2018), for example, introduce endogenous firm entry into a flexible price E-DSGE model to show that, in response to a gradual emission mitigation policy, firms tend to transfer the higher abatement cost to households by charging higher price mark-ups. By contrast, the number of producers displays a U-shaped behaviour, first decreasing and then increasing, implying a lower market concentration in the long run. Annicchiarico and Dilusio (2019), on the other hand, develop a multi-region E-DSGE model to analyse the international aspects of environmental policies. More specifically, employing an open economy model with two interdependent countries, they show that unexpected disturbances which affect a country may generate spillover effects, whose sign and intensity depend not only on the nature of the shock, but also on the environmental policy regime that is in place.

One of the few E-DSGE studies that explicitly focuses on a markedly lower time frequency (decades), commonly chosen in prominent integrated climate-economy models, is Golosov et al. (2014). Based on a multi-sector stochastic neoclassical growth framework that is augmented to include (carbon dioxide) pollution externalities in such a manner that they directly affect production, they show that, under quite reasonable assumptions, the model delivers a simple closed-form formula for the marginal externality damage of emissions. While providing a blueprint for an optimal (global) carbon tax, the formula reveals that pollution damage is proportional to current GDP, with the proportion depending on only three factors: discounting, the expected damage elasticity (the percentage of the output flow lost from a percentage change in the amount of carbon in the atmosphere) and the rate of decay of the atmospheric carbon concentration.

While – for reasons of tractability – the majority of E-DSGE models capture environmental externalities in a (highly) reduced-form fashion, **Cai et al. (2012) develop a DSGE extension of Nordhaus' dynamic integrated assessment model "DICE-2007", thereby allowing a mutual interplay between climate and economics.**[65] Employing a modified version of this model, which incorporates beliefs about the uncertain economic impact of possible abrupt climate changes (tipping events) and an empirically plausible calibration of Epstein-Zin preferences to represent attitudes towards risk, Cai et al. (2013) find, among other things, that the threat of a tipping point induces significant and immediate increases in the social cost of carbon, even for low-probability and low-impact tipping events.

Overall, E-DSGE models appear to be a valuable supplement to long-run climate models, featuring a relatively high tractability and a comparatively detailed representation of the economy. Nevertheless, in order to make practical use of E-DSGEs in policy analysis, a key prerequisite is to evaluate the size of the trade-off between tractability and the ability of these models to adequately capture the macroeconomic consequences of anthropogenic emissions.

Box 6
Data needed and available for climate analysis

Climate change is new territory for central banks. Its relevance is growing rapidly, accompanied by stronger demand for the underlying data and indicators required to assess the economic impact and financial system vulnerabilities stemming from physical and transitional risks, as well as to monitor and facilitate the transition to a greener economy via sustainable finance.

To address those needs, the ESCB Statistics Committee (STC) created an ad hoc expert group to provide a systematic overview of the existing data sources and user needs, together with the methodological challenges and data gaps that need to be overcome.

The expert group conducted two exercises: (i) a stocktaking survey on available data sources, covering the ESCB statistical departments; and (ii) a user consultation on the priorities related to climate change indicators, encompassing several ESCB committees and SSM fora. A literature review and an overview of other European and global initiatives were compiled to complement the findings. The group also interacted with several other fora covering

65 The DICE-2007 integrated assessment model links factors affecting economic growth, carbon emissions, the carbon cycle, climate change, climatic damages and climate-change policies. For a detailed description of the model, see Nordhaus (2007).

statistical issues, such as the NGFS workstream on bridging the data gaps and the Task Force on Sustainable Finance (TFSF) set up by the Committee on Monetary, Financial and Balance of Payments Statistics (CMFB), to discuss synergies and avoid potential overlaps.

The findings were summarised in a report that was presented to the STC in October 2020.

User needs

While the ECB's monetary policy strategy review was still ongoing, many of the committees consulted indicated that analytical work in the area was under development and, consequently, data needs were still evolving. However, three key priorities emerged – and even if the analytical objectives and mandates differ across the users, the same data could fulfil various demands. The expert group recommended initiating statistical work, starting from the development of the following set of indicators:

- exposure of financial institutions to climate-related physical risk;
- carbon footprints of financial institution portfolios;
- number and value of "green" financial instruments (bonds, investments, loans) that are issued, and their relevance in financial sector holdings.

All three sets of indicators would be required at both granular (entity, asset) and more aggregated levels (sector, country). While the individual level data would form the basis for the further aggregations, it is recognised that fragmented coverage and potential biases in the reporting population might pose challenges and a sound methodology for estimation of missing data and grossing-up methods would be an important part of the future work.

Most of the committees have focused on financial institutions and their portfolios. However, the prerequisite for calculating indicators for the financial sector is the underlying exposures to non-financial corporations and households. Data on the non-financial sector would help meet important analytical needs of the Monetary Policy Committee (MPC) and could also be used for broader research purposes.

While this information was identified as the priority for ESCB statisticians at the present time, it is self-evident that user needs emerging from the monetary policy strategy review and similar exercises will need to be tackled flexibly. It might be possible for further indicators to be provided in collaboration with other initiatives. Emissions and energy pricing are required, together with economic and fiscal indicators, to assess climate policies and their economic impact, which means they also constitute a high priority for the MPC. Here collaboration with the European Statistical System/TFSF could lead to improvements in existing data collections or the development of new indicators constructed using the data from the EU Emissions Trading System (EU ETS) and Eurostat environmental accounts (especially the modules on environmental taxes, environmental goods and services sector, and environmental protection expenditure).

In addition, ad hoc modules in existing surveys (e.g. the ECB's Consumer Expectations Survey, Household Finance and Consumption Survey or Survey on the Access to Finance of Enterprises) could be used to collect information on consumer preferences for sustainable products, or household expectations on climate change and its implications for their expenditures.

While the expert group focused on climate-related measures, users signalled a need for broader sustainability indicators such as environmental, social and governance (ESG) ratings, which might be required for investment strategies, including central banks' monetary policy operations or own portfolio investments. Substantial improvements in quality, scope, coverage (non-listed, smaller companies), data disclosure (single access according to standardised templates) and development of the reporting standards would be required to make progress in this area. These issues are being tackled by the Corporate Sustainability Reporting Directive (CSRD) published on 21 April 2021 to replace the Non-Financial Reporting Directive (NFRD), with support from the Eurosystem.[66] For financial institutions, the EBA's Action Plan on Sustainable Finance aims to strengthen the disclosure of ESG factors and incorporate the ESG risks in the regulatory and supervisory framework for credit institutions and investment firms.[67] In this context, the EBA published its report on management and supervision of ESG risks for credit institutions and investment firms on 23 June 2021 and is currently finalising its work on Pillar III disclosures on ESG risks.

Regarding sustainable finance, two legislative initiatives launched by the European Commission will be crucial for establishing a harmonised classification and definition, and subsequently collecting data: (i) the recently adopted EU taxonomy defining sustainable activities, and (ii) the EU green bond standard (GBS) to build on the taxonomy. The EU GBS sets out the required alignment of underlying investments with the taxonomy, the necessary disclosure information and the verification process. The legislative proposal was published on 6 July 2021, alongside the Commission's new sustainable finance strategy, and it is anticipated that application will commence in 2023. The adaptation and mitigation aspects of the EU taxonomy will come into effect in 2022. The definition of activities related to the four other environmental objectives in the EU taxonomy (sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, protection and restoration of biodiversity and ecosystems) will be finalised in the course of 2022 and enter into force in January 2023.

The ECB supports this work participating as an observer in the Platform on Sustainable Finance. This body was mandated to advise the Commission on sustainable finance policy – including the technical screening criteria for the EU taxonomy – and to monitor and report on capital flows towards sustainable investments.[68]

Available data sources

A wide variety of sources for climate-related information and broader sustainability issues were identified in the stocktaking exercise on existing databases. However, a large number of sources is more a sign of a fragmented ecosystem of environmental information than an indication of wide access to environmental data.

The System of Environmental Economic Accounting offers a harmonised framework for macroeconomic analysis. This is consistent with the structure and accounting principles of the System of National Accounts, using the same concepts (e.g. value added), definitions (e.g. residency principle) and classifications (e.g. institutional sectors and activity classifications).

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66 See Eurosystem reply to the European Commission's public consultations on the Renewed Sustainable Finance Strategy and the review of the Non-Financial Reporting Directive, published on 8 June 2020.

67 See the EBA's dedicated webpage.

68 See the Commission's dedicated webpage.

Granular data on emissions and green instruments are currently available mostly from commercial data sources. Specialised providers have emerged in addition to established providers of financial data who started to offer ESG data and information on sustainable financial instruments. Similarly, there are several public sources (including the Risk Data Hub operated by the Commission's Data Risk Management Knowledge Centre) and private providers for physical risk data.

The expert group collected information on the pros and cons of the various data sources and access modalities. Particular attention was paid to those databases that can be easily linked by a common identifier or established statistical classification (LEI code, ISIN, NACE) to financial databases available at central banks (such as AnaCredit, the Centralised Securities Database (CSDB), Securities Holdings Statistics (SHS) and potentially also national credit registers) to maximise their usability, as well as to sources that include as many (harmonised) geographical areas as possible – such as European countries – or have a global coverage.

Timeline

The expert group recommended the STC to develop indicators step-by-step, depending on the users' analytical priorities and methodological and practical challenges. Data access is one of the first issues to be overcome. While public sources could be shared within a common ESCB platform, restricted licences for commercial datasets would require other solutions (e.g. sharing of code and aggregated output). It is also recognised that the quality of data from existing data sources requires improvement and estimation methodologies used by commercial providers often lack transparency.

While reporting and disclosure of non-financial information might take a few years to enhance, it is recognised that climate-related measures are already urgently required in the short term. Consequently, the expert group recommended that work be started on drawing up experimental indicators using data that are already accessible, followed by gradual enhancements. Given data characteristics and availability (e.g. public and commercial data sources), various sets of the prioritised indicators would follow a slightly different timeline.

The STC will consider the development plan proposed by the expert group when defining its work plan for the coming years.

Experimental indicators

There is still some way to go before the STC will be ready to adopt the set of indicators to be produced regularly by the E(S)CB. In the meantime, it could start by defining a set of experimental statistics to be derived from the following indicators:

- **Firms' exposure to physical risk and corresponding financial institution portfolios**
  First indicators could cover the most common hazards such as flooding, with the dataset being extended later to other types of events, such as droughts, wildfires, windstorms, earthquakes, cold spells and heatwaves. Hazards metrics need to be matched with asset information to estimate the potential impact. AnaCredit information on the borrower and the collateral (value and location) can be used to construct the physical risk exposures of financial institutions. However, assessing physical risk exposures requires the location of not only a company's headquarters but also its facilities. Such information is currently available only for a subset of the largest companies – which could be included in the first set of indicators – while additional sources of geolocation information would be explored at a later stage. Initially, the indicators would be constructed for wider regions (NUTS 3 level) and more precise estimates utilising exact geographical location could be provided in the subsequent phase.

- **Firms' carbon footprint of and corresponding financial institutions portfolios**
  Experimental indicators would be based first on available commercial data sources, taking into account data quality caveats. They would cover Scope 1 (direct emissions by an organisation) and Scope 2 (indirect emissions from purchased electricity) – the most commonly reported data by firms. Reporting of Scope 3 (all other indirect emissions) is still in its infancy and could be included only at a later stage, with improved disclosure envisaged in the Corporate Sustainability Reporting Directive (CSRD). First estimates could be aggregated at sector level. Furthermore, corporate emissions could be matched with CSDB/SHS and AnaCredit to estimate the carbon footprint of financial institution portfolios.

- **Issuance and holdings of green bonds**
  Information on green labels could be incorporated in the ESCB databases, such as the CSDB and SHS, which will make it possible to calculate issuance and holdings of green bonds. When the EU standard for green bond enters into force in 2023, it will facilitate harmonised classification. Future developments would include expansion to other assets (loans and other financial instruments) and cover not only climate mitigation and adaptation but also broader sustainability issues.

The availability of indicators to the ESCB would depend on the confidentiality and licence restrictions of the underlying data. Where direct access cannot be granted, selected aggregates could be made available, as well as calculations and the underlying code(s) to facilitate the consistent calculation of the indicators.

The set of experimental indicators described above is a first step to address the most pressing users' needs. The climate-related work will occupy ESCB committee agendas for the for the next few years, and the statistical work will need to adapt to address evolving analytical requirements for policymaking and research.

Box 7
Predictions of a macro-financial model for the transition period from a low-carbon tax to the optimal carbon tax level

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Economic models are ideal for simulating climate policy scenarios and deriving predictions not only for the long run but also for the transition period to a new steady state of the

economy. Donadelli et al. (2019) simulate a macro-financial DSGE model to obtain predictions for macroeconomic quantities, environmental variables and asset prices for the transition period from no carbon tax to the optimal carbon tax level.

The model features three production sectors. The clean sector does not consume any fossil fuels, implying that its output (the “clean” good) is produced using only capital and labour and does not create any greenhouse gas (GHG) emissions. In addition to capital and labour, the dirty sector utilises fossil fuels to produce a “dirty” good. This production process generates emissions which lead to higher global temperatures. The oil sector owns the fossil fuel reserves of the economy and can also exploit more oil wells using capital and labour. The households consume an aggregate of the clean and the dirty goods and additionally derive utility from the level of environmental quality. Environmental quality declines non-linearly with higher global temperatures. The regulator can levy a carbon tax on dirty goods producers whose revenue is transferred to the households.

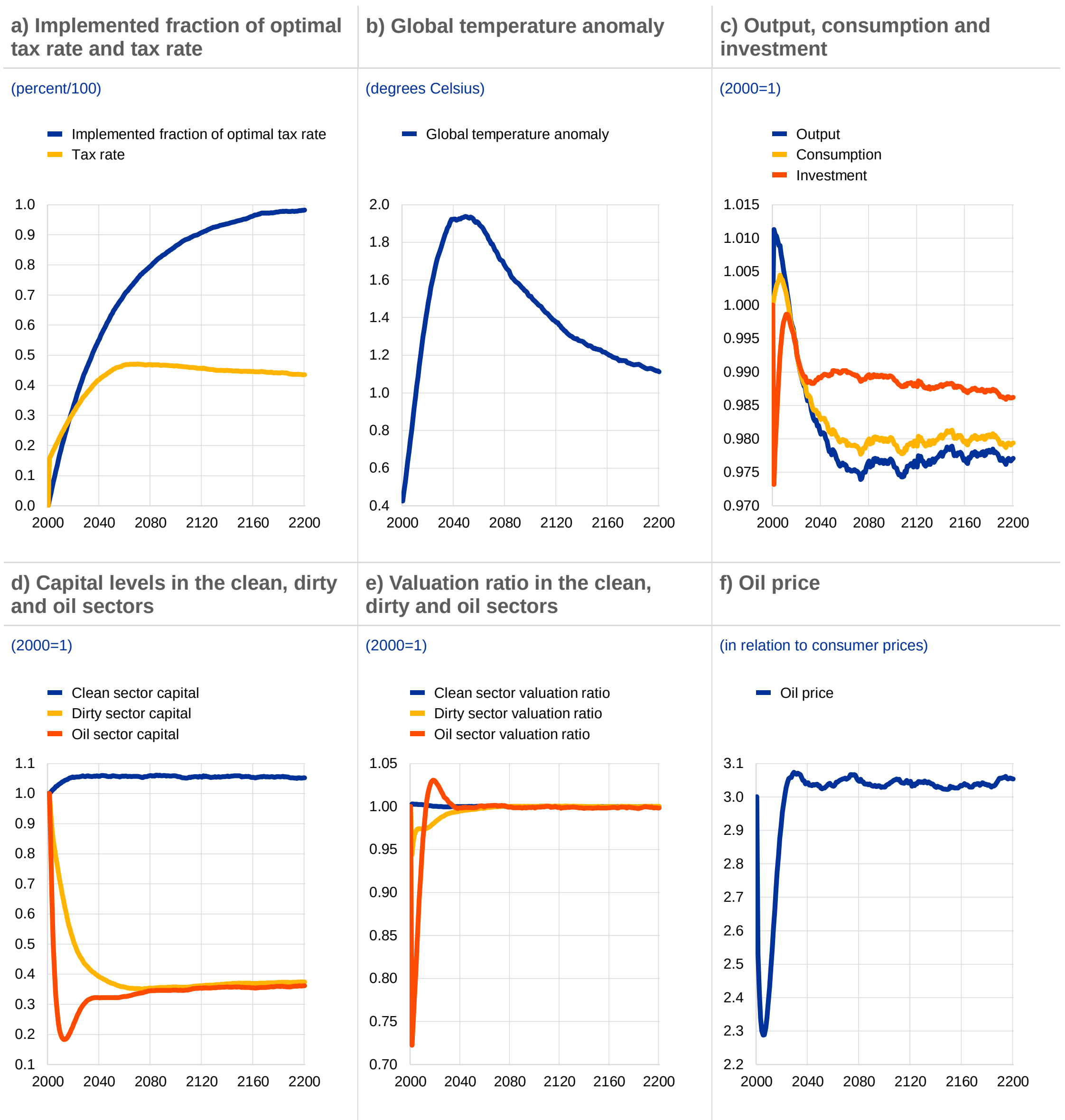
Using the model to simulate a transition from no carbon tax in 1995 (the signing of the Kyoto Protocol) to the socially optimal carbon tax level, the following dynamics emerge for a transition period of 200 years.

The implemented carbon tax rate rises quickly and stabilises at around 45% of the production volume of the dirty firms (corresponding to around 20-25% of their turnover) after around 100 years into the transition period. This implies a significant and quick reduction in the amount of GHG emissions, which leads to the global temperature anomaly peaking at slightly below 2°C around 2050. Aggregate output, consumption and investment all converge to lower values after the transition period (~1-2% lower than pre-transition levels). A significant reallocation of capital from the dirty and oil sectors to the clean sector occurs in the economy, which leads to a large devaluation of oil and dirty firms at the start of the transition period, before stabilising again. Similarly, the large decline in demand for oil at the start of the transition period leads to a massive drop in the price of oil, which then stabilises once the oil sector reduces its supply.

A further analysis aimed at varying the speed of transition to the optimal carbon tax reveals that a faster convergence to the socially optimal level entails larger and faster declines in aggregate output and consumption, **but it also yields a lower increase in the global temperature.** Moreover, the implemented carbon tax rate does not need to be set as high as in a scenario where the optimal carbon tax is implemented more slowly.

Chart A

Transition dynamics implied by the macro-financial model



Source: Adapted from Donadelli et al. (2019).

4 The impact of climate change on the financial system

Chapter 4 at a glance

- The transition towards a low-carbon economy, depending on how fast and orderly it occurs, could potentially cause large swings in asset prices and generate substantial volumes of stranded assets.
- Stranded assets can arise from policies put in place to penalise carbon use, shifts in investor and consumer preferences, and new technologies that render older technologies obsolete.
- Stress tests suggest that asset and capital losses for financial institutions and investors could be significant in scenarios involving a disorderly transition, but more manageable should the transition take place earlier and/or in an orderly fashion.
- The environmental externalities of economic activities are not adequately priced into financial markets. Research into the degree to which any transition risk is reflected in prices remains inconclusive, although there are signs of differential pricing since the Paris Agreement was signed at the end of 2015.
- In general, banks appear to have been slower at pricing climate risks than institutional investors. Information on the sustainability of financial assets – where available – is inconsistent, incomplete, largely incomparable and at times unreliable.
- Uncertainty generated by the current poor quality of disclosures on climate-risk exposures and the lack of widespread certification of green activity remains a marked impediment to efficient market pricing.
- Emerging evidence suggests that the financial structure can affect the speed at which the economy decarbonises. Equity markets can support innovation. While banks may hesitate, without proper incentives, to finance green innovation, they can support the widespread adoption of new green technology.
- The evidence on the extent to which green bonds have contributed to meaningful decarbonisation is scant and mixed, in part reflecting the relative immaturity of the market.

4.1 The potential impact of transition risk on financial institutions

The exact climate policies that will be introduced to underpin the transition to a low-carbon economy remain uncertain. So far, academics, public authorities and policymakers have primarily focused on two main types: carbon-penalising policies, which aim to reduce emissions through their pricing, such as a carbon tax or cap-and-trade emissions trading schemes; and green-supporting initiatives, which aim to create incentives for financial agents to invest in green projects by lowering their relative cost of funding.

The overall economic impact of carbon-penalising measures depends on the speed of transition and the availability of alternative energy sources (Acemoglu et al., 2012). A sudden and abrupt transition, before the necessary technology for the generation, storage and transmission of clean energy has been introduced, is likely to systematically increase energy prices, putting a strain on energy-intensive industries and firms. Conversely, rapid technological progress or shifts in consumer and investor preferences could lead to capital tied to fossil fuels becoming obsolete and also result in large volumes of stranded assets, even in the absence of a systematic increase in energy prices.

Stranded assets will naturally lower company valuations, potentially to a substantial degree. Investors with portfolios concentrated in carbon-intensive sectors may suffer significant losses as equity prices and company valuations adjust. Furthermore, firms will need to replace carbon-intensive assets with others that are more environmentally friendly or change their entire business model. Such large-scale investments may require greater leverage, thereby further straining balance sheets and impairing creditworthiness. Thus, institutions with credit-related exposures may see the share of non-performing exposures (NPEs) rise sharply.

A number of recent stress tests have pointed to financial stability risks in the euro area arising from stranded assets created by the sudden and unexpected introduction of carbon-penalising policies. The exercise carried out by De Nederlandsche Bank (DNB) considered a sudden global increase of USD 100 in the price of carbon (Vermeulen et al., 2018). Under this scenario, banks in the Netherlands would lose around 2% of their total assets and deplete 3.4% of their Common Equity Tier 1 (CET1) ratio, through both their exposures to marketable securities and their loan books. Similarly, Dutch insurers and pension funds would lose 8% and 10% of their assets respectively, via the impact on bond and equity prices.

The DNB stress test also demonstrated the risks of assets being stranded by a technological breakthrough. The scenario assumes a sudden breakthrough that doubles the share of renewables in the energy mix over a period of five years. As a result, carbon-intensive assets become stranded, causing banks to lose 1% of assets and lowering the CET1 ratio by 1.8%. Insurers and pension funds lose 2% and 3% of assets respectively.

Overall, the literature finds the impact of climate-mitigating policies on financial stability to be contained, provided the implementation is gradual and communicated to stakeholders in a forward-looking manner. The ESRB[69] recently extended the DNB climate stress-testing exercise to the euro area by taking the same scenarios and combining them with the ECB's dynamic banking stress test framework. Results suggest that the costs to the banking sector arising from a rise in carbon price or a sudden technological breakthrough are likely to be manageable over the next five years, although that analysis does not take into consideration the effect of the pandemic on the starting point. (A review of the ECB's climate stress test is presented in Box 8).

According to the limited analysis that is available, green-supporting policies may pose lower risks to financial stability than those that are carbon-penalising, but may be less effective at reducing carbon emissions. Take, for example, the proposal made by the European Commission, supporting the introduction of a green-supporting factor (GSF) that reduces the credit risk weight assigned to green loans.[70] One estimate that uses a stock-flow consistent model finds that banks would only generate a positive impact on green investments if they significantly reduced the interest rates charged to green firms (Dunz et al., 2019). Yet these lower interest rates risk impairing bank profitability, creating green asset bubbles and sharply devaluing carbon-intensive assets, thus increasing the volume of NPEs. By contrast, the same framework finds that a carbon tax would be more effective at incentivising green investments, but the overall macroeconomic effects would lead to a larger increase in NPEs and greater volatility in banks' capital adequacy than would the GSF.

4.2 Pricing of physical and transition risks

There is nascent literature studying the impact of physical and transition risks on asset prices, although it remains incomplete and conclusions remain tentative. The literature mainly focuses on the extent to which the private exposure to climate risk is factored into asset prices. In that regard, the extent to which valuations reflect the social cost of carbon receives little attention.

The insurance sector has had the most extensive experience in analysing the financial impact of physical risk stemming from climate change, but there are few studies that explore the consequences for asset prices. For example, the evidence concerning the impact of rising flood risks on real estate prices and the extent to which mortgage lenders systematically assess the value of collateral in the light of these risks is inconclusive.[71] The evidence concerning the extent to which prices of coastal homes vulnerable to sea level rises are affected is similarly mixed.[72]

69 See ESRB (2020).

70 See Dombrovskis (2018).

71 See, for example, Bakkensen and Barrage (2017); Faiella and Natoli (2018); Garbarino et al. (2020).

72 See Bernstein et al. (2019); Murfin et al. (2020).

Only a handful of studies have looked at the impact of physical events on financial markets in general and on equity markets in particular. Drought indices appear to predict food company stock returns, indicating that investors are relatively inattentive to the impact of droughts on these companies (Hong et al., 2019). In the context of gradual warming, that inattentiveness may be somewhat justified given that, historically, temperature exposures are generally unrelated to sales, productivity and earnings (Addoum et al., 2019). Nonetheless, there is some evidence that investors have begun to demand compensation for the uncertainties surrounding the occurrence and impact of weather events (Kruttli et al., 2020).

The literature on the impact of transition risk is more developed, with a number of strands and measurement approaches. The most prominent methodology relies on measuring the abnormal returns of green over carbon-intensive assets, using returns on long-short portfolios around specific events,[73] constructed using data on credit spreads, option-implied volatilities or equity prices.[74] A second major line of research focuses on textual analysis of firm-specific documents or public statements and newspapers.[75]

Table 6 summarises the findings of major papers in the literature, which exhibit marked heterogeneity regarding the statistical significance, size and sign of the carbon premium across regions, industries, time periods and investor horizons. To an extent, the divergent findings appear to reflect different methodologies, data and sample periods. On balance, the evidence weighs more towards a positive carbon risk premium – implying that investors require additional compensation for bearing exposure to carbon risk – than for a negative carbon premium. In addition, the carbon premium seems to have become more important over time and there are some signs that it is present across a number of markets, including equity, options, fixed-income and loan markets.

Relatedly, low-carbon firms are positively affected by positive climate policy news, at least in the short run. Event studies focusing mostly on equity prices confirm quite unambiguously that market participants reward low-carbon firms in response to positive climate policy news in the short run. Moreover, firms that are subject to climate risks underperform relative to non-risky firms in the aftermath of extreme weather events such as tornados, hurricanes and floods. In the longer run, however, the effects of climate policy news may also be less obvious. For example, there is some evidence that the most climate responsible firms can earn positive

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73 Long-short portfolios are frequently used in financial markets and involve constructing a portfolio that is long in some stocks and short in other stocks, based on certain criteria. Orthogonalising returns with respect to a set of well-established risk factors is a standard procedure in empirical asset pricing, in order to account for the influence of other sources of systematic risk. The goal is to determine “abnormal” asset returns, which go above and beyond an asset’s response to standard market risk factors. The most popular model for systematic risk is the Fama-French three-factor model, where the three factors are given by the excess market return and the returns on two aggregate long-short portfolios of firms sorted on market capitalisation (size factor) and book-to-market ratio (value factor).

74 See Oestreich and Tsiakas (2015); Barnett (2018); Delis et al. (2018); Görgen et al. (2018); In et al. (2018); Ilhan et al. (2021); Bolton and Kacperczyk (2020a).

75 See Berkman et al. (2021); Donadelli et al. (2019); Engle et al. (2020); Meinerding et al. (2020); Bua et al. (2021).

abnormal returns even following negative climate policy news, such as the US withdrawal from the Paris Agreement in 2017.

Multiple studies find evidence of investors requiring compensation for holding stocks of high-carbon emitters – a carbon risk premium – albeit mainly in the wake of the Paris Agreement.[76] The existence of a carbon premium is not universal across countries, with carbon betas only positive in countries more likely to be affected by the transition to a low-carbon economy (Görgen et al., 2018). That said, it does appear widespread across North America, Asia and Europe, with a significant increase following the Paris Agreement (Bolton and Kacperczyk, 2020b). There is evidence of a negative risk premium linked to a firm's greenness and environmental transparency in Europe.[77]

Nonetheless, investor awareness appears incomplete and several studies find only limited evidence of pricing differentials between green and other assets, suggesting that the market prices carbon inefficiently. Retail investors sell carbon-intensive stocks when the weather is abnormally hot.[78] The return on equity of relative polluters has not been discernibly different from that of relatively clean firms, and there appears to be no statistical difference between the performance of sustainable and traditional investments.[79]

Moreover, it appears that banks have been slower than institutional investors to price in climate risks. Only recently – since 2015 – have banks started to price the climate risk of lending to firms that own large fossil fuel reserves, and thereafter only by a marginal increase in the spread of two basis points (De Greiff et al., 2018). There is, however, evidence that greener firms receive a lower spread on syndicated loans, particularly from relatively greener banks (Degryse et al., 2020).

At the sectoral level, transition risks are larger for carbon-intensive industries, including fossil fuels and utilities, industrial mining and the automotive industry.[80] However, the effects of the transition can extend beyond these industries, as stranded fossil fuel assets can create international cascades of capital stranding via global production networks (Cahen-Fourot et al., 2019).

Little is known about the impact of climate risk on the pricing of sovereign bonds, but it appears to be more significant for developing and emerging economies. One recent study focusing on South-East Asia – an area particularly prone to climate risks – finds that sovereign bond yields of emerging economies highly exposed to climate risk contain higher premia, whereas there is no significant premium for advanced economies (Volz et al., 2020). That difference in part likely reflects greater resilience in advanced economies, which can mitigate the impact on bond spreads (Cevik and Jalles, 2020).

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76 Bolton and Kacperczyk (2020a), for example, confirm that specific timing for a significant impact of carbon emissions on US stock returns.

77 See Alessi et al. (2019); Bernardini et al. (2021).

78 See In et al. (2019); Choi et al. (2020).

79 See ESRB (2020); Rodriguez (2010); Balcilar et al. (2017).

80 See Ramiah et al. (2013); Barnett (2018); Donadelli et al. (2019).

The long-run economic effects of transition risk can differ greatly from the short-run effects, and standard long-short portfolio analysis may struggle to disentangle the two horizons. Long-term investors care more about transition risks than short-term investors. For example, a term structure of discount rates based on real estate data finds an average return of 6%, but much lower rates of 2.6% for horizons of 100 years and longer.[81] The decline in social discount rates since the 1990s has, according to Bauer and Rudebusch (2020), caused estimates of the social cost of carbon to at least double in size. Thus, the long-run gains from climate policy should be discounted at a much lower rate than typically assumed in climate models, generally increasing the present value of climate-related mitigation policies.[82]

Finally, the literature on the impact of climate announcements on financial markets has mostly focused on policy-driven shocks – typically easier to identify – rather than on transition risk as a whole. In order to overcome these limitations, some recent studies have resorted to textual analysis. Event-study analysis looking at the impact of news-related transition risks on the market valuation of firms investing in carbon-intensive assets finds some evidence of investors beginning to incorporate expected changes in energy policy into their assessment of firms. However, that has generally not produced large and sudden movements in equity prices (Batten et al., 2016). Box 9 sets out two recent text-based analyses of the impact of physical and transition risk on asset prices.

Overall, the literature so far on carbon risk pricing is preliminary and any conclusions should be drawn with caution. Nonetheless, it seems unlikely that climate risk is adequately priced. It is unclear to what extent investors understand the true underlying nature of risks that likely differ from past experience, including the presence of tail risks, non-linearities and tipping points.[83] The marked heterogeneity of the impact of climate-related risks across different households, firms, regions and sectors means that these shocks can act in quite different ways from macroeconomic shocks that investors are more accustomed to modelling. Even assuming those global risks are understood, the availability of information on company exposures is very limited, and there is as yet no universally accepted and applied standard for disclosures. While some attempts have been made to classify firms according to their climate disclosures, the firm-level correlation between the various measures remains low, bringing into question their robustness.[84] That lack of comparable information makes any assessment of risk difficult.

Given the patchy availability of essential information, it is perhaps unsurprising that investors appear to value transparency. Firms with better corporate social responsibility scores obtain cheaper equity financing.[85] While higher emissions are associated with lower firm values, voluntary disclosure of emissions

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81 See Giglio et al. (2015).

82 See, for example, Dietz et al. (2016).

83 See Solomon et al. (2009); Weitzman (2009); Ackerman (2017).

84 See Carbone et al. (2019).

85 See El Ghoul et al. (2011).

both mitigates the negative valuation effect and provides protection against regulatory changes.[86]

Table 6

Summary of literature on market pricing of environmental risk

Paper	Method	Data	Risk premium	Key takeaways
Ilhan et al. (2021)	Option-implied volatilities, risk-neutral moments. Firms sorted on carbon intensity (=emissions over market cap).	S&P 500 firms/2009-16.	1 standard deviation increase in average log of industry carbon intensity increases cost of option protection against downside tail risks by 10%.	Carbon tail risk is priced in options.
Huynh and Xia (2020)	Climate change risk betas for corporate bonds (covariance of excess returns with innovations in climate change news index).	Environmental scores (ESCORE) data, US corporate bond data, climate change news index from Engle et al. (2020)/July 2002-December 2016.	1 standard deviation increase in climate risk beta leads to 22 basis points lower future expected bond returns. Effect for long-term bonds = 2 x effect for short-term bonds.	Long-term corporate bonds significantly more negatively affected by climate-related risk than short-term corporate bonds.
Hsu et al. (2019)	Pooled OLS regression of firm stock returns on their toxic chemical emissions.	All NYSE firms with positive chemical emissions/1992-2015.	Long-short portfolio (high vs. low toxic emission intensity) gives average excess return of 5.52% per year. 1 standard deviation increase in average firm-level emission intensity increases expected stock returns by 6.8-9.9%.	Positive risk premium for firms with high toxic emissions (beyond CO2).
In et al. (2019)	Portfolio sort on carbon efficiency (= emissions over revenues).	Trucost, MSCI ESG, Compustat and CRSP/2005-15.	Long-short portfolio (high minus low efficiency) generates positive alpha of 3.5-5.4% per year.	Negative carbon premium, in contrast to results of other papers. Potentially due to not controlling for additional risk factors and industry/ firm characteristics.
Delis et al. (2019)	Regression of loan spreads on fossil fuel reserves (pre- and post-2015).	Hand-collected data on fossil fuel reserves (= proxy for climate policy exposures) + DealScan syndicated loan data/2007-16.	1 standard deviation increase in climate policy exposure (proxied by fossil fuel reserves) leads to 2 basis points more interest on loans after 2015.	After Paris Agreement, fossil fuel firms have to pay a slightly higher interest rate on loans.
Ramelli, Ossola, Rancan (2019)	Event study around 2019 Climate Strike.	Sector-country-level emissions from Eurostat (4,000 firms), Sustainalytics ESG data (1,500 European firms)/2019.		1 standard deviation higher carbon intensity implies 25 basis points lower cumulative abnormal returns (CAR) in the event window. Brown firms have more negative climate policy betas.
Ramelli, Wagner, Zeckhauser, Ziegler (2019)	Event study around Trump election in 2016. Carbon intensity and climate responsibility measured using external ratings of management practices.	MSCI KLD, Vigeo Eiris, CRSP, Compustat/2016.		Carbon-intensive firms have 2-10% higher CAR in the event window. Highly climate-responsible firms have 2.25% higher CAR in a longer window. Election of Trump led to short-run gains for carbon-intensive firms. But also longer-run gains rewarding highly climate-responsible firms.

[86] See Matsumura et al. (2014); Jouvenot and Krueger (2020).

Paper	Method	Data	Risk premium	Key takeaways
Oestreich and Tsiakas (2015)	Portfolio sort on carbon emissions. Fama-MacBeth regressions with dirty-minus-clean factor.	EU ETS data, Datastream for 65 large German stocks/2005-12.	Until 2009: large brown-minus-green premium (up to 17%), DMC-factor significant in Fama-MacBeth regression. After 2009: no premium Reason: brown firms received free carbon emission allowances.	Positive premium in the EU ETS until 2009, when carbon emission allowances were still granted freely.
Chava (2014)	Pooled OLS regression of firm stock returns and bank loan rates on dummy variables (firms w/wo environmental concerns).	MSCI KLD, CRSP, Compustat, Dealscan and I/B/E/S databases/1992-2007	96 basis points per year higher expected equity returns for climate-irresponsible firms. 25 basis points per year higher bank loan rate.	Positive carbon premium in the equity market. Climate-irresponsible firms pay higher interest on bank loans 1992-2007.
Krueger et al. (2020)	Ordered logit on respondents' ordering of risks.	Survey of 439 institutional investors.		Climate risk ranked below financial, operating, governance and social risks. Transition risk more material than physical risk. Equity valuations do not sufficiently incorporate climate risk.

4.3 Financing the green transition

While climate-related disruption can pose risks to financial stability and the pricing of climate-related risks is currently inadequate, financial markets have a key role to play in financing the transition and helping to reduce the carbon footprint of the economy. There is evidence that the structure of the financial system, including the relative importance of bank and market finance, may influence the effectiveness of efforts to limit environmental pollution.

One strand of research is critical about the ability of banks to finance innovative projects, which are an important mechanism for containing environmental pollution. First, banks may be technologically conservative: they may fear that funding new (and possibly "greener") technologies erodes the value of the collateral that underlies existing loans, which mostly represent old, carbon-intensive technologies.[87] Second, banks may also hesitate to finance green technologies if the related innovation involves assets that are intangible, firm-specific and linked to human capital. Such assets are difficult to redeploy elsewhere and therefore hard to collateralise.[88] Third, banks may also simply lack the know-how and human capital to screen and monitor new (green) technologies at the early stages of adoption.[89] Fourth, banks may operate with a shorter time horizon (the loan maturity) than equity investors and hence be less interested in whether funded assets will become less valuable, or even stranded, in the more distant future.

87 See Minetti (2011); Degryse et al. (2020).

88 See Hall and Lerner (2010); Carpenter and Petersen (2002).

89 See Ueda (2004); Nanda et al. (2015).

But other research is more optimistic about the role of banks in limiting pollution. There is some evidence that credit-constrained firms reduce emissions if the constraint is relaxed by an increased supply of bank lending.[90] Banks may refuse to lend to a firm if they fear that it may create an environmental liability with financial and reputational repercussions.[91] And there is some evidence that banks are increasingly pricing climate policy exposures in their loan portfolios and reducing their lending to polluting firms.[92]

The shift in lending practices appears more marked for those banks that have subscribed to green development objectives, for instance by joining the United Nations Environment Programme Finance Initiative, which aims to mobilise private sector finance for sustainable development.[93] So even if banks may not necessarily be funding the development of green technology, they are increasingly funding its adoption across the economy. In addition, research analysing US interstate banking deregulation has found that more competitive banking markets can be supportive of innovation by young, private firms.[94] To the extent that these results can be generalised, the evidence suggests that more intense competition in banking could also support green innovation.

Compared to banks, equity markets may, on average, be better suited to financing (green) innovations that are characterised by both high risks and high potential returns. Cross-country evidence suggests that high-tech industries dependent on external finance are more likely to file patents in countries with better developed equity markets, but less likely when credit markets are more developed.[95] In particular, equity markets have a comparative advantage in financing technology-led growth, whereas credit markets mainly foster growth in industries that rely on external finance for physical capital accumulation.[96] A majority of the funds that firms raise in public stock issues is invested in R&D.[97]

Equity investors may care more about future pollution and therefore be better at pricing long-term risk.[98] On the other hand, a stock-market listing may lead to short-termism and distorted investment decisions if company managers believe that equity investors do not properly value long-term projects.[99] In that case, stock markets may blunt managers' incentives to reduce the long-term environmental impact of firms.

While existing research on banks and stock markets as constraints on industrial pollution is limited and inconclusive, more recent evidence appears to favour equity investors over creditors. Carbon emissions per capita have

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[90] See Levine et al. (2018); Goetz (2018).

[91] See Dasgupta et al. (2002).

[92] See De Greiff et al. (2018); Altunbas et al. (2020).

[93] See Degryse et al. (2020).

[94] See Chava et al. (2013).

[95] See Hsu et al. (2014).

[96] See Brown et al. (2017).

[97] See Kim and Weisbach (2008).

[98] See Gibson et al. (2018); Ilhan et al. (2021).

[99] See Narayanan (1985); Asker et al. (2015).

declined by between 30% and 50% in industrialised economies since the 1970s. Importantly, this decline has been much more pronounced in countries where equity markets are larger, relative to credit intermediation.[100] This effect appears to come through two distinct mechanisms. The first is a faster reallocation of funds away from carbon-intensive sectors and towards green sectors in countries with relatively deeper equity markets. The second is a faster reduction in carbon emissions per unit of output in carbon-intensive sectors in countries with deeper equity markets. In these, the rate of green innovation is also higher, suggesting that equity markets are superior to banks in pushing firms to develop and adopt green technologies. At the same time, as noted above, banks are increasingly lending to green firms, too. This is important for the euro area, since it will need the banking sector to play a key role in implementing the green transition, given the preponderance of banks in the financial system. It also calls for greater urgency in completing the capital markets union to bolster greater use of equity.

Green bonds also provide a financing vehicle to reduce carbon emissions, although there are only a limited number of studies that try to measure the role they have played to date. The question is inherently difficult to assess, and the results are not conclusive. In part, this reflects the continued relatively small size of the market, the lack of clear standards for green bonds and the reporting of the use of proceeds, and the fact that emissions are mostly measured at company level. A recent analysis by the Bank for International Settlements (BIS) finds no strong evidence that green bond issuance is associated with a reduction in carbon emission levels over time at the firm level.[101] Put simply, firms that issue green bonds do not behave significantly differently from firms that do not issue such securities. This result likely arises from the prevailing uncertainty surrounding what qualifies as a green activity, the lack of granular information on activities and the lack of ex post verification and accountability. In other words, what is known as greenwashing appears to remain prevalent.

Conversely, there is some evidence that public companies issuing green bonds improve their environmental performance through the signalling channel.[102] As the commitment towards the environment materialises, companies reduce their carbon emissions and achieve higher environmental ratings. This evidence counters the greenwashing argument somewhat. If companies issued green bonds and portrayed themselves as environmentally aware, but without any intent to deliver, it would not be possible to observe tangible improvements in environmental performance post issuance. Moreover, issuing green bonds appears to have a positive effect on a company's stock price and plays an active role in improving the company's profitability, operational performance and capacity for innovation. Box 10 reviews recent developments in the green bond market and the role of supranational organisations in its growth. Multilateral banks can also play a key role in fostering green investments. Box 11 examines the approach of the European Investment Bank to climate change.

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[100] See De Haas and Popov (2019).

[101] See Ehlers et al. (2020).

[102] See Zhou and Cui (2019); Flammer (2020).

Box 8
The ECB's economy-wide climate stress test

The ECB is finalising its economy-wide climate stress test, which aims to capture potential structural vulnerabilities created by both transition risk and physical risk in the euro area. It uses innovative data solutions to map the exposures of four million non-financial corporations (NFCs) worldwide to transition risk and physical risk. It then matches these firms to the loan books and financial asset portfolios of euro area banks with the help of regulatory datasets (AnaCredit and SHS-G) in order to assess the banking sector's vulnerability to climate risk under different climate scenarios.

This box summarises one step in that process – the analytical approach to capturing the threats posed to NFCs – and the main results on corporates' creditworthiness. The proposed methodology can assess, among other factors, changes in firms' probability of default under various climate scenarios and also account for the interplay between transition and physical risk over a 30-year horizon.

The scenarios covered in the exercise are drawn from the climate scenarios set out by the Network for Greening the Financial System (NGFS).[103] They comprise: an orderly transition (OT), where climate policies are implemented effectively in a timely manner; a disorderly transition (DT), where policymakers are either late to implement transition policies or do so in an ineffective manner; and a hot house world scenario (HHW), where the status quo persists and no further climate policies are enacted. The OT scenario is associated with limited transition costs for the economy, due in part to assumptions regarding technological progress and adoption. The disorderly scenario has higher transition costs and could entail higher physical risk, leading to lower levels of GDP after 2025. By contrast, the hot house scenario has little transition risk, but physical risk increases significantly, resulting in damage that is greater in the long run than the transition costs arising under either the orderly or the disorderly scenario.

Under the transition scenarios, climate policies function as a Pigouvian tax, forcing both producers of greenhouse gases (GHG) and consumers of carbon-intensive goods to pay for their share of carbon emissions. The modelling framework determines the impact on demand and supply separately. Transition risk is assumed to affect revenues mainly through macro-financial variables and Scope 3 emissions, which help capture how much the consumption of goods produced by a firm contributes to environmental pollution. For example, higher carbon taxes would increase the cost of a car for consumers through both the initial purchase price and the price of fuel throughout the vehicle's lifetime.

Similarly, production costs for companies depend on the carbon and energy intensity of production, the renewable share of energy generation and the carbon price. The introduction of climate policies leads to an increase in operating expenses due to higher carbon and energy prices. Firms react quickly by reducing both emissions and energy consumption, meaning that the new policies only have a limited impact on production costs. In the medium term, this impact is further mitigated as firms invest in green technologies to further improve their energy efficiency and decrease their emissions. Conversely, in the HHW scenario, in the absence of technological

[103] See NGFS (2020b).

development firms do not realise such efficiency gains in operating expenses, as their energy consumption rises while electricity prices remain relatively flat.

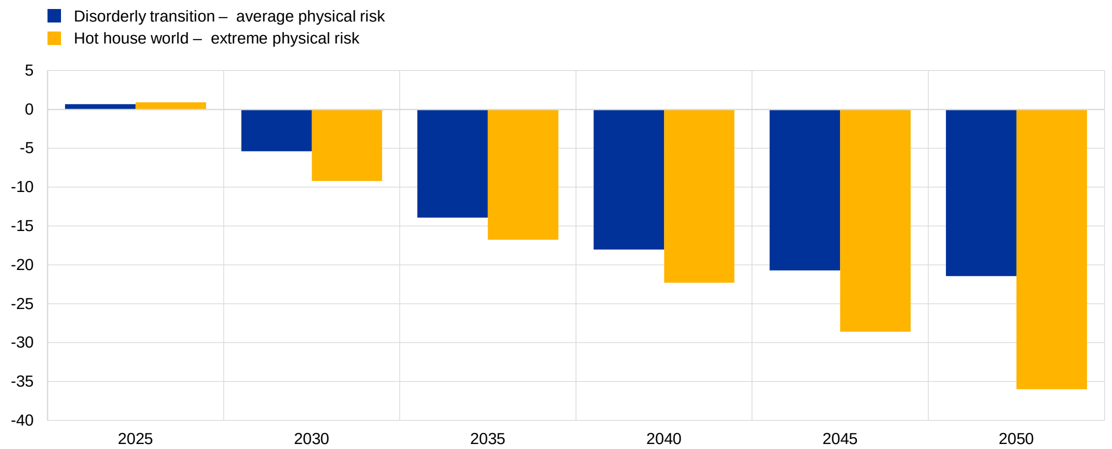
The impact of physical risk on corporate profitability mainly stems from an increase in insurance premiums combined with damage to physical capital from natural catastrophes. This is modelled using granular geolocational data to obtain annual probabilities of exposure to extreme weather events for the next 30 years and to generate an annual expected loss rate for firms' physical capital due to natural hazards.

Chart A highlights the impact on the profitability of the median firm in the sample, when the demand and supply side effects of both physical risk and transition risk are combined. Under both transition scenarios, NFCs experience gains in cost efficiency and hence see their return on assets (ROA) increase in the long run. However, as climate policies are implemented later and less effectively in the DT scenario, a higher ROA is observed for firms until 2030, before falling below OT scenario levels as transaction costs increase. Under the HHW scenario, profitability growth is constrained by higher energy consumption, physical damage and higher insurance premiums, as well as the failure to tap the cost efficiencies that arise under the transition scenarios. In other words, while transition policies are costly in the short term, NFCs will be more profitable in the long run compared with a world where climate policies are never implemented.

Chart A

Change in ROA for the median firm in Europe

(percentage difference in adverse scenarios compared to orderly transition)



Source: ECB staff.

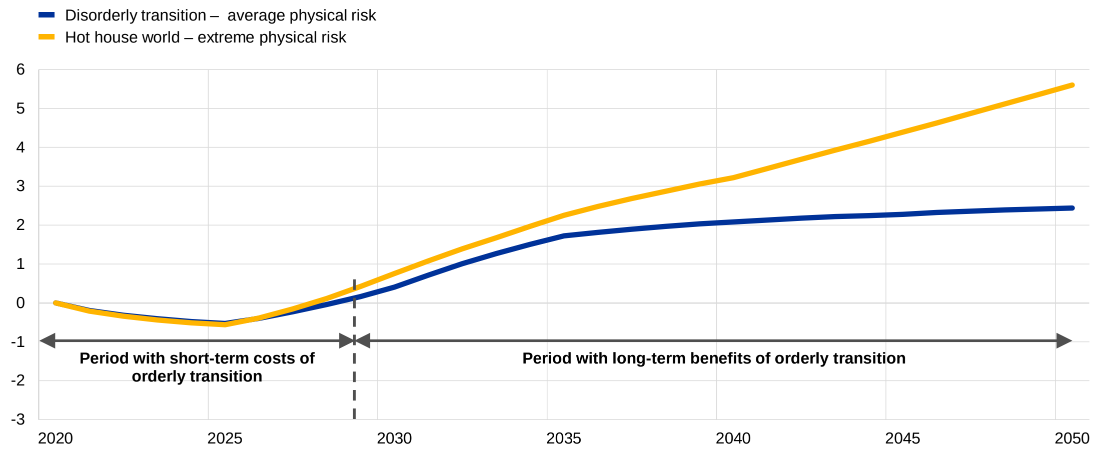
The change in ROA is combined with endogenous estimates of leverage to estimate the impact of climate risk on firm-level probabilities of default (PDs). Leverage is an important component of firms' creditworthiness and it is affected by both transition risk and physical risk. When faced with high transition risk, firms will need to invest in green technologies and replace carbon-intensive assets in order to reduce their emissions. Under this methodology, it is assumed that firms make these investments by taking on additional debt, thus increasing leverage. Similarly, damage from high physical risk leads to increased leverage, as firms are assumed to take on additional debt to recuperate the share of destroyed assets from natural hazard events that are not covered by insurance.

The short-term costs of an orderly transition are more than offset by the long-term benefits of policy action to mitigate climate change. Under both the OT and the DT scenario, the median firm in the sample experiences a sharp increase in PD during the first five years, as it issues additional debt to invest in low-carbon assets and reduce emissions (Chart B). Yet this increase in leverage is quickly outweighed by the hike in profitability, allowing firms to repay the debt and reverse the rise in PD. In the long run, PDs in both the OT and DT scenarios fall below those under the HHW scenario, which remain fairly stable throughout the horizon. It can be concluded that the threat to the financial system posed by a green transition is limited, as any short-term transition costs are quickly outweighed by the long-term benefits deriving from lower corporate default rates.

Chart B

Change in PD for the median firm in Europe

(percentage difference in adverse scenarios compared to orderly transition)



Source: ECB staff.
Notes: The ECB's economy-wide climate stress test estimates the one-year PD over a horizon of 30 years. The estimation methods follow a standard Altman Z-score, where PDs are a function of corporate profitability and leverage. A shock is applied to profitability and leverage using a multitude of macroeconomic drivers, supply and demand side microeconomic climate drivers (e.g. carbon price, energy efficiency) and climate mitigants and amplifiers (insurance coverage and premiums). Climate-related financial shocks are obtained from ECB calculations using NGFS scenarios.

Focusing on the median firm can be misleading, as climate risk disproportionately affects firms in certain geographical areas and sectors. For transition risk, the results of Chart B generally hold for all firms, even those that are considered most carbon-intensive. Although NFCs that lie above the 90th percentile of carbon intensity (defined as tonnes of C02/total assets) do experience significantly higher increases in leverage and PD shortly after climate policies are implemented, by the end of the horizon they perform better than in the HHW scenario (Chart C, panel a).

However, results suggest that firms that are highly exposed to physical risk have the potential to hamper financial stability (Chart C, panel b). The degree of exposure to extreme weather events is highly dependent on the firms' location. For the purposes of this exercise, firms with extreme exposure to physical risk are considered to be those that have a 1% probability of being hit by wildfires, sea levels rising or rivers flooding. This amounts to around 20% of European firms in the sample. The impact of physical risk outweighs that of transition costs, with PDs in the HHW scenario rising higher than in the OT or DT scenario. Unlike with transition risk, which is mitigated after 2030, PDs under the HHW scenario rise constantly, directly correlated to the increasing level of physical damage. For these exposed firms, the mitigating impact on physical risk of a transition to a carbon-neutral economy is particularly beneficial.

Chart C

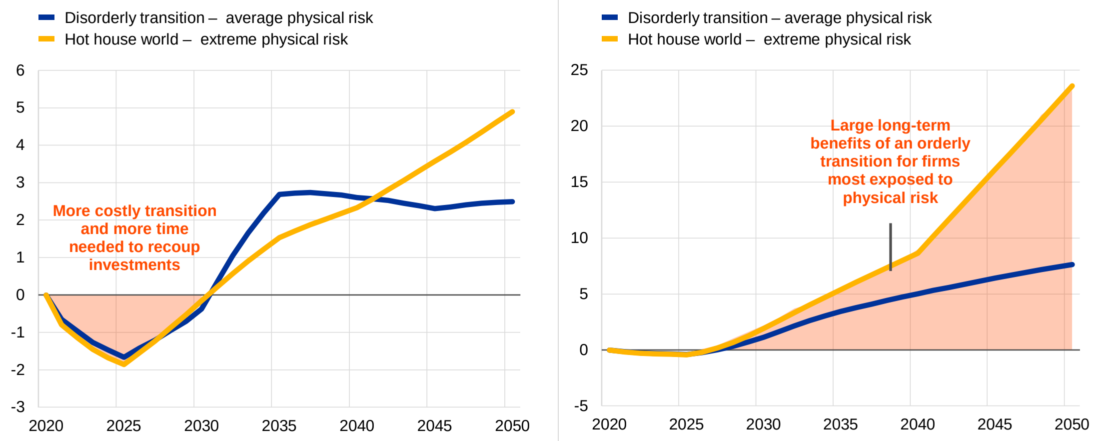
Tail climate risks for European NFCs

a) Change in PD for carbon-intensive firms in Europe

(percentage difference in adverse scenarios compared to orderly transition)

b) Change in PD for firms vulnerable to physical risk in Europe

(percentage difference in adverse scenarios compared to orderly transition)



Source: ECB staff.
Note: See Chart B above.

Box 9
Using text-based analysis and asset price data to identify transition and physical risk shocks

This box summarises two different approaches to identifying climate risk by means of textual analysis. The first method, adopted by Meinerding et al. (2020), identifies transition risk shocks by combining textual analysis of newspapers and asset price data. The second, implemented by Bua et al. (2021), detects and distinguishes physical and transition risk events by performing textual analysis to exploit newspaper content.

Meinerding et al. (2020) use a two-step process to identify transition risks. The first stage counts the number of articles in ten major US newspapers in a given month that contain the terms “climate change” and “economic”. This time series is then normalised and detrended. In the second stage, the authors construct long-short US equity portfolios based on firms’ carbon footprints, with portfolio returns orthogonalised with respect to the three Fama-French factors. Transition risk shocks are defined as instances where both the news index and the portfolio returns are more than one standard deviation away from the mean. The result is a time series of exogenous shocks to transition risk that can be readily applied for policy purposes.

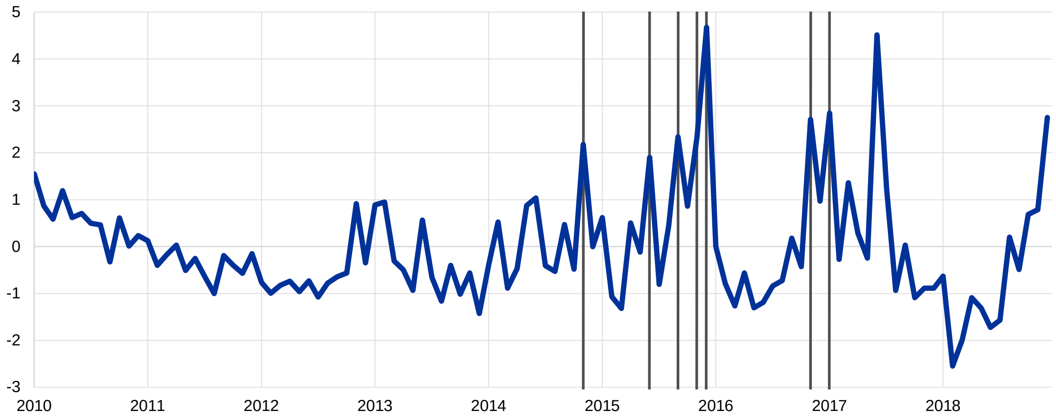
Chart A illustrates the shock series for the United States. The blue line depicts the climate news index from the first step. The black bars indicate months when both the news index is at least one standard deviation above its mean and one of the long-short portfolio returns is at least one standard deviation away from its mean. The procedure identifies seven major events as exogenous transition risk shocks, which can then be matched to specific events using the underlying newspaper analysis and also used in econometric analysis. The identified shocks include the widely recognised speech on climate change by Bank of England Governor Mark Carney in September

2015, the Paris Agreement during November and December 2015 and the election of Donald Trump as US President in November 2016.

Chart A

Transition risk shock events

(percentages)



Source: Factiva.
Notes: The chart shows the ratio between the “number of articles mentioning climate change AND economics” and the “number of articles mentioning economics”. The series is normalised and detrended before plotting.

Plugging the shock series into several small-scale macro-financial Bayesian VARs, the authors find that, overall, positive shocks to transition risk increase the aggregate risk premia in financial markets, lower industrial production in sectors prone to transition risk and increase uncertainty in these sectors as measured by the volatility of equity returns.

Since physical risks differ in nature from transition risks, the transmission of each risk type through the financial system needs to be explored and assessed separately. Yet identification remains challenging, given that physical risk and transition risk do not develop independently of each other. Bua et al. (2021) propose a method to capture and distinguish physical risk from transition risk events by means of textual analysis, building on the existing literature.

In the first step, the authors separate and aggregate authoritative texts on climate change published by governmental and research organisations by the topics of physical risk and transition risk. The authors then create two lists of unique terms from physical risk and transition risk documents and one parallel list from daily news coverage. Figure A illustrates the terms associated with physical risk and transition risk as word clouds, with the size proportional to the relevance for the document content. For example, terms such as “ecosystems”, “sea level” and “precipitation” fall under the physical risk topic, while “hydrofluorocarbon” (HFC), “hydrochlorofluorocarbon” (HCFC) and “greenhouse gas” (GHG) come under the topic of transition risk.

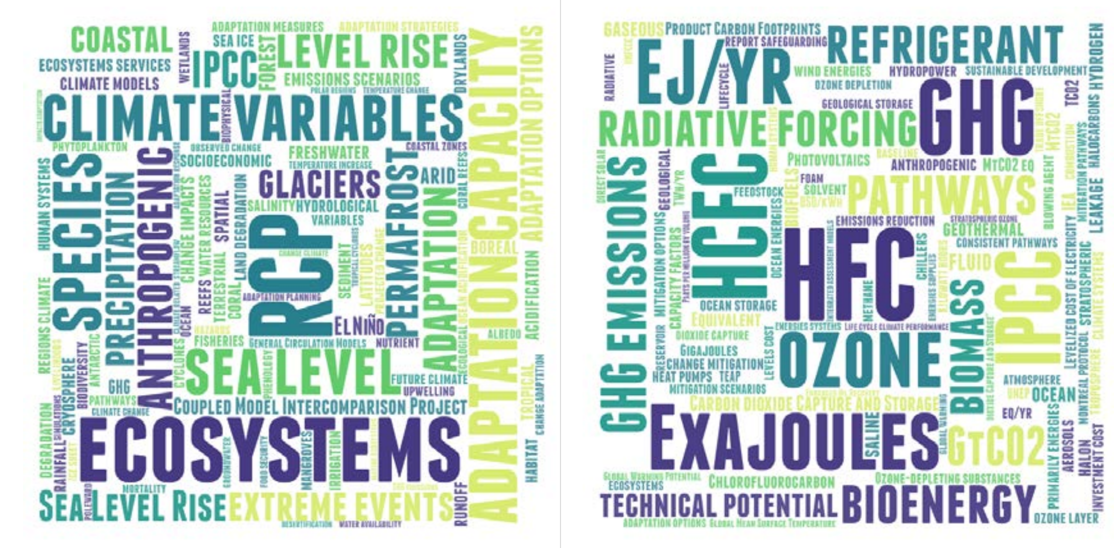
The estimation technique makes it possible both to make a distinction between physical risk and transition risk and to address the issue of concepts common to both of these risk types. For instance, the term “GHG” appears in both lists, but to a different extent, playing a primary role in the transition risk glossary and a minor one for physical risk. The term “adaptation”, on the other hand, is a concept common both to physical risk and transition risk and appears in both lists. However, its meaning differs, depending on whether it is considered in the context of physical risk or transition risk and thus on the other terms in the list. These examples suggest that the lists drawn up are likely to capture and contextualise commonalities and interconnections between the two complex concepts of physical risk and transition risk.

Figure A

Word clouds of climate risk terms

a) Physical risk terms

b) Transition risk terms



Notes: Word cloud summaries for the physical risk (panel a) and transition risk (panel b) terms. Term sizes are proportional to their relevance for the topic. For the full list of acronyms, see Bua et al. (2021).

Using the terms to quantify the intensity of the news coverage of physical risk and transition risk suggests growing media attention to such risks, with as greater overall focus on transition risk. The authors create a Physical Risk Index (PRI) and a Transition Risk Index (TRI) time series covering the period 2005-21. The PRI detects events concerning chronic risk (e.g. rising sea levels and permafrost thawing), acute risk (e.g. heatwaves and floods), adverse impact on the ecosystem (e.g. biodiversity loss) and related socio-economic risks (e.g. migration). The TRI detects events related to the introduction of new regulations to curb GHG emissions (e.g. the EU's carbon market reform and the Montreal Protocol), as well as news discussing the importance of technological innovation and renewable energy to help the transition.

Box 10

The green bond market and the role of supranational organisations in its development

Green bonds can play a significant role in financing the transition to a low-carbon economy (Sartzetakis, 2020). The term "green bond" refers to fixed income securities whose proceeds are earmarked for environmentally friendly projects. Green bonds make it possible to spread the cost of the green transition over time. This makes them ideal for financing the very large, very long-term investments needed for the transition.

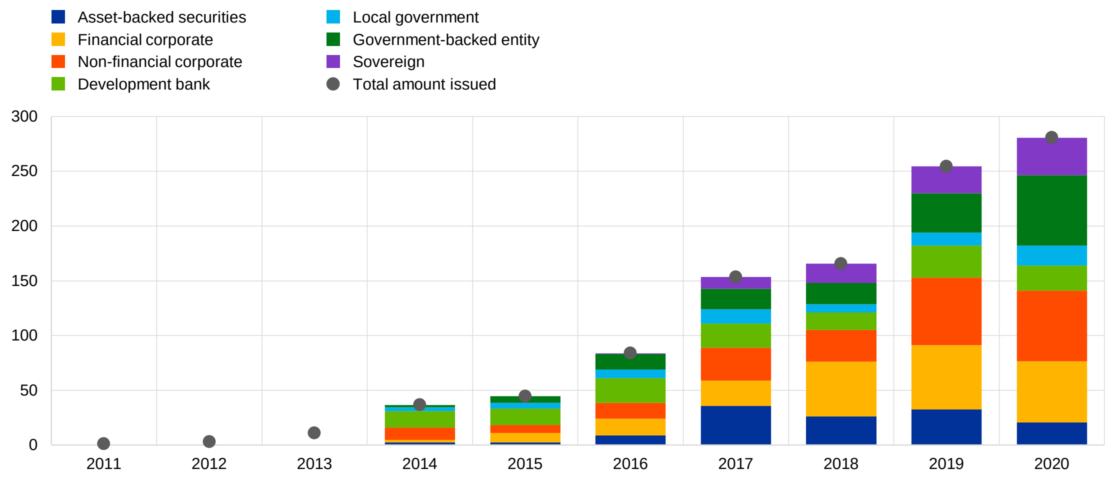
The market for bonds classed as green has developed rapidly in recent years, with global issuance rising from around USD 2 billion in 2011 to more than USD 281 billion in 2020

(Chart A). Issuance remained strong in 2020, despite the pandemic. Issuer diversification has also grown with the market. While the market used to be dominated by issuance from development banks, by 2017 the private sector accounted for over half of total new issuance. A watershed moment came in 2014 with the establishment of the Green Bond Principles by the International Capital Market Association (ICMA), which made issuance more attractive for the private sector. In terms of the types of project financed, while renewable energy remains the largest category, building efficiency and low-carbon transport projects account for an ever larger share of total new issuance (see Box 15).

Chart A

Annual issuance volume in the green bond market

(USD billions)



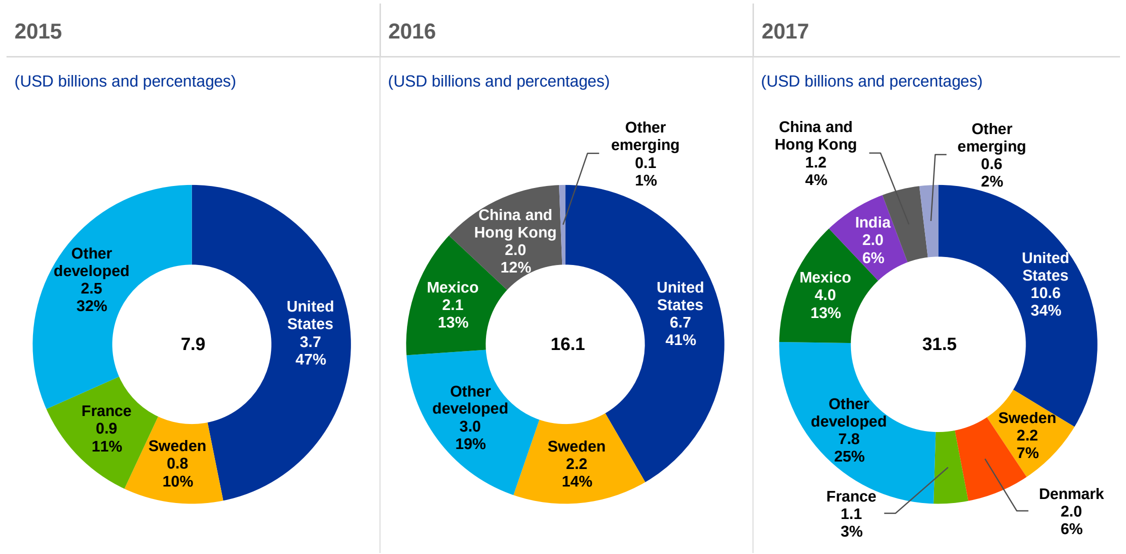
Source: Climate Bonds Initiative (2020).

The issuer's country of origin has become steadily more diversified over time. Although the market is still dominated by a few countries, primarily EU Member States and the United States, geographic dispersion has been growing over time, with many new issuers from various countries gradually coming to the market (Chart B). In total, in 2017 there were 239 issuers from 37 countries, of which 146 (60%) entered the green bond market for the first time that year.

The market for green bonds has potential for further growth, as the current outstanding amounts make up a very small fraction of the global debt market. To reach its potential and support more investment, the green bond market has to become deeper. Various challenges remain to be addressed before this is achieved. One important challenge is to widen the scope of low-carbon investments that have access to the green bond market. A significant proportion of these projects related in particular to energy-efficient buildings, which are heavily under-represented in the green bond ecosystem, involve small and medium-sized entities with no direct access to the bond market. On the demand side, the main issue is to make green bonds more attractive to investors in order to increase the size of the market. Sartzetakis (2020) argues that this is hard to achieve with financial incentives alone, as green bonds do not command sufficient premia to compensate for the lack of credit signal provided by the green bond label. In particular, although the label ostensibly provides an additional characteristic for the bond in addition to the standard array (maturity, coupon, credit quality, etc.), it has in fact raised new informational frictions regarding the types of project qualifying for green finance and the assorted monitoring issues. Reducing informational asymmetries with regard to the projects to be financed and the allocation of the proceeds, as well as establishing mechanisms to monitor the projects' development over time will go a long way towards rectifying this problem. A benchmarking tool is also needed to facilitate comparison and enhance transparency in terms of the post-issuance environmental impact of bonds.

Chart B

Geographical distribution of green bond issuance



Source: Climate Bonds Initiative (2018).
Notes: Other developed = Canada, Netherlands, Germany, Finland, Italy, Spain, Switzerland, United Arab Emirates, Australia, Norway, Japan, United Kingdom, Belgium. Other emerging = Argentina, South Africa, Morocco.

Overall, the overarching objective in further development is to bridge demand and supply in the green bond market by further developing international guidelines and standards, overcoming the lack of historical data, improving awareness, as well as reducing the cost of green bonds standardisation, reporting and reviewing. To move in this direction, the European Commission joined with relevant authorities from Argentina, Canada, Chile, China, India, Kenya and Morocco in October 2019 to launch the International Platform on Sustainable Finance (IPSF). The objective of the IPSF is to "help scale up the mobilisation of private capital towards environmentally sustainable investments". It aims to do so by strengthening international cooperation on approaches and initiatives for the capital markets (such as taxonomies, disclosures, standards and labels) that are fundamental for private investors to identify and seize environmentally sustainable investment opportunities globally.[104]

Public entities can play a key role in helping to develop the green bond market, complementing initiatives like the IPSF. The main obstacles are traditional financial frictions such as informational asymmetries, which prevent small firms from accessing the market and improving the attractiveness of green labels, and network effects. Given the global dimension of the issue and the size of the investment required, there is scope for a supranational organisation such as the European Investment Bank (EIB) to become more actively involved in the issuance of green bonds and disbursement of funds. The EIB paved the way for the green bond market by issuing the world's first Climate Awareness Bond (CAB) in 2007. As of December 2019, the EIB remained a leading issuer of green bonds with over €26.7 billion raised across 13 currencies, of which the

[104] To find out more, visit the European Commission's IPSF website.

equivalent of €3.4 billion was raised in 2019. Looking to the future, the EIB aims to channel funds of around €1 trillion into investments in climate action and environmental sustainability in the critical decade from 2021 to 2030.[105]

The EIB can also play a role in enhancing the international role of the euro through its involvement in green financing. The euro is already the leading currency for green bond issuance. Entities resident in the EU have become the largest issuers of green bonds and, in 2019, almost half of global green bond issuance was denominated in euro (Chart C, panel a).[106] The euro has also become the currency of choice for non-euro area issuers, as around half of euro issuance has come from non-euro area entities of late (Chart C, panel b). The prevalence of euro-denominated green bonds could thus bolster the international role of the euro. The EIB can complement the actions of other EU authorities in this regard, by helping to establish the taxonomy of sustainable activities eligible for green financing to prevent "greenwashing", which would support the development of a green bond market in the EU. This would further aid issuance of euro-denominated green bonds and expand the euro share of a rapidly expanding market.

The coronavirus (COVID-19) pandemic may have ushered in a new era for green bonds. The European Commission signalled in September 2020 that it was planning to issue €225 billion in green bonds to fund the pandemic recovery package. This amount is roughly equal to total global green bond issuance in 2019, so the move will help to augment the role of supranational institutions in deepening the green bond market and cement the leading role of the EU and the euro in global green bond issuance.

To deal with the economic and social fallout from the pandemic, the European Commission, the European Parliament and EU leaders have agreed on a recovery plan that will lead the way out of the crisis and lay the foundations for a greener, more digital and more resilient Europe. The EU's long-term budget, coupled with the Next Generation EU initiative –- a temporary instrument designed to boost the recovery – will be the largest stimulus package ever financed through the EU budget, amounting to a total of €1.8 trillion. An overall amount of €373.9 billion will be earmarked for natural resources and the environment (€356.4 billion from the Multiannual Financial Framework 2021-2027 and €17.5 billion from the Next Generation EU package), the highest ever share of the European budget.

[105] To find out more, visit the EIB's website.

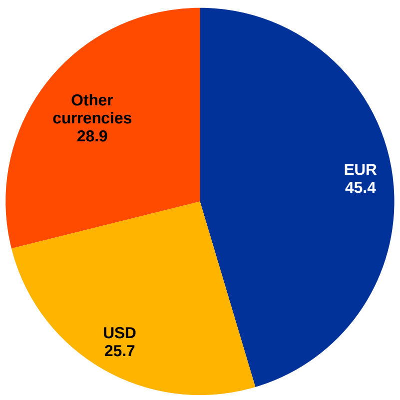
[106] See European Central Bank (2020a).

Chart C

Green bonds outstanding: currency breakdown and issuers' residency

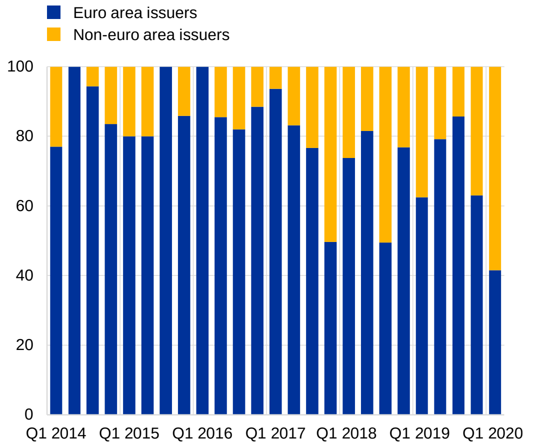
a) Currency breakdown of green bond issuance in 2019

(percentages)



b) Share of euro area and non-euro area issuers of green bonds denominated in euro

(percentages)



Sources: Dealogic and ECB calculations.
Note: Panel b: the latest observation is for 31 January 2020.

Box 11

The European Investment Bank and its approach to climate change

The European Investment Bank (EIB) has a long-standing history of financing green projects carried out by both the private and the public sector. Since 2012 the EIB has provided €197 billion of finance supporting over €670 billion of investment in projects that protect the environment, reduce emissions and help countries adapt to the effects of climate change. €171 billion is focused on climate action and €26 billion dedicated to environmental protection.

The EIB is the world's leading issuer of green bonds, raised across 17 different currencies. Between the inaugural issuance in 2007 and the end of 2020, the EIB supplied over €33.7 billion of green bonds with maturities ranging from two years to 30. While EIB green issuance accounted for 75% of the global green bond market in 2007, this shared had declined to just 2% in 2019 (EIB, 2021b).

In November 2019 the EIB approved ambitious commitments to climate action and environmental sustainability. The EIB decided to increase its level of support for climate action and environmental sustainability to over 50% of its overall lending activity by 2025 (EIB, 2019). Moreover, the EIB agreed to ensure that "all its financing activities are aligned to the goals and principles of the Paris Agreement by the end of 2020". In this context, the EIB agreed to ensure that all its activities did no significant harm to the low-carbon and climate-resilience goals of the Agreement.

In November 2020 the EIB approved the EIB Group Climate Bank Roadmap 2021-2025, setting out how it aims to support the objectives of the European Green Deal (EIB, 2020). Concretely, implementing the roadmap will require the adoption of (i) a framework for aligning new financing operations with the Paris Agreement, underpinned by a new carbon pricing policy; (ii) the proposal to migrate to the EU taxonomy for tracking EIB climate action and environmental sustainability finance; and (iii) an updated climate strategy reflecting the latest scientific knowledge and incorporating the new EIB climate action and environmental sustainability targets. The following paragraphs consider the key elements of the roadmap for the ECB's discussion on climate change.

The EIB plans to ensure that its Paris alignment framework is applied across all its products and operations. So far, the framework has been applied almost exclusively to projects, as the proceeds of an EIB investment loan are directed towards a defined project. In the course of 2021, the EIB intends to also develop counterparty alignment guidelines aimed at verifying whether the wider corporate activities of the counterparty are supported under the EIB alignment framework (EIB, 2020). In the meantime, the EIB Group will continue with its existing approach, which is anchored in an assessment of the relevant corporate decarbonisation plans of high-emitting counterparties. For intermediated operations (i.e. those operations conducted in partnership with other financial institutions, such as commercial banks, public financial institutions, and equity and debt funds), the EIB intends to strengthen its alignment framework. Nevertheless, it will mainly rely on the assessment of underlying sub-projects and/or sub-loans conducted by the financial intermediary, based on agreed contractual documentation (EIB, 2020).

(a) Use of the EU Taxonomy Regulation

The EIB is committed to aligning its tracking methodology for climate action and environmental sustainability finance with the framework defined by the EU Taxonomy Regulation, as this develops over time (EIB, 2020). Migrating to the EU taxonomy will include applying its logic and structure for determining a substantial contribution to the six specified environmental objectives, doing no significant harm to any of the six objectives and meeting minimum social safeguards. Whilst aligning with the EU taxonomy, including in its technical criteria, the EIB will also retain its externally audited tracking system for climate finance, which is harmonised with other international financial institutions.

In migrating to the EU taxonomy, adjustments will need to be made to the current climate finance tracking system, but no major changes are foreseen for intermediated financing. These adjustments will ensure that the EU taxonomy technical screening criteria are reflected in the EIB definitions and related internal guidance. Simplified approaches will be employed to continue supporting the tracking system for intermediated financing – including but not limited to that for SMEs. Moreover, the EIB plans to work with bank networks to help financial intermediaries adopt the EU taxonomy.

The EIB will develop interim definitions to enable comprehensive tracking of the parts not yet covered by the EU taxonomy from the start of 2021. For instance, in 2021 the EIB included the protection and restoration of biodiversity and ecosystems (as per the EU Taxonomy Regulation) for its Sustainability Awareness Bonds (EIB, 2021a). This approach addresses the problem that the technical screening criteria for a substantial contribution to the four environmental objectives other than climate will not be established in a Taxonomy delegated act before the end of 2021. An adjusted set of definitions will then be adopted once the relevant delegated act has been published.

The EIB has committed to adopting the "do no significant harm" criterion to climate change mitigation and adaptation as a "floor" for its operations. This means that projects will have to comply – at a minimum – with this technical criterion as established by the EU taxonomy in order to be eligible for EIB financing. This will be done through adequate project-level management of physical climate risk – as assessed by the EIB's climate risk assessment (see below).

(b) Managing climate change-related risks

The EIB's approach to managing physical climate risk in projects is rooted in its climate risk assessment (CRA) system. This was introduced in February 2019 with the aim of helping the EIB and its clients to understand how climate change may affect their projects and identify adaptation measures. The CRA supports the EIB's climate goals by ensuring some level of adaptation financing in a large number of EIB projects, particularly infrastructure lending. As part of the assessment, an initial screening based on the sub-sector and country of operation is performed for new projects. Any projects initially assessed as being at risk undergo more detailed screening. A climate risk and vulnerability assessment is carried out during the appraisal to identify measures to reduce the potential impact on the project. At the end of the process, the EIB estimates the residual physical climate risk for each operation. The EIB is also developing risk assessment systems similar to the CRA to measure specific environmental aspects of projects. To limit the adverse impact on biodiversity as much as possible, the EIB has developed and tested a Biodiversity Risk Assessment (BRA) system at the project level that will be implemented in the first half of 2021 (EIB, 2021c).

Transition risks are also closely scrutinised as part of the economic appraisal of a project. As a starting point, the EIB calculates and reports all significant absolute and relative emissions of investment projects. With all new operations being Paris-aligned as of 2020, the transition risks of new operations will be substantially reduced.

The EIB has also started to develop counterparty-level climate risk and environment assessment models. Climate risk screening tools have been developed for each of the EIB's main credit segments to assess the climate risk of its counterparties (rather than projects). The methodology captures physical risk, transition risk and a mitigation/adaptation capability for each counterparty. Moreover, the EIB is developing country-specific climate risk scores and industry scores, modelling both physical and transition risk for all countries and sectors where the EIB operates.

The EIB has produced the first set of disclosures in line with the guidelines drawn up by the Task Force on Climate-Related Financial Disclosures (TCFD). The reports have been published in 2021 to complement the existing sustainability-related reports, such as the annual sustainability report, the carbon footprint report, the Global Reporting Initiative (GRI) disclosures and the Sustainability Accounting Standard Board (SASB) report, all of which are published on an annual basis. For the first time, the EIB has prepared a TCFD report to describe how it integrates climate-related risks and opportunities in its governance structure, strategy, risk management and metrics, and targets (EIB, 2021c).

(c) Development of new financial products to support green finance

The EIB plans to build up its range of green products by offering green loans. The aim is to add green loan products to its green debt offer, allowing for wider eligibility in line with the new climate action and environmental sustainability criteria. The EIB is also developing a green bond product (including green hybrid bonds) as a financing instrument (i.e. as a loan substitute). This will enable the EIB to participate in the green bond market not only as an issuer but also as a buyer (EIB, 2020).

Further development of the EIB's intermediated lending products is ongoing with a view to of making it easier for (mainly) SMEs and mid-caps to access green finance (EIB, 2020). The objective is to establish dedicated climate action and environmental sustainability loans and tranches, whose eligibility criteria are aligned with the EIB's new definitions of climate action and environmental sustainability. In this context, the development or enhancement of products supporting green transformation will be among the key business development priorities of the European Investment Fund. It is expected that these will be provided in the form of guarantees, counter-guarantees or credit enhancement to proactively promote environmental goals and significantly improve financing conditions for final beneficiaries.

5 Implications of climate change for the conduct of monetary policy

Chapter 5 at a glance

- Macroeconomic and financial market disruptions linked to climate change and transition policies could affect the conduct of monetary policy and the ability of the ECB to deliver on its price stability mandate through various channels.

- Depending on the nature and speed of the transition policy, climate risks may affect the transmission of monetary policy through financial markets and the banking sector, notably via the stranding of assets and sudden repricing of climate-related financial risks. If the financial system is weakened, the transmission of monetary policy may be impaired.

- Several risks related to climate change may imply a dampening force on the natural rate of interest (r^*), on top of the factors that have already driven its secular decline over the past few decades. On the other hand, higher demand for investment for adaptation and reconstruction purposes may push up r^*, all else being equal. An increase in productivity related to innovation may also exert upward pressure on the natural rate. The net effect of these two opposing forces is uncertain ex ante. However, should the forces dampening the natural rate prevail, the policy rate could hit the effective lower bound (ELB) more often, limiting the monetary policy space for conventional tools.

- Climate risks may complicate the correct identification of shocks relevant for the medium-term inflation outlook, making it more difficult to assess the monetary policy stance and potentially increasing the prevalence of output and price stabilisation trade-offs.

- Uncertainty about the magnitude of the effects of climate change and the horizon over which they will play out in the economy may compound these effects.

- A set of model simulations illustrates how physical risk and transition risk related to the climate could combine with financial fragilities, which themselves could be the result of climate risks materialising, and which could significantly restrict the ability of monetary policy to respond to standard business cycle fluctuations.

- The transition is likely to have a substantial effect on economic and financial activities, relative prices and inflation, output growth and productivity, and hence on the optimal response of monetary policy, particularly if it occurs in a disorderly fashion.

5.1 Introduction

Climate change could have a number of implications for the conduct of monetary policy as a result of its potential impact on the macro economy and financial markets, as discussed in the previous chapters. Two aspects in particular have attracted the attention of academics and experts recently. The first concerns the possible implications of climate change and mitigation policies for the ability of central banks to deliver on their price stability mandate. The second concerns the extent to which central banks themselves can play a supporting role in mitigating the risks associated with climate change, while staying within their mandate. Related to this, an additional question concerns the contributions that central banks can make to support the green transition.

The literature has identified three main channels through which climate change may affect the conduct of monetary policy.

First, climate risks may affect the transmission channel of monetary policy. This may be especially evident in the potential impact on financial markets and the banking sector due, for example, to the stranding of assets and the sudden repricing of climate-related financial risks, as discussed in the previous chapter (Section 5.2). In the banking sector, the value of collateral may fall and credit losses may materialise. This could dent the capital and liquidity positions of banks and other financial intermediaries, thereby weakening their ability to channel funds to the real economy. If the financial system is weakened, the transmission of monetary policy is impaired.

Second, several risks related to climate change may have a dampening effect on the natural rate of interest. These would come on top of the factors that have already driven the secular decline in this variable over the past few decades. The natural rate of interest, or r^*, provides an important benchmark for assessing the monetary policy stance for a given level of the policy rate. If climate-related factors were to cause r^* to fall further, which is not clear at the current juncture, the policy rate could hit the ELB more often and thus limit the monetary policy space for conventional tools (Section 5.3). This in turn could coincide with low fiscal space in some countries if, for example, public debt is already too high, possibly leading to macroeconomic stabilisation against standard fluctuations to be provided sub-optimally across the business cycle.

Third, climate risks may further complicate the correct identification of shocks relevant for the medium-term inflation outlook. This would make it more difficult to assess the monetary policy stance and potentially increase the prevalence of output and price stabilisation trade-offs for central banks that focus on price stability (Section 5.4). Uncertainty surrounding the magnitude of the effects of climate change and the horizon over which they will play out in the economy will further complicate the assessment of appropriate monetary policy actions. Uncertainty may also destabilise the expectation-formation process of economic agents, in particular with regard to inflation expectations. Finally, the effects of physical risk and transition policies could be asymmetric and heterogeneous among economic agents as well as across sectors and countries. This could further complicate the behaviour of a central bank that focuses on price stability, especially in the euro area, a large monetary union with a relatively small central fiscal budget to counter asymmetric shocks and largely independent structural and fiscal policies at the country level.

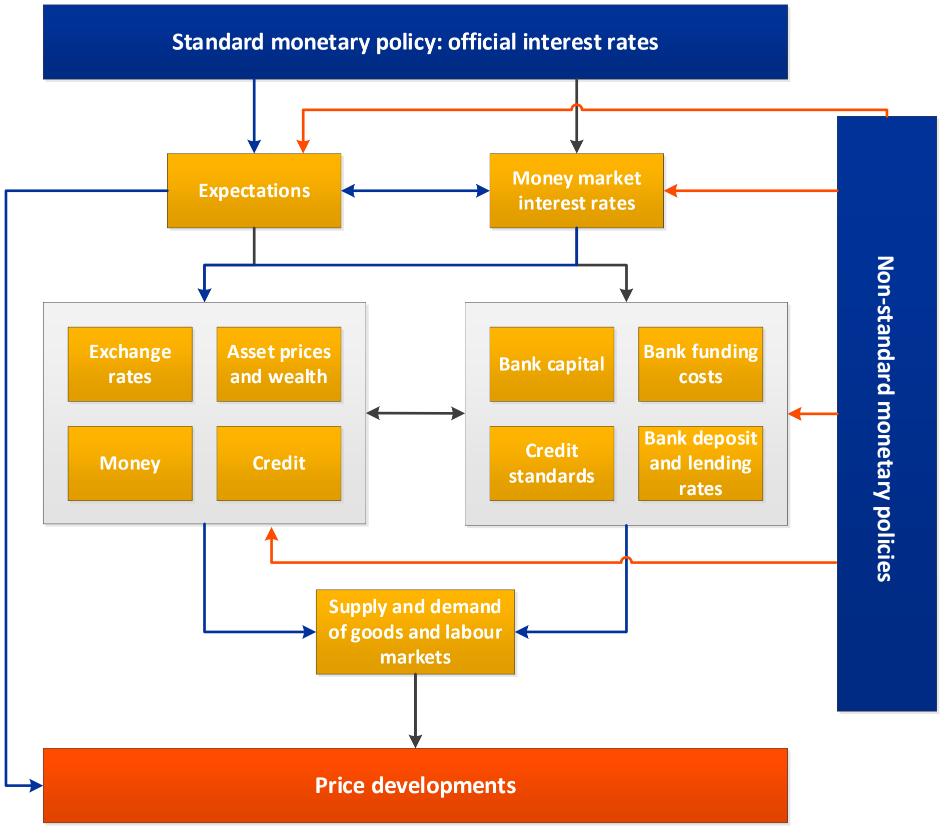
Drawing all the channels together, Section 5.5 will present some model-based simulations illustrating plausible situations where climate change might complicate the conduct of monetary policy and might affect the ability of the ECB to ensure price stability, in particular in the light of economic disruptions and more frequent and persistent supply and demand shocks.

5.2 Implications of climate change for the transmission of monetary policy

Climate change is likely to put a strain on financial intermediaries and their ability to effectively transmit the monetary policy stance to the economy.[107] Figure 3 provides a schematic representation of the main channels through which monetary policy decisions pass through financial intermediaries to affect the economy in general and the price level in particular, distinguishing between standard and non-standard monetary policy decisions (see Beyer et al., 2017, and further references therein). The black and blue arrows indicate a stylised scheme for the transmission of standard monetary policy decisions via official interest rate adjustments that influence expectations and money market conditions, which are then transmitted through the banking system (as well as the rest of the financial system) to affect economic activity and price developments with a lag. The right rectangle in the chart highlights the inner working of the banking sector, which plays an important role in the euro area economy. Monetary policy transmission can be affected by changes in bank capital, bank funding costs, credit standards, and bank deposit and lending rates. Non-standard monetary policy measures can serve to safeguard specific transmission channels that become impaired or to ease the overall monetary policy stance when the policy rate approaches the ELB. The red arrows in the chart show how central bank interventions in specific market segments can directly affect expectations and the term structure of interest rates, and support asset prices and/or overall lending in the banking sector. These measures are also likely to influence market conditions for non-bank credit and may support market liquidity and market functioning.

[107] These include credit institutions, insurance companies, brokers-dealers and different types of investment funds (pension, money market, mutual funds). For simplicity, this section will mostly refer to all of these as “banks”.

Figure 3
Transmission mechanisms of monetary policy



Source: Beyer et al. (2017).

The main transmission channels of monetary policy are also listed in the first column of Table 7. They comprise the interest rate channel, the credit channel, which works via bank and non-bank lending, the asset price channel, the exchange rate channel and the expectations channel. In the near future, these channels could all be increasingly exposed to climate-related risks. While distinguishing between the possible impact of physical risk and transition risk, the discussion below only provides notional indications until more is known about the timing, severity and trade-offs among the various risks.

Table 7

Monetary policy transmission: effects of climate change

	Physical risk from more common extreme weather events and persistent warming	**Transition risk** from carbon pricing and reducing emissions
Interest rate channel	Non-interest cost factors become more relevant, lowering investment and saving response to interest rate changes.	Uncertainty about timing and speed of policy response raises risk premia and volatility. Natural rate of interest affected.
Credit channel	Financial losses reduce borrower net worth, bank collateral and profitability. Non-performing loans constrain credit supply. Uncertainty reduces market funding of banks.	Financial losses reduce borrower net worth, bank collateral and profitability. Non-performing loans constrain credit supply. Uncertainty reduces market funding of banks.
Asset price channel	Physical risks destroy capital and residential property. Financial losses lower firm valuations.	Demand shifts across sectors and regions. Stranded assets.
Exchange rate channel	Devaluation incentive for short-term competitiveness gain. Higher volatility.	Carbon border adjustment may disrupt trade routes and global value chains.
Expectations channel	Monetary policy less predictable since shock persistence uncertain, blurring supply/demand.	Time-inconsistent transition policies reduce monetary policy credibility and effectiveness of forward guidance.

Interest rate channel

Climate change is likely to reduce the interest rate sensitivity of investment and savings, as also argued in Chapters 1 and 2. Greater risk aversion and higher uncertainty stemming from climate-related risks (both physical and transition) could prompt households to increase precautionary saving and firms to reduce investment. If the interest rate sensitivity of investment falls, a given change in the policy interest rate will have a smaller impact on output. Thus, standard monetary policy will become less effective.

Credit channel

Although the role of non-bank financial intermediaries has grown steadily in the euro area in recent years, banks remain the largest financial sub-sector and a key intermediary for the effective transmission of the ECB's monetary policy stance to the euro area real economy.[108] The credit channel is likely to reflect some of the most significant impact of climate change on monetary policy transmission.

First, the credit channel may be affected by a deterioration of borrower creditworthiness caused by climate change. Firm and household balance sheets may be hit – directly and indirectly – by various physical risks, such as floods, wildfires or storms. New environmental regulations and transition policies may also reduce the net present value of many assets and thus impair collateral values and the ability to borrow. Lenders might well consider loans more risky if households and

[108] European Central Bank (2020b).

firms show a higher probability of default. The net supply of loans could therefore decline at any given level of the risk exposure desired by lenders (see Box 8).

Second, more frequent and disruptive extreme weather events could increase banks' stocks of non-performing loans (NPLs), with negative consequences for their balance sheets. Moreover, in an abrupt and disorderly transition, credit spreads could rise for carbon-intensive firms if a significant share of their assets became stranded, for example, or liability risks materialised. This is likely to put pressure on the balance sheets of banks and other lenders as carbon-intensive assets and loans are revalued. Moreover, fire sale effects during recent financial crises suggest that credit ratings could trigger downward spirals, with significant macroeconomic consequences.

The asset-pricing literature has established that financial intermediaries are not always efficient in allocating capital to investment opportunities. Mounting empirical evidence suggests that resilience and constraints among financial intermediaries matter for asset prices, risk premia and credit allocation (He et al., 2017; Adrian et al., 2014). Specifically, when hit by an adverse shock to the value of assets on their balance sheet, financial intermediaries tend to reduce their leverage by selling assets, thereby increasing the risk premia of the financial instruments and products (loans) that they offer. As a result, these shocks might generate not only declines in the value of collateral the financial intermediaries have available but also increases in interest rates through higher risk premia. These frictions would ultimately also reduce the quantity of loans supplied to the real economy.

Third, a further source of stress could come from market funding of banks, which could dry up amid mounting uncertainty related to climate risks. Of course, the market is not the only source of funding for banks. Since the great financial crisis, central banks have increasingly intervened to ease financing conditions for banks, with a view to ensuring the smooth provision of credit to firms and households in the real economy. However, climate risks may also affect the collateral that banks need for central bank refinancing operations. Given their obligation to manage risk prudently, central banks may need to adapt their collateral framework to adequately reflect climate risk.[109] If this is done by introducing restrictions on the pool of bank assets eligible for refinancing, additional central bank measures may be required to ensure the continued provision of adequate liquidity in the banking sector.[110]

Fourth, the credit channel of monetary policy transmission could also be affected by the impact of climate change on the level of interest rates and bank profitability. The current low-interest rate environment has already eroded bank profitability, possibly weakening interest rate pass-through to bank lending rates.[111] If climate change leads to an even longer period of low interest rates, bank interest rate margins could remain compressed for longer or could be further compressed,

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109 See Villeroy de Galhau (2019) and Coeuré (2018).

110 Better risk management could also be achieved by promoting a shift to low climate risk assets, especially if the process is introduced gradually.

111 See Deutsche Bundesbank (2019).

denting their profitability even more.[112] In these conditions, banks could find it difficult to meet capital requirements, which means they could further restrict their loan supply.[113]

Asset price channel

Climate change is likely to cause risk premia and financial market volatility to rise, which would impair monetary policy transmission through the asset price channel. For a start, extreme weather events could lead to more frequent and more severe episodes of financial market disruption. At the same time, gradual warming could redistribute demand across regions and sectors of production, affecting firms' relative return on equity. In this context, it is widely anticipated that sudden changes in transition policies (or only changes in their credibility) could create "stranded assets", triggering corporate revaluations. In addition, physical risks will lower the value of residential property or capital assets in areas exposed to wildfires, floods or desertification. Such losses will, in turn, have wealth effects on household consumption and influence corporate investment through Tobin's Q.

Corporate borrowing via financial markets could also affect the asset price channel, as climate change may increase the riskiness of corporate bonds and the likelihood of rating downgrades or default among households and firms. Furthermore, more frequent and more damaging extreme weather events and changes to the regulatory environment may challenge the stability of insurance companies, disrupting asset prices through non-bank financial intermediaries. Some physical risks may become uninsurable, forcing households, businesses and governments to pay higher premia on their debt.

Exchange rate channel

Under normal conditions, the exchange rate reinforces the desired effect of monetary policy. Higher interest rates encourage the currency to appreciate, which also contributes to slowing economic activity and overheating prices. However, the additional uncertainty and higher macroeconomic volatility from climate change could eventually impair the exchange rate channel of monetary policy transmission. For example, a disorderly transition to a low-carbon economy could reverse the sign of exchange rate responses to monetary policy. Even in an orderly transition as envisaged by the Network for Greening the Financial System (Network for Greening the Financial System, 2019a and 2020a), climate change is likely to alter the composition of output in certain countries and the pattern of international trade more generally. Over time, this could erode the terms of trade in countries that are more exposed to climate risks. In particular, climate change may transform the exposure of individual euro area countries to extra-euro area trade, which would weaken the exchange rate channel for some euro area countries while strengthening it for

[112] See Boucinha and Burlon (2020).

[113] See Altavilla et al. (2018) or Brei et al. (2019).

others. By accentuating differences across the euro area in this way, climate change could affect monetary policy transmission as well as exchange rate pass-through to overall euro area inflation.[114]

Expectations channel

The growing uncertainty associated with climate change might also weaken the expectations channel of monetary policy transmission. A disorderly transition and financial market disruption could make it more difficult for central banks to distinguish demand shocks from supply shocks. This, in turn, could pose a challenge for central bank communication and confuse private sector expectations of future monetary policy.

At present, both the theoretical and the empirical literature investigating the impact of climate change on monetary policy transmission is limited. It will be important to fill this gap in the future – to support the rationale for any proposed changes to the implementation framework, for example – because the ability of the monetary policy instruments to affect the stance relies on the smooth transmission of monetary policy.

5.3 Climate change and the natural rate of interest: implications for the policy space

This section reviews the theoretical and empirical literature assessing the impact of climate change on the drivers of the natural rate of interest (*r).** It comprises two parts: a conceptual part listing the main drivers of *r** identified in the literature, followed by some conjecture on the potential future impact of climate change on these drivers and the possible development of *r** in the euro area.

5.3.1 Conceptual issues

The natural rate of interest *r can be defined as the rate that is consistent with stable inflation when the economy is growing at its trend.** The New Keynesian literature defines the natural rate of interest as the real interest rate that would prevail in equilibrium in an economy without nominal rigidities in wages and prices.

While the natural rate is not directly observable, estimates of its value provide a benchmark for the stance of monetary policy (Lubik and Matthes, 2015). Hence, the lower *r**, the tighter the policy space for central banks to provide monetary accommodation and the higher the risks of hitting the ELB.[115]

[114] See Ortega and Osbat (2020).

[115] This adds to the uncertain impact of climate change on output gap measures; since productivity and inflation trends may change, cyclical deviations become more uncertain.

A useful starting point is the neoclassical growth model formulation of the natural rate (Ramsey, 1928):

$$r^* = \frac{1}{\sigma} g + n + \rho \tag{1}$$

where *g* is the growth rate of labour-augmenting technological change and *n* is the rate of population growth. The parameter σ denotes the intertemporal elasticity of substitution in consumption and reflects the responsiveness of the growth rate of consumption to the real interest rate. In this simple model, the inverse 1/σ captures risk aversion. ρ is the rate of time preference: the lower ρ, the higher the current discounted value of future damage stemming from climate change. Recent studies show that other factors, including government policies and income inequality, affect *r**.

Estimates of the natural rate of interest are subject to large uncertainty. And yet, there is clear empirical evidence to suggest that long-term real interest rates have been falling since at least the mid-1980s in advanced economies and that *r** might have followed a similar path over the past 30 years (Brand et al., 2018). Recent studies using different methodologies confirm this decline (Hamilton et al., 2016; Laubach and Williams, 2015). Rachel and Smith (2015) discuss the relative importance of different drivers of *r** and conclude that, rather than slower global growth, shifts in saving and investment preferences appear more important in explaining its long-term decline. These trends are likely to persist in the future, suggesting that the natural rate of interest may remain low. Climate change may impact all the drivers of *r** affecting its future development, as discussed below.

5.3.2 Conjectures on the impact of climate change on *r**

Overall, various studies argue that climate change is, on net, likely to put downward pressure on *r through several channels.** Yet the extent and timing, and possibly even the direction, of the impact are still highly uncertain. This compounds the already large uncertainty of estimating future trends in *r** when relying on past data (Cantelmo, 2020; Brand et al., 2018).

Demographic trends

Most advanced economies are experiencing a demographic transition, reflecting low fertility rates, rising life expectancy and a changing age composition. Brand et al. (2018) find that the net effect of these trends is to have reduced real interest rates in the euro area by around 1 percentage point since the 1980s. There are several channels through which the demographic transition can affect *r**.

- **Lower labour supply (lower *n*):** This leads to higher capital per worker, which reduces the marginal product of capital in steady state and hence *r**. Climate change, in particular extreme heat, could lead to more disease and a permanent reduction in effective labour supply among older cohorts, and even reverse life-expectancy trends. The impact of climate change could differ across countries, as labour supply might rise in some countries due to climate-induced immigration. These effects are very uncertain and could manifest themselves over very long horizons (see Feyen et al., 2020, and Section 1.1 above).

- **Life expectancy and age composition:** To the extent that climate change may reduce life expectancy and rebalance the age composition of the population towards younger cohorts, as older individuals are more vulnerable to the physical effects of climate change, the impact on the natural rate may be positive. Most studies indicate that ageing has a downward influence on r^*, with the life-expectancy channel usually being stronger than the age-composition channel.

The net impact of climate change on demographic trends is thus ambiguous. While it might reduce labour supply and labour productivity so as to exacerbate the negative effect on r^*, it could also have a positive effect on r^* by reversing the current trend towards higher life expectancy and changing the age composition of the population in favour of younger cohorts.[116] When extrapolating demographic trends, Brand et al. (2018) predict that these factors alone could dampen real interest rates by 0.25-0.5 percentage points by 2030.

Productivity growth

In the Ramsey model, higher productivity growth increases households' expected future income, reducing their need to save in order to sustain future consumption. Lower savings then translates into a higher marginal product of capital and thus higher r^*. Climate change can also affect productivity in different ways.

The "comfort" temperature for humans lies between 18ºC and 22ºC. Extreme temperatures above or below this range can have major physiological effects on mortality, health and, in turn, labour supply and productivity (Seppänen et al., 2007). Existing evidence finds that labour productivity decreases by 2% per degree above comfort temperature (Heal and Park, 2016). The possibility to adapt to higher temperatures mitigates this impact.

Besides having a permanent effect on total factor productivity growth, physical risk will likely affect the capital stock directly, if commercial property and production equipment is damaged at a faster pace than under current climate conditions (a higher obsolescence rate).[117] This will lead to resources

[116] In addition, it is possible that migration policies will be adopted to dampen the impact on demographics.

[117] In a similar vein, Batten (2018) argues that gradual global warming will cause a diversion of resources from productive investment to the adaptation to higher temperatures, thereby also reducing productivity prospects. Dietz and Stern (2015) analyse how the damages to the capital stock also diminish knowledge production and knowledge spillovers and hence lower the long-term growth rates of the economy.

being diverted from innovation to reconstruction, adaptation and damage mitigation. If substantial resources are redirected to fund adaptation policies, they cannot be invested in R&D, thus lowering productivity growth.

With climate change unabated, transition risks might also turn productive investments into stranded assets. Hence, both physical and transition risks can lead to increasing rates of capital depreciation, thereby lowering the capital stock.[118]

At first glance, the effect of climate-induced replacement on total factor productivity is unclear. Struck by a natural disaster, firms could exchange damaged machinery for the latest, more productive technology, which could boost productivity in the affected region. But if the damage to physical assets multiplies, more capital will be deployed for replacement and repair investments, leaving firms with less funding for R&D and lowering their capacity to roll out new technologies.

Policies to mitigate and adapt to climate change could also have substantial indirect short- and long-term effects on productivity growth. This could involve the following:

- Firms might have to invest to comply with new rules and regulations; this might divert resources from other productive inputs while not increasing value added.
- Some firms might not be able to afford such investments and could be forced out of the market; entry barriers might thus increase (OECD, 2006).
- The impact on frontier firms (positive) and laggards (negative) in a given sector will differ (Albrizio et al., 2014).
- The range of inputs and production processes might narrow, leading to poor decisions.
- Innovation will be encouraged, benefiting productivity growth in the long run (Porter hypothesis, in Porter, 1991, and Porter and van der Linde, 1995; see also Lee et al., 2011).
- The emergence of new sectors and activities might be promoted.

Although inconclusive, empirical evidence tends to indicate a negative impact on productivity growth in the short run while in the long-term results are mixed.

Risk aversion and changes in preferences and precautionary savings

Risk aversion is a channel through which climate change affects the natural rate. Climate change, adaptation and the transition to a carbon-neutral economy

118 Climate policy will play an increasingly important role and form a trade-off between short-run growth and long-run environmental quality (“weak” green growth) but could lead to productivity growth even in the short term if it fosters low-carbon innovation (“strong” green growth). Climate policy will change the relative price of energy inputs, which will affect the type of technologies that are developed (Acemoglu et al., 2012).

may go in tandem with higher economic tail risk and uncertainty (Batten et al., 2019). Empirical research shows that investors translate climate-related uncertainty into a higher risk premium (Bansal et al., 2019). A higher risk premium increases the propensity to save and the demand for low-risk assets, two factors that can reduce *r** (Bansal et al., 2019; Cevik and Jalles, 2020; Battiston and Monasterolo, 2020). The resulting macroeconomic effect is a reduced willingness to invest and a greater propensity to save – two factors that lower the natural rate of interest.

These effects might be asymmetric. Physical risks might affect the risk aversion of agents in vulnerable regions and sectors, while transition risk can affect risk aversion across all horizons, depending on the policy adjustment scenario. A scenario with an erratic and uncertain adjustment path will likely increase risk aversion and market volatility more than a clear and well-communicated climate policy. Box 12 discusses the impact of risk aversion on *r** in a standard New Keynesian framework.

Another contributing factor could be higher demand for safe assets, reinforced by climate change-related uncertainty. For instance, increased uncertainty about firms' asset values and public finances in the transition to a carbon-neutral economy may boost the demand for safe assets. As a result, the premia market participants are willing to pay for holding safe assets, which do not risk becoming stranded, are likely to rise, putting downward pressure on *r**. This involves the safe asset channel, which asserts that safe assets hold a convenience yield that lowers the bond yield. An increased demand for safe assets will then have a downward effect on the natural rate of interest (Del Negro et al., 2017; Caballero and Farhi, 2018). Given that there is no pan-European safe asset, here too there might be asymmetric effects in the euro area.

Overall, the precise impact on *r through such financial channels is hard to quantify.** Research in terms of quantity and intensity on how risks associated with climate change are priced into bond yields is scarce. Nonetheless, available analysis indicates that financial risks stemming from climate change can put further downward pressure on *r** through higher premia.

Fiscal policy, climate change and indirect impact on *r**

Climate change could increase government debt as a result of higher mitigation and adaptation investment or greater expenditure to cover health and other costs of natural disasters. A larger supply of sovereign assets in the economy might then increase *r**. But the quality and composition of fiscal policies in the context of climate policies also matters. The positive sign on *r** assumes an orderly transition with adequate carbon pricing, whereby the proceeds are mostly used for social spending to compensate the losers from carbon pricing. The impact on *r** could be mitigated or the sign of the impact could switch if all the proceeds were used to support public investment and innovation, which would promote total factor productivity growth (and thus improve long-run fiscal sustainability).

Income inequality

Rising income inequality can lower the equilibrium real interest rate *r as a consequence of reduced consumption and increased desired savings (Rachel and Smith, 2015; Auclert and Rognlie, 2016).** Climate change is likely to increase income inequality (Diffenbaugh and Burke, 2019) and thus reduce *r**.

Conclusions

This section has reviewed several channels through which climate change might affect the natural rate of interest *r.** The two most powerful channels seem to be the impact on productivity, and uncertainty and risk aversion. Overall, climate change can be expected to drive both down, at least until the transition is completed. This would put further downward pressure on *r**, except in the case of "strong" green growth that would boost productivity. Yet this is subject to nuances and qualifications, and the need for investment to support the transition and technological innovation may exert countervailing influences.

The uncertainty associated with climate change and the transition path will encourage households to raise their precautionary savings and may induce firms to postpone investment, putting downward pressure on market interest rates. Ultimately, the path of interest rates and *r** will depend largely on the credibility of policies governing the transition to a low-carbon economy. Along this adjustment path, the reallocation of capital across sectors and the impact on firm valuations and risk premia can lead to complex dynamics affecting aggregate variables and ultimately the natural rate of interest.[119]

5.4 Climate risks and the conduct of monetary policy

The implications of climate change for the conduct of monetary policy have received only little attention from both policy and academia. This section takes a conceptual point of view to discuss four channels through which climate change could affect the monetary policy framework of the Eurosystem: (i) the macroeconomic context and interactions with other policies, (ii) the transmission of climate change to price stability risks, (iii) the possible implications for some design features of the monetary policy framework, and iv) the role of uncertainty and its impact on monetary policy strategy.

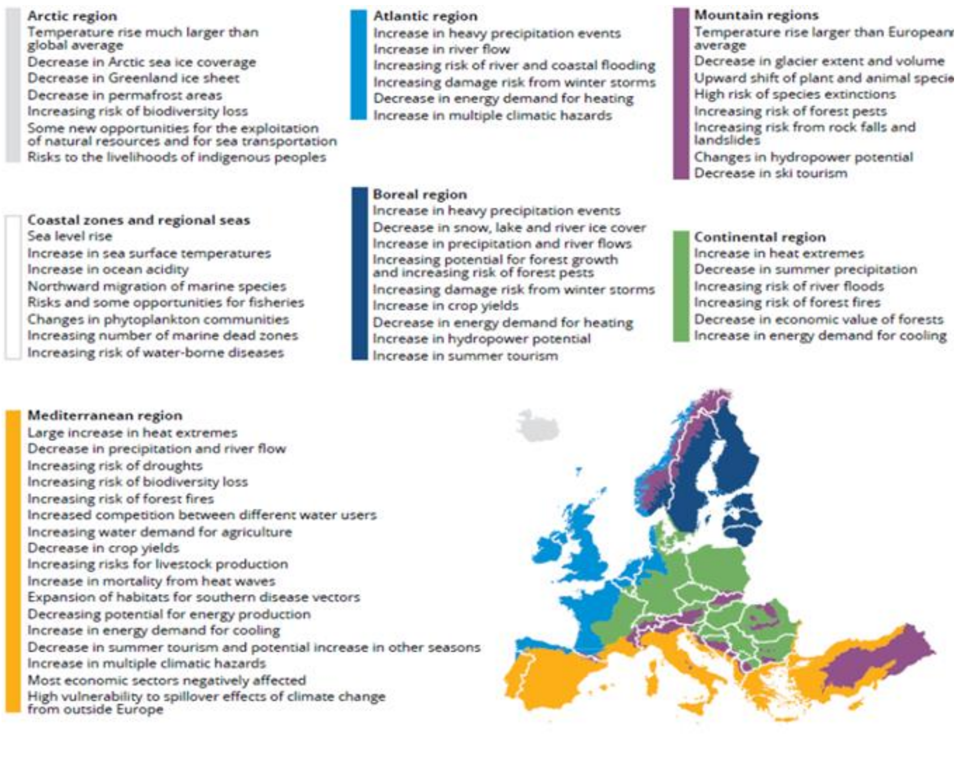
There is a need to elaborate the possible future implications for the conduct of monetary policy and the design elements of the ECB's monetary policy strategy, should climate change affect the economy of the euro area as predicted. In this context, it is important to bear in mind that greater certainty about the impact for the strategy will only emerge over time, given our still limited knowledge of the possible effects and the long-term nature of climate change.

[119] See Donadelli et al. (2019).

5.4.1 The context: monetary policy, heterogeneity and interactions with other policies

The diverse nature of physical risks across the euro area may make it harder to formulate a single monetary policy. It is clear from the discussion in Chapter 1 that different physical risks will materialise in different regions with different probabilities and different severity; the diverse nature of physical risks in the euro area is greater than it would be in a small, open economy simply due to the dimensions and geographic diversity involved. An increase of 1.5ºC in the average temperature across the euro area could comprise an increase of more than 2ºC in some regions and less than 1ºC in others. Rising sea levels will affect countries with long coastlines disproportionately; the melting of glaciers will have no material impact in many countries, while a few will suffer severe repercussions. Figure 4 shows the different regional vulnerabilities to physical risk, as compiled by European Environment Agency (2017).

Figure 4
Geography of physical risks



Source: European Environment Agency (2017), p. 24.

Transition policies will also have asymmetric effects in the euro area, even though EU goals are shared. Different starting levels of greenhouse gas (GHG) emissions will cause the impact of transition policies to vary throughout the euro area.

These country-specific differences are likely to lead national policymakers to make dissimilar policy decisions, especially when shaping fiscal policy to aid those most affected by these risks. In addition, the ability of national policymakers to absorb these climate-related risks and provide a cushion against asymmetric shocks will differ according to local levels of public debt and the sustainability of public finances. In the absence of more effective private and public risk-sharing mechanisms, fiscal divergence within the euro area might increase. Monetary policy aiming at price stability, on aggregate, cannot compensate for the limited scope of national stabilisation policies. In fact, climate change might cause the natural rate of interest to decrease yet more (see Section 5.3), which would further squeeze the monetary policy space. Even though these challenges should be carefully addressed and their implications kept in mind, especially through the development of appropriate modelling tools, it is worth recalling that this is not something novel and ECB monetary policy had dealt with a number of asymmetric shocks. In addition, climate change policies and their funding are at the centre of the action of the EU, which implies that a number of policies and funding instruments will be available to support an orderly transition.

5.4.2 Demand and supply shocks, and the transmission of climate change to price stability risks

The potential for, and response to, economic shocks represents the challenge more closely linking climate change and monetary policy. Climate change will be a source of more frequent, intense and persistent shocks to the economy that are hard to disentangle. The intrinsic non-linearities raise uncertainty about the likely effects and economic correlations.

Extreme weather events can primarily be thought of as supply shocks, which in the short run tend to increase prices, while at the same time lowering output. From the central bank perspective, supply shocks are problematic, as they present a dilemma between stabilising inflation and boosting economic activity. As such, supply shocks are more difficult to counter from a monetary policy perspective than demand shocks. Typically, central banks tackle this dilemma by calibrating the policy response to the size and persistence of the shock. If they assess it to be short-lived and unlikely to affect the medium-term inflation outlook, they may “look through” such a shock. Under these conditions, the central bank may tolerate the temporary effects on inflation without taking any action, in order not to cause undue volatility in output and employment. If they assess the shock to be more persistent, with a risk that it may lead to second-round effects on wages and inflation and an unanchoring of inflation expectations, monetary policy action may be warranted. However, as climate change amplifies the frequency and severity of supply shocks, making them more persistent, it may become increasingly difficult for central banks to “look through” such shocks (Batten et al., 2016; Rudebusch, 2019).

In addition to supply shocks, extreme weather events can also cause demand-side fluctuations. For example, losses deriving from extreme weather events could reduce households’ wealth and hence consumption. Moreover, preparing for such events could also lead to precautionary saving. While reconstruction activities may lead to an increase in spending, business investment could be negatively affected by financial losses following climate disasters (Batten et al., 2019), while uncertainty may create further headwinds for investment. Negative demand shocks could also result from transition policies, as stricter climate policies cause dislocations and assets to be stranded in high-carbon sectors, for example.

The transition towards a climate-neutral economy will affect prices, and hence price stability, through various channels. The transition can be brought forward by policy changes, technological progress and changes in preferences. As discussed in Chapter 2, the most stringent policy response to climate change is the introduction of a carbon tax or an emissions trading scheme. Economically, they have similar effects: by raising their price, they reduce demand for products or processes that rely on carbon-intensive technologies, thereby making climate-neutral technologies more competitive. To the extent that consumer goods rely on these carbon-intensive technologies, and in the absence of immediate carbon-free substitutes, this will directly raise inflation. Whether this increase will be a one-off or a slow-moving, prolonged process of higher inflation depends on the policy design. But a widely cited proposal by US economists suggested increasing the carbon tax every year until emission-reduction goals are met, which might lead to a period of upward pressure on inflation, or possibly even high inflation, depending on the starting point.[120] The economists also proposed a carbon border adjustment, which the European Commission has now also taken up. New regulations on emission standards for houses, cars or production processes will also cause relative prices to change. Again, the size and sign of the impact will depend on policy design and the available substitutes, making them difficult to predict. The same holds true for the effects of technological progress through innovations on the supply of climate-neutral goods as, almost by definition, the emergence and effects of innovations are difficult if not impossible to forecast. Finally, changes in consumer preferences triggered by a growing awareness of the dire consequences of climate change might precipitate demand shifts that also lead to (relative) price changes.

5.4.3 Impact of climate change on design features of the monetary policy framework

Central banks have not yet taken the impact of climate change into account in the design of their monetary policy strategy. However, some considerations may be formulated on the need to reconsider certain design elements in the future, should the impact of climate change affect the economy of the euro area as predicted.

Policy horizon

Climate change shapes economic and financial trends over horizons that exceed the traditional monetary policy horizon ("tragedy of the horizon"). However, climate change can also affect financial and economic variables within the

[120] The Economists' Statement on Carbon Dividends was published in January 2019 and signed by more than 3,500 US economists, including all living former Chairs of the Federal Reserve and 27 Nobel Laureate economists.

monetary policy time horizon, as seen for instance in changes in agents' behaviour induced by transition policies, by the persistent impact of a number of shocks and by asset prices reflecting future climate risks. In practice, this may mean that some of the climate change shocks may call for the medium-term policy horizon to be lengthened to take account of the impacts of possibly repeated and correlated climate and/or transition shocks to price stability if, for example, they lead to trade-offs between inflation and employment. At the same time, the credibility of the central bank may be compromised if the time horizon is extended too far into the future and inflation targets are missed too often. In this case, clear communication about the policy intentions of the central bank will be essential to mitigate credibility losses.[121] That said, the challenges for monetary policy are expected to be contained if the transition is orderly and spread over decades. Overall, the medium-term formulation of the ECB monetary policy seems to equip the central bank with the requisite flexibility at the current juncture.

Policy space

Climate change may put downward pressure on the drivers of *r (see Section 5.3).** This will reduce the policy space for central banks, as it increases the likelihood that the ELB will become binding, which adds to the uncertain impact of climate change on the output gap. Unconventional policy tools may not be able to compensate in full for the reduced policy space for conventional monetary policy. Moreover, such tools come with potential side effects. Thus, it will be important to apply policies that can help to avoid the ELB being hit. However, it is worth recalling that the uncertainty about the size, and even the direction, of the impact of climate change on the natural rate of interest is very large.

Overall, the secular nature of climate change and the still limited knowledge of its possible effects suggest that more precise indications of its impact for monetary policy strategy may only emerge slowly over a prolonged period of time.

5.4.4 Climate change, fundamental uncertainty and monetary policy

The economic impact of climate change is surrounded by fundamental uncertainty, in the sense that it is indeterminate and cannot be quantified based on known probability distributions of events (Knight, 1921). It depends on physical, social and economic systems that involve complex interactions, non-linear dynamics and chain reactions (Bolton et al., 2020). Both physical and transition risks are inherently fat-tailed events that are not reflected in past data, with a potentially unlimited downside exposure (Weitzman, 2009). Hence, climate change

121 Bolton et al. (2020) suggest that central banks have a special perspective that private players and other policymakers cannot necessarily adopt, given their interests and time horizons. In this view, central banks could promote long-termism, including by proactively supporting the values and ideals of sustainable finance, in order to break the tragedy of the horizon. However, these actions might require significant changes in the strategies and possibly also the mandates of central banks.

will be a source of more frequent, intense and persistent shocks to the economy that are hard to disentangle. The intrinsic non-linearities raise uncertainty about the transmission mechanism of monetary policy and economic correlations. This unsettles monetary analysis and makes it more difficult to identify the appropriate monetary policy response. For monetary policy, this has implications for modelling tools and the policy strategy more generally.

Existing macroeconomic and climate-economy models may not be able to accurately predict the economic and financial impact of climate change (Network for Greening the Financial System, 2019a). They are based on past data and known relationships, meaning that they do not capture unknown future systemic risks posed by climate change. Barnett et al. (2020) conclude that the impact of the interacting uncertainties stemming from climate and economic modelling is multiplicative and when both are large, their combined impact can be truly substantial. Bolton et al. (2020) suggest that scenario-based analyses supported by non-equilibrium models should be explored by central banks, but they acknowledge that these will not be sufficient to guide decision-making, as their use remains limited by the radical uncertainty inherent to climate change. They advise "going beyond models", by developing more holistic approaches that can better embrace the fundamental uncertainty of climate change as well as the need for system-wide action.

In the literature, alternative and often qualitative strategies that aim at strengthening the resilience and robustness of the system are associated with fundamental uncertainty (Kay and King, 2020). Similar to what Bolton et al. (2020) call an "epistemological break" in the approach of central banks, regulators and supervisors, there is a movement from risk management approaches towards strategies which seek to build the resilience of complex adaptive systems that are affected by climate change. Risk management strategies tend to deal with measurable uncertainty (risk). There are risk management strategies in monetary policy that call for policy gradualism (Brainard, 1967), or more aggressive responses by the central bank (e.g. Tetlow, 2018). Barnett et al. (2020) suggest that a decision-maker that is averse to ambiguity over models and to potential model misspecification due to climate risk is more cautious in its responses. The "epistemological break" required by the immeasurable uncertainty associated with climate change might call for monetary policy strategies that are flexible and adaptive to changing circumstances with regard to methods and goals, and have multiple alternative instruments and solutions, as well as a margin of safety (Ben-Haim and Demertzis, 2016). In the same spirit, Bolton et al. (2020) advocate a systemic approach of policymaking that aims at coordinating fiscal, monetary, prudential and carbon regulations to support the environmental transition, especially at the ELB.[122]

Robust control, which insures against the maximally worst outcome, is a well-known policy strategy to cope with fundamental uncertainty ("min-max"

[122] For a discussion of how fiscal and monetary policies can work together when interest rates are near the ELB, in full respect of central bank independence and the primacy of the price stability objective, see Panetta (2021).

strategy, Hansen and Sargent, 2008). Olalla and Gómez (2011) apply the robust control tool to a Neo-Keynesian model to study the effect of model uncertainty in monetary policy. Typically, policies drawn up using the "min-max" strategy are more aggressive than those reached under no uncertainty. One objection to this is that worst-case events are rare and actually unknown. It seems odd to design policies for events about which the least is known (Sims, 2001). Moreover, robust control does not account for the trade-off between robustness against uncertainty and the ambition of the policy goal. This trade-off is central in the info-gap approach (Ben-Haim, 2010). A robust policy strategy according to this method implies that if the central bank aims at a precise inflation target, it needs to compromise on the degree of confidence in achieving it. In return, confidence and robustness against uncertainty increase if the inflation target is less precise. Ben-Haim et al. (2018) apply info-gap theory to evaluate different monetary policy reaction functions. They find that in the euro area, a standard Taylor rule – based on a well understood macroeconomic model – is more robust to uncertainty than complicated rules that include, say, financial variables. Such rules would come with additional uncertainties as regards the effects of policy interventions, given the trade-offs and interactions that financial factors have with price stability. For the ECB, this implies that price stability should remain the primary objective of monetary policy, given the uncertainties surrounding the long-run impact of climate change on the economy. However, indicators of such effects (such as relative price changes on product markets, risk premia on green and polluting assets in asset markets and sectoral credit flow relocation) should be developed and used to validate the longer-term implications of climate change for price stability.

5.5 Simulations

This section presents a set of model-based simulations illustrating some plausible scenarios under which climate change might complicate the conduct of monetary policy and impair the ability of a central bank to ensure price stability. The aim of these scenarios is to incorporate the channels of impact discussed in previous sections. Given the wide range of potential future outcomes, these scenarios naturally do not cover all eventualities. Nonetheless, they provide a framework to discuss the potential impact of climate change on monetary policy and the consequent implications for strategy.

Three separate scenarios are presented. The first considers the ability of monetary policy to stabilise the standard business cycle in an environment characterised by less effective transmission of monetary policy impulses due to financial factors, a lower natural rate of interest and possibly more constrained fiscal policy. For the sake of simplicity, this is called the "new normal".

The second scenario analyses how the conduct of monetary policy may be affected by transition and mitigation policies. The transition to a low-carbon economy, even if smooth, is likely to have significant effects on economic and financial activities, relative prices and inflation, output growth and productivity, and hence on the optimal response of monetary policy. These transition paths take the long-run NGFS scenarios as a baseline but consider their impact at business-cycle frequency.

The third scenario looks at the potential impact of more frequent and disruptive extreme weather events which, as argued in the previous chapters, is a likely result of climate change. This will expose the euro area and the global economy to new types of supply and demand shocks that cannot be extrapolated from history, but which may have large and unpredictable economic consequences.

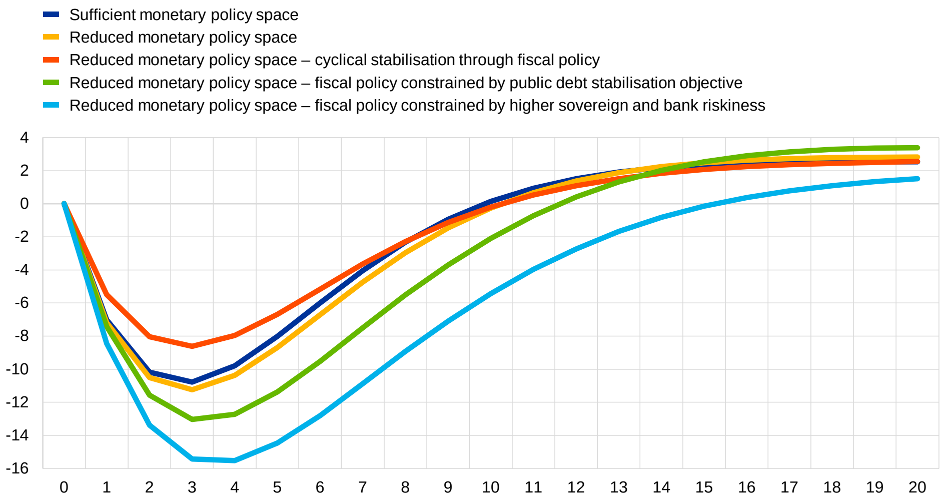
5.5.1 Macroeconomic stabilisation under the "new normal"

The first scenario considers a sizeable business cycle shock and incorporates the potential impairments to monetary policy discussed in the sections above. The three main impairments applied here are lower equilibrium real rates (see Section 5.3), reduced fiscal capacity arising from the impact of disasters and the transition to a carbon-neutral economy (see Sections 1.2, 2.4 and 5.4), and financial fragility (see Section 4.1). This scenario looks at how climate change affects the operation of monetary policy by way of its impact on longer-run trends and underlying conditions, rather than being a source itself of shocks at business-cycle frequency.

In the baseline, the economy is hit by a strong negative demand shock, unrelated to climate change, which exhausts monetary policy room for manoeuvre by pushing it close to the ELB. The shock is modelled as a preference shock with a persistence of 0.75, and the ELB for the nominal short-term interest rate is assumed to be 60 basis points below zero. This baseline is shown by the dark blue line in the following charts. Output falls to a trough of nearly 11% below steady state (Chart 25). Monetary policy reacts by cutting interest rates sharply from an initial 3.5% to close to the ELB. This policy accommodation is sufficient to drive a recovery, with output returning to its steady-state level ten quarters after the initial shock.

Chart 25
Output

(deviation from steady-state level, percentages)

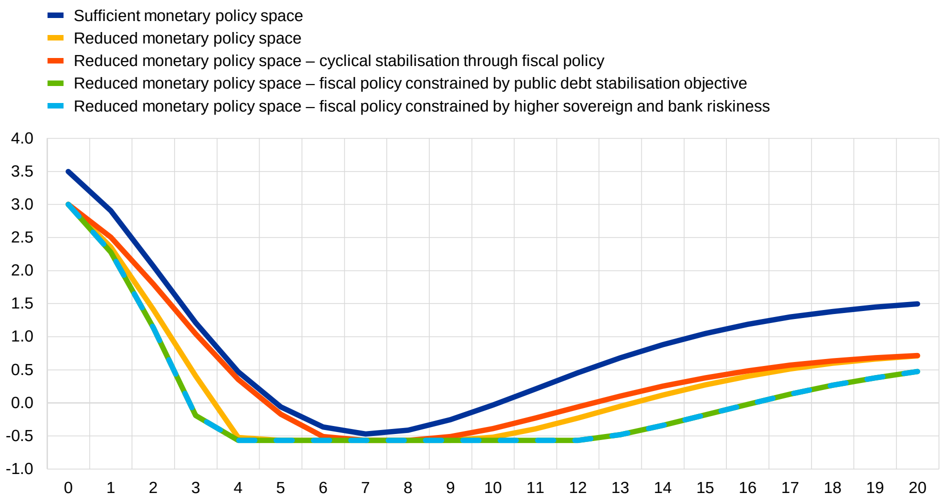


Sources: ECB simulations based on the NAWM model and Darracq Pariès et al. (2020) (light blue line).

Yet the speed at which output returns to trend depends on the available policy space, the degree to which fiscal policy provides support and the effectiveness of the transmission channel. The remaining elements of this scenario explore these dimensions in turn, holding the initial shock described above constant throughout. The first change from the baseline, shown in the yellow line, assumes that the equilibrium real rate, *r**, is 50 basis points lower. This has the effect of reducing the available monetary policy space, and the nominal interest rate reaches the ELB and remains there for seven quarters (Chart 26). This more constrained monetary policy marginally deepens and prolongs the downturn.

Chart 26
Monetary policy rate

(percentage point deviations from steady-state level, annual)

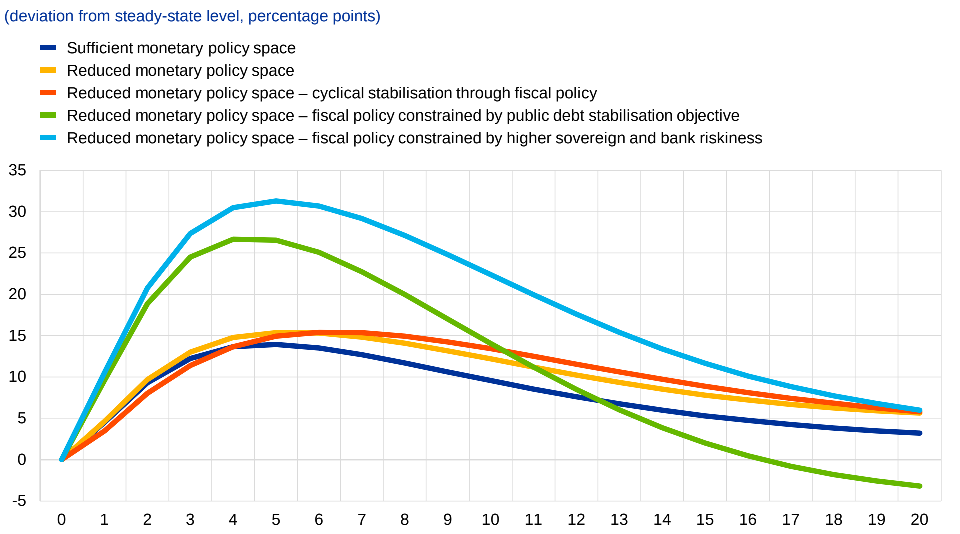


Sources: ECB simulations based on the NAWM model and Darracq Pariès et al. (2020) (light blue line).

Fiscal policy can help to stabilise output by increasing government spending to counteract the temporary fall in demand. In normal times, the effectiveness of fiscal policy is somewhat blunted by the reaction of monetary policy, crowding out expenditure. However, when monetary policy is constrained by the ELB, fiscal policy becomes more potent and can contribute more meaningfully to stabilising output. This is shown in the red line. Despite the lower starting point for *r**, the overall decline in GDP is moderated, even compared with the baseline scenario. This is, however, only the case in the short run. In the medium term, higher public debt incurred during the fiscal stabilisation period reduces the speed of output recovery.

Yet fiscal policy itself may be constrained if rising public debt levels force it to reorient towards a debt stabilisation policy. As discussed earlier in this paper, climate change could increase government debt as a result of higher adaptation costs coupled with higher social security expenditure to cover health and other costs stemming from natural disasters and potentially higher long-term unemployment arising from the transition to a carbon-neutral economy. Higher debt, in turn, can reduce the available fiscal space for macroeconomic stabilisation (Leeper et al., 2010). As shown by the green lines, prioritising the objective of stabilising public debt can have adverse effects when interacting with an ELB. As public spending is reduced with the aim of moderating debt dynamics, the decline in total demand in fact results in a higher debt path over the short run (Chart 27). The decline in output is far more marked, and the policy rate reaches the ELB faster and remains there for nine quarters.

Chart 27
Public debt-to-GDP ratio



Sources: ECB simulations based on the NAWM model and Darracq Pariès et al. (2020) (light blue line).

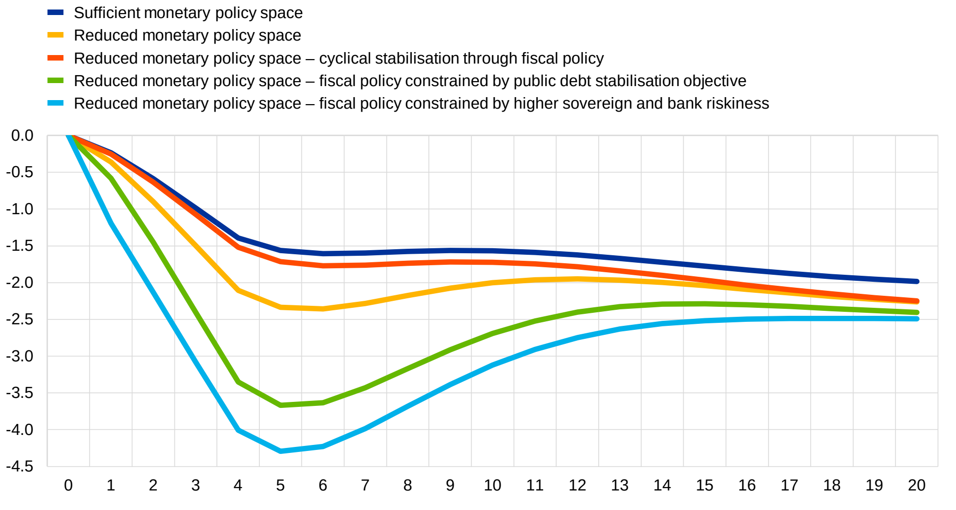
Finally, we consider the impact of an impaired financial system, which could be trigged by losses arising from physical risk or stranded assets generated by the transition. We use the model devised by Darracq Pariès et al. (2020) to quantify the impact of tighter lending conditions on economic output, shown in the light blue lines.[123] The overall impact on output is marked, resulting in a trough in activity that is almost double that of the baseline scenario.

In each scenario, inflation falls and is slow to return to the steady state (Chart 28). Because the shock is substantial and somewhat persistent, inflation falls and remains low for a prolonged period in all scenarios, especially when the ELB is reached. The decline is most marked in the scenarios where fiscal policy is constrained, containing prolonged periods of deflation. The fall in inflation creates an endogenous propagation mechanism that exacerbates the downturn in activity. When the nominal policy rate is constrained by the ELB, falling inflation pushes up real interest rates, which further reduces aggregate demand and triggers a negative feedback loop that prolongs the duration of the ELB, the recession and the persistence of the low-inflation episode.

The shock is sufficiently large in all cases to push the return of inflation to steady state beyond the five-year horizon shown here. The policy rate moves away from the ELB beforehand, since the reaction function – in line with a Taylor rule – reacts in part to the output gap which becomes positive towards the latter part of the projection. Nonetheless, the short-term policy rate remains subdued for a prolonged period, until inflation eventually returns to the steady state.

Chart 28
Inflation

(percentage point deviation from steady-state growth, annual percentages)



Sources: ECB simulations based on the NAWM model and Darracq Pariès et al. (2020) (light blue line).

[123] The actual mechanism in Darracq Pariès et al. (2020) operates via the link between the sensitivity of sovereign debt pricing to default risk and the impact on the financial system, similar to the sovereign-bank nexus witnessed in the euro area during the global financial crisis. The model is used here to provide consistent estimates of the impact on credit provision and how that in turn affects economic activity.

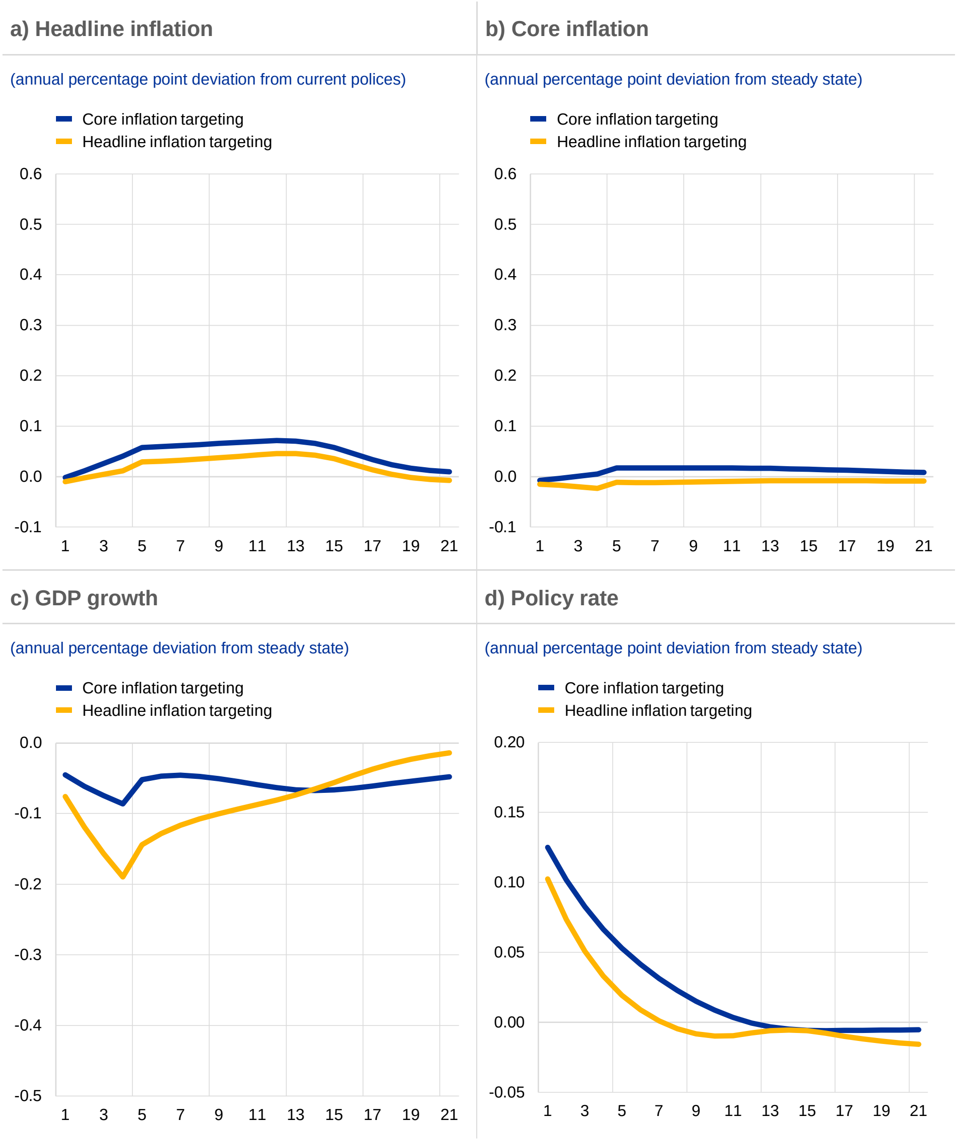
5.5.2 Transition risks

The second scenario considers the impact on the business cycle of policies to bring about the transition to a carbon-neutral economy. These scenarios are based on the long-term NGFS scenarios and draw on the more granular Banque de France scenarios discussed in Section 2.4 above. The transition scenario considers two paths for carbon taxation that – according to NGFS modelling using integrated assessment models – deliver carbon neutrality by mid-century. As such, both paths are consistent with the Paris Agreement goals and the EU's climate targets. These transition scenarios are constructed using the model contained in Adjemian and Darracq Pariès (2008) to better capture the impact on production.

The first path considers an orderly transition to carbon neutrality. Starting from now, the effective price of energy rises by around 3.5% per year relative to the baseline of current policies. The policy change is well communicated, and consequently is modelled here as an anticipated shock. The pass-through to headline inflation depends on the degree to which the central bank acts to offset the impact of the relative price shock on headline inflation. Chart 29 (panel a) shows the impact on headline inflation. In the first instance, the central bank "looks through" the relative price shock and targets only core inflation, as shown by the blue lines. Alternatively, the central bank could strictly target headline inflation and react more strongly to deviations, as shown in the yellow lines. Note that the stronger reaction of the central bank is itself anticipated by agents.

Regardless of which policy reaction the central bank adopts, the impact on growth and inflation are muted, given the gradual, anticipated nature of the increase in energy prices. In part, this is a result of the assumptions embedded in the NGFS scenario, where a smooth technological transformation takes place to reduce the carbon intensity of production and electricity generation. Nonetheless, an orderly transition is unlikely to threaten the central bank's ability to maintain price stability.

Chart 29
Orderly transition

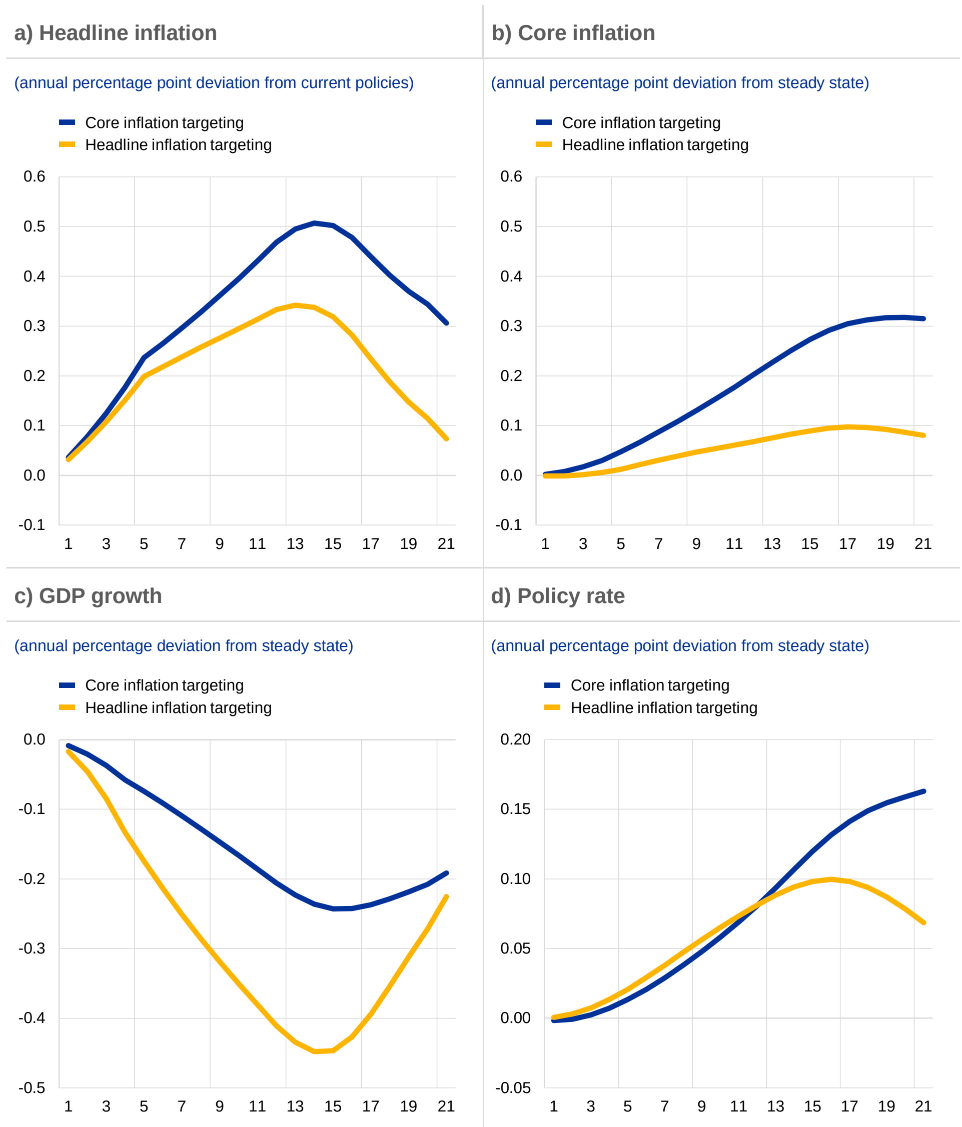


Source: ECB calculations.

The second transition path considers a disorderly transition to a carbon-neutral economy. This scenario uses the sudden transition from Allen et al. (2020) as a baseline. Starting from 2025, the effective price of energy rises by 13.5% per year, resulting in a far more marked relative price shift. This sharper increase in carbon prices derives from a sudden change in policy that households and firms were not expecting, so is modelled here as an unanticipated shock.

The results of this disorderly transition are presented in Chart 30. As before, the blue lines show the scenario where the central bank “looks through” the relative price change and targets core inflation, and the yellow lines where it targets headline inflation. For the core-targeting scenario, headline inflation increases, reaching 0.5 percentage points above baseline by the fourth year. GDP growth is somewhat lower, falling by just over 0.2 percentage points by the fourth year. By contrast, should the central bank choose to lean against the increase in headline inflation, the downward impact on GDP growth is exacerbated.

Chart 30
Disorderly transition



Source: ECB calculations.

The divergence in inflation outcomes between the two transition scenarios derives from both the different magnitudes in energy price changes and the degree to which agents anticipate the changes. Beyond the initial surprise, it is reasonable to expect that agents begin to anticipate the increase over time. As such, the overall impact on inflation in the sudden transition scenario should become more muted beyond the horizon shown in the charts.

These transition scenarios do not currently incorporate other potential channels of impact. These include (i) the risk that inflation expectations become unanchored in the disorderly scenario; (ii) the impact of financial sector losses on transmission and economic activity; and (iii) whether the sudden transition results in a heightened sense of uncertainty among businesses and households, weighing on investment and consumption. The channels could magnify the economic impact of the sudden transition and potentially exacerbate the growth/inflation trade-off faced by the central bank. Work is ongoing to better understand the impact through these channels.

5.5.3 Physical risk

The third scenario considers how rising physical risks interact with monetary policy. Although not explicitly calibrated to match the NGFS hot house world scenario, it explores the impact of large disasters occurring more frequently. In other words, rather than being rare and localised in nature, they are sufficiently common across the euro area, and sufficiently large in magnitude and area affected, that combined they affect aggregate euro area activity. This scenario is presented in the form of stochastic simulations carried out using the NAWM-II model (see Coenen et al., 2018), which is an estimated open economy model of the euro area, with a detailed financial sector. The simulations start from the non-stochastic steady state of the model, and 10,000 quarters are simulated. In each quarter, the variables are affected by shocks, which are drawn at random from their estimated, historical distribution in the baseline model.

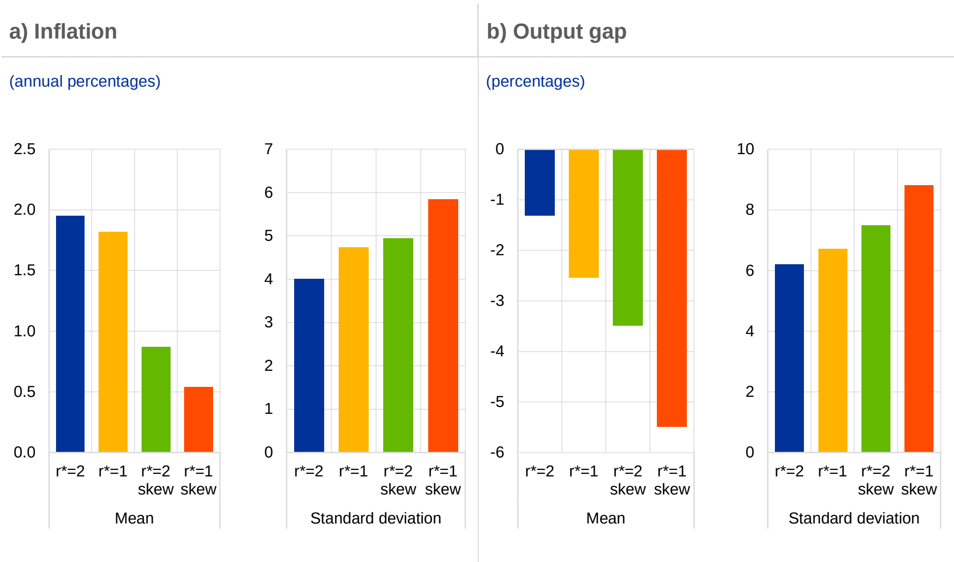
Disasters are represented by an additional infrequent event that occurs randomly, with a 10% chance of taking place in each quarter. The disaster is designed as a random set of demand and supply shocks, which are a combination of negative demand, price mark-up and permanent total factor productivity shocks. The selected shocks capture both temporary and permanent drops in productivity (which can be related to the impact of natural disasters) together with other types of supply disruption due to climate events. The negative demand shocks capture the increase in uncertainty due to the disaster as well as the transmission of Keynesian supply shocks (see Guerrieri et al., 2020).

The shocks are again drawn from their estimated distribution, but are constrained to be recessionary in nature. The overall distribution of shocks therefore implies that output becomes skewed to the downside. Since the additional disturbances are a combination of both demand and supply shocks, the initial impact on inflation is uncertain a priori. Moreover, as there is increasing evidence that the natural rate of interest has declined in recent years (see, for example, Brand et al., 2018), and that climate disaster events could lower it further, the stochastic simulations are run using differing assumptions on r^*.

Under the baseline assumption of the current distribution of shocks and an r^* equal to 2%, inflation averages 1.95% (Chart 31, panel a). In this scenario, the output gap is on average negative, since periods with a negative output gap exceed periods with a positive output gap, due to the negative amplification of ELB episodes (Chart 31, panel b). These episodes occur on average in 12% of the sample, with an average duration of 11 quarters (Chart 32). Under the assumption of the current estimated distribution of shocks, but a lower assumed *r**, average inflation drops to 1.82% and ELB episodes become moderately more frequent and somewhat longer lasting.

Chart 31

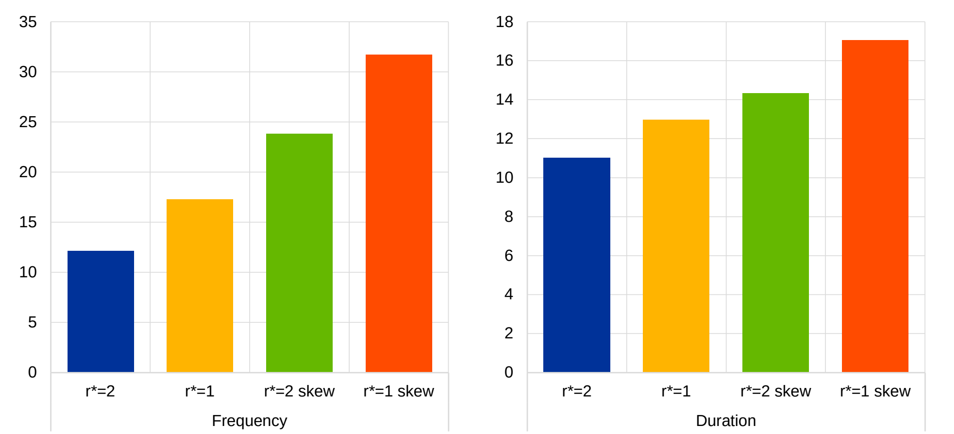
Physical risk



Source: ECB calculations.
Notes: The charts depict the steady-state probability distributions of annual inflation, output gap and the short-term nominal interest rate that are obtained by carrying out stochastic simulations around the models' non-stochastic steady state under alternative values of the equilibrium annual real interest rate (*r**=2% and *r**=1%). The annual short-term nominal rate is subject to an effective lower bound of -60 basis points and steady-state inflation is set to 2%. The bars marked as "skew" correspond to the simulations in which disaster shocks are introduced.

Chart 32

Short-term nominal rate



Source: ECB calculations.
Note: See Chart 31.

Under the assumption of more frequent major disasters, average inflation falls markedly below the ECB's target. Even with *r** still at 2%, average CPI inflation drops to 0.87%, and ELB episodes occur almost a quarter of the time, with the average episode lasting 14 quarters. With the lower r^*, inflation averages 0.54%, and ELB episodes occur almost a third of the time and last an average of 17 quarters. Thus, even though disasters may increase inflation in the short run, the overall negative impact on output eventually weighs on inflationary pressure. With major disasters occurring more frequently, monetary policy is unable to stimulate the economy sufficiently to maintain price stability, particularly with a lower equilibrium rate.

Box 12
Climate change in a standard New Keynesian framework

This box provides an illustration of how climate change might affect the conduct of monetary policy through its impact on inflation and the natural rate of interest. The analysis is carried out using the small-scale New Keynesian model described in Economides and Xepapadeas (2018). The innovation is the addition of a climate module, which introduces a trade-off from energy use, embodied through the negative effects of increasing temperatures on total factor productivity (TFP). While more energy use increases output in the near term, it also has a detrimental effect on the climate and thus on an adjusted TFP factor. Temperature anomalies are defined in the model as deviations from the average global temperature in the pre-industrial period. The intensity of the damage from climate change, which is a function of the temperature anomalies, depends on the parameter ψ, which captures the damage elasticity of output. The simulations explore the impact of a 1% shock to TFP for various values of the parameter ψ.

Endogenising the discount factor: impact on the natural rate of interest

Climate change may affect the natural rate of interest via the discount rate and risk aversion. Here the model is extended to allow the discount factor to depend on both aggregate consumption and the stock of emissions. However, individuals do not internalise the effect of their own actions on the aggregate economy. It is assumed that the discount factor is falling in aggregate consumption, denoting lower willingness to trade-off current for future consumption (lower patience). Equally, patience is higher when consumption growth is expected to be positive.[124]

No agreement exists in the literature about the effect of environmental quality on the discount rate. Some studies posit that higher emissions lead to a rise in patience from a concern for the welfare of future generations.[125] Others, citing relevant results from behavioural research, argue that individuals who experience high environmental quality value it more, leading to an opposite relationship between emissions and environmental quality.[126] Given this uncertainty, we examine both the case with a positive relationship between the stock of emissions and patience and the case with a negative sign.

For plausible calibrations of the model, the direct effect of climate change on the discount rate is small. This is illustrated by the next set of simulations. Starting from a benchmark case where the discount factor depends only negatively on consumption and not on emissions, panel a in Chart A shows how the discount factor rises when the shock hits and then slowly converges back

124 This specification, which is standard in the literature, guarantees stable long-run consumption paths. It is also necessary for a stable consumption path in the long run. See Obstfeld (1990).

125 See Le Kama and Schubert (2007).

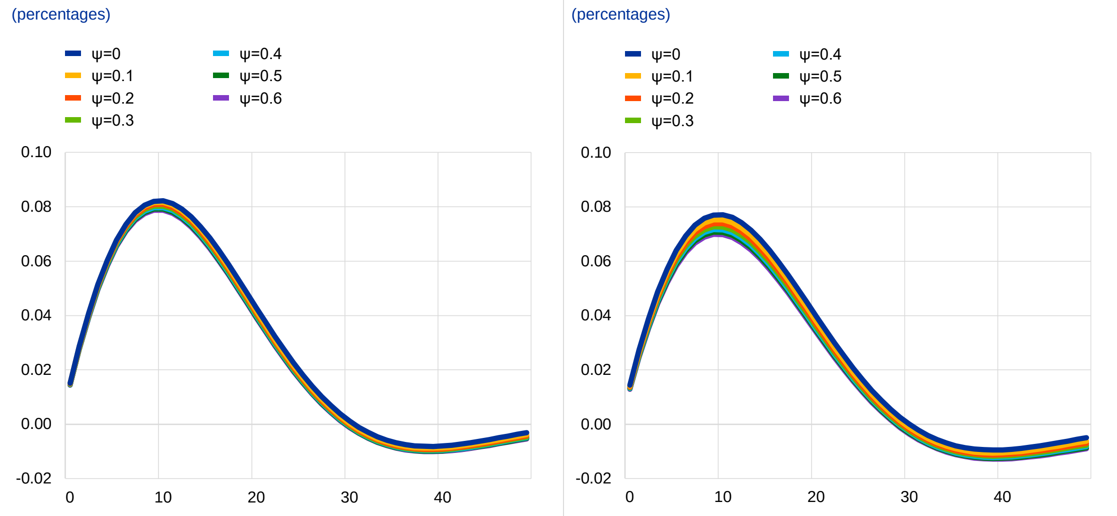
126 See Vella et al. (2015).

towards the steady state. The path is also unaffected by ψ. Panel b considers the case where there is a positive relationship between the stock of emissions and patience. Lower emissions resulting from the lower level of economic activity put downward pressure on patience, but the overall effect is small, never exceeding 1 basis point at the peak, compared to the case where the discount factor does not depend on emissions. Results are similar for the case of a negative relationship between emissions and patience.

Chart A

Endogenous discount factor

a) Discount rate falling in consumption | **b) Discount rate falling in consumption and rising in emissions**



Source: Adapted from Economides and Xepapadeas (2018).
Note: The graphs show the response of the discount rate under a negative TFP shock of 1%.

Indirectly, however, the effects of climate change could be material, as they induce more frequent volatility in consumption. In the model's calibration, a 10 basis point increase in the discount rate from a modest 1% TFP shock yields a 0.1 percentage point reduction in *r**. It seems apparent that larger supply shocks, which are expected to occur once climate change intensifies, will imply larger reductions in *r**, further increasing pressures from other secular forces.

Risk aversion

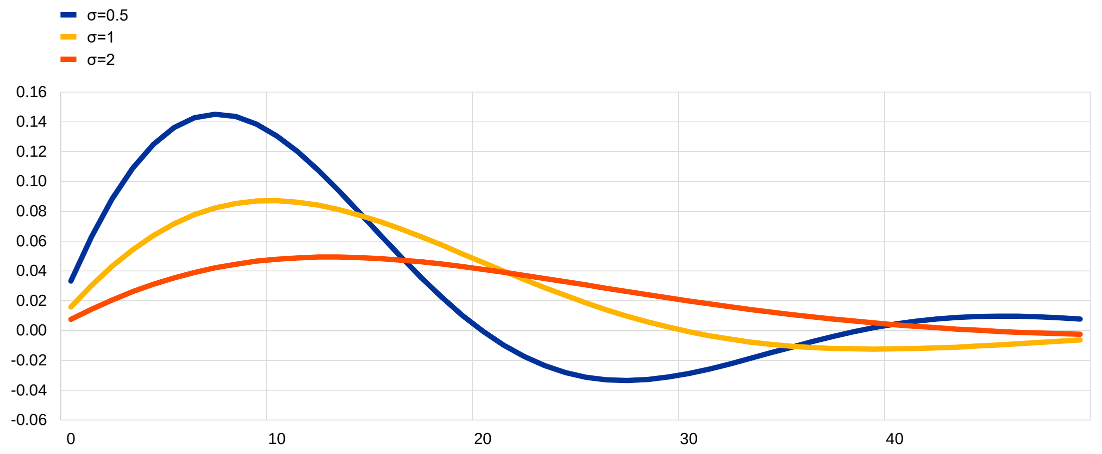
Contrary to what is commonly believed, higher risk aversion induced by more frequent climate shocks may not necessarily put downward pressure on *r.** This is shown in our final set of simulations, assuming constant relative risk aversion preferences, where a high level of risk aversion is equivalent to a low value of the elasticity of substitution, σ. Chart B shows the case under the baseline assumption of ψ=0.1 and where the discount factor depends only on consumption. The discount factor rises substantially more on impact and remains high for some time under the low σ, high risk aversion, scenario. This is because risk-averse agents draw down their asset holdings to maintain a flat consumption path. The more risk-averse agents instead respond to the lower interest rate by shifting their portfolio towards capital (whose return is now higher).

Further analysis is needed to study how climate change may affect *r (see Section 5.3).** While an increase in risk aversion may be expected to raise the desire to save along the transition path, this analysis shows that higher steady-state levels of risk aversion may lead to counterintuitive results by inducing a desire to smooth consumption. It should be mentioned that the standard framework used here conflates the desire to avoid risk with the desire to smooth consumption. Recursive preferences, which allow a separation of the two, may be optimal in this setting.

Chart B

Endogenous discount factor under different risk aversion assumptions

(percentages)



Source: Adapted from Economides and Xepapadeas (2018).
Notes: The chart shows the response of the discount rate under a negative TFP shock of 1%. The parameter σ is the elasticity of intertemporal substitution.

6 The Eurosystem's mandate

Chapter 6 at a glance

- Any action by the Eurosystem needs to comply with its Treaty mandate. Such actions can be covered by the ECB's primary objective to maintain price stability or its secondary objective to support, without prejudice to price stability, the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union. These include the objective of working for the sustainable development of Europe based on a high level of protection and improvement of the quality of the environment.
- Several "horizontal" provisions also need to be taken into account by all EU institutions – including the ECB – in their policies and activities. Article 11 TFEU requires the ECB to integrate environmental protection requirements into the definition and implementation of its policies and activities. Article 7 TFEU requires the ECB to ensure "consistency" between its policies and activities, taking all of the EU's objectives into account and in accordance with the principle of conferral of powers.
- Where the ECB takes into account climate-related considerations in the context of fulfilling its tasks, it also needs to observe the general principles of EU law – in particular, the principles of proportionality, institutional balance and equal treatment – as well as the specific provisions of EU primary law applicable to the ECB, namely the open market economy principle and the prohibition of monetary financing.

6.1 Introduction

This chapter describes the legal framework under which the ECB may take action related to climate change and highlights some of the key challenges arising in this context.

6.2 Actions of the Eurosystem in compliance with their mandate

A number of questions need to be addressed when assessing, from a legal perspective, whether the ECB could take action related to environmental protection when carrying out its monetary policy tasks in a manner that is consistent with its mandate under the Treaty on the Functioning of the European Union (TFEU) and the ESCB/ECB Statute.

Compliance with the mandate is a necessary pre-condition to any action taken by the Eurosystem. In line with the general EU principle of conferral, the ECB may only act within the limits of the competences the Member States conferred on it in the Treaties to attain the Treaties' objectives.[127] All action that the ECB may take must fall within the limits of its competences which, in the area of monetary policy, are defined by the "objectives" and "tasks" set out in Article 127 TFEU, as well as by the instruments used.[128]

The TFEU states that the primary objective of the European System of Central Banks (ESCB) is to maintain price stability.[129] Action taken by the ECB related to climate change falls within the remit of the primary objective provided it meets certain conditions. Importantly, the action needs to pertain to the primary objective, for example, because it is necessary to preserve the transmission mechanism and thus the singleness and effectiveness of monetary policy. If taking into account climate change considerations is necessary to maintain price stability, the ensuing action would fall within the remit of the primary objective. In this case, the ECB would not be directly pursuing environmental objectives, but rather its primary objective of maintaining price stability.

Monetary policy measures which incorporate climate change considerations to pursue price stability may have indirect effects on the economy or the environment. However, monetary policy measures would not be treated as equivalent to economic or environmental policy measures only because they may have such effects. This is because indirect effects in other policy fields are permitted according to the case law of the Court of Justice of the European Union (CJEU).[130] However, such measures would still need to observe the general principles of EU law, in particular, the principle of proportionality, the principle of an open market economy and the principle of equal treatment (discussed further below).

The ECB "shall support the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union as laid down in Article 3 of the Treaty on European Union".[131] Article 3(3) TEU provides that the Union "shall work for the *sustainable development* of Europe based on balanced economic growth and price stability, a highly competitive social market economy, aiming at full employment and social progress, *and a high level of protection and improvement of the quality of the environment*" (emphasis added).

Actions as part of the secondary objective are subject to two specific limitations. First, it should be without prejudice to the primary objective. If support for the general economic policies in the Union conflicts with price stability, the Treaties require primacy to be given to price stability. Second, the ECB's mandate with regard to economic policies in the Union is "supportive". This means that the ECB does not bear the primary responsibility for these policies and does not have the power to make policy autonomously. The ECB may only contribute to the

[127] See Article 5 TEU.

[128] See Case C-493/17, Weiss and Others, EU:C:2018:1000, paragraph 53; Case C-62/14, Gauweiler and Others, EU:C:2015:400, paragraph 46.

[129] See Article 127(1) TFEU, Article 119(2) TFEU, Article 282(2) TFEU and Article 2 ESCB/ECB Statute. Moreover, under Article 119(2) TFEU, monetary policy must be "single".

[130] See, for example, Case C-62/14, Gauweiler and Others, EU:C:2015:400, paragraphs 51, 52 and 57 to 59.

[131] See Article 127(1) TFEU, Article 119(2) TFEU, Article 282(2) TFEU and Article 2 ESCB/ECB Statute.

attainment of the Union's objectives by supporting the relevant Union policies through which the competent institutions have fleshed out the objectives.[132] In other words, Article 127(1) TFEU does not establish any standalone obligation for the ECB to pursue environmental objectives directly. It rather requires the ECB, without prejudice to price stability, to support the relevant economic policies in the Union, through which other institutions may also promote environmental objectives, when carrying out its tasks. Moreover, like action taken pursuant to the primary objective, the ECB's action would need to observe the principles of proportionality, an open market economy and equal treatment.

An additional specific legal basis for ECB action can be found in Article 18.1 of the ESCB/ECB Statute, which requires the ECB and the national central banks to conduct credit operations with lending based on adequate collateral. This implies notably that the Eurosystem should aim to operate in such a way as not to incur losses in its monetary policy operations. If clear physical and transition risks related to climate change affect the risks to collateral reflected in the ECB's balance sheet, action taken by the ECB to mitigate these risks is within the remit of Article 18.1 of the ESC/ECB Statute. As regards outright purchases, risk management considerations could lead Eurosystem central banks to take similar measures with a view to protecting their balance sheets against potential losses.

6.3 The role of Article 11 TFEU and horizontal provisions

In addition to the provisions of the treaties which set out the mandate of the ESCB, the ECB must comply with other treaty provisions which do not establish a legal basis for action, but rather duties with which it must comply in all policies and activities.[133] These include the requirements of Article 11 TFEU, that "[e]nvironmental protection requirements must be integrated into the definition and implementation of the Union's policies and activities, in particular with a view to promoting sustainable development".[134] Whilst this does not imply any express obligation to attain specific concrete results in support of the Union's climate policy, the provision is interpreted as establishing a requirement to "take account of" environmental objectives, which are to be integrated into the definition and implementation of the tasks of an EU institution.[135] Moreover, Article 7 TFEU sets out a consistency clause requiring the Union to ensure "consistency" between its policies and activities, taking all of its objectives into account and in accordance with the principle of conferral of powers. Consistency, in this sense, would require Union institutions, on the one hand, to refrain from making decisions that counter policies promoted by other institutions and, on the other hand, to positively consider them in

132 Article 192 TFEU provides that the responsibility for attaining the objectives of the Union policy on the environment provided by Article 191 TFEU lies with the Union's legislator, the European Parliament and the Council.

133 See Articles 8-13 TFEU and the Charter of Fundamental Rights of the European Union.

134 Article 37 of the Charter of Fundamental Rights of the European Union provides that a "high level of environmental protection and the improvement of the quality of the environment must be integrated into the policies of the Union and ensured in accordance with the principle of sustainable development".

135 See Case C-487/06 P, British Aggregates Association v Commission, EU:C:2008:757, paras. 90 to 92.

the design of their own policies.[136] The various general objectives – such as those mentioned in Article 11 TFEU – do not alter the hierarchy of objectives, where the Treaty explicitly provided for the primacy ("without prejudice") of price stability over other objectives of the Union.

6.4 Complying with general provisions of EU primary law relevant for climate-related action

Where the ECB includes climate change considerations in its monetary policy strategy and framework, it must also respect the general provisions of EU primary law. In particular, this encompasses the principles of proportionality, institutional balance and equal treatment, as well as specific provisions of EU primary law applicable to the ESCB, including the principle of an "open market economy" and the prohibition of monetary financing.

First, the ECB's environment-related action needs to respect the principle of proportionality. The CJEU has applied the principle of proportionality to the Eurosystem's monetary policy, ruling that ECB action may be validly adopted and implemented only insofar as the measures that it entails are proportionate to the objectives of that policy. Accordingly, the ECB's monetary policy measures must be suitable for attaining the Eurosystem's objectives and not go beyond what is necessary to achieve those objectives.[137] The ECB must also comply with procedural requirements, ensuring that its analysis of a proposed measure carefully and impartially examines all the relevant elements of the situation in question, giving an adequate statement of the reasons for its decision.[138]

Second, the principle of institutional balance requires the ECB to exercise its powers with due regard for the powers of the other institutions.[139] The objectives of the ESCB should not be interpreted in a way as to have the effect of transferring to the ECB responsibilities that the Treaties have ascribed to other Union institutions. In the context of the environment, Article 192 TFEU provides that the Union legislator, i.e. the European Parliament and the Council, is competent to decide what action should be taken by the Union to achieve the objectives of preserving, protecting and improving the quality of the environment and promoting measures at international level to deal with environmental problems, in particular combatting climate change. When exercising its powers, the ECB must ensure it does not infringe the principle of institutional balance by demonstrating insufficient regard for the competences of the other institutions.

Third, the principle of equal treatment requires the ECB to ensure that comparable situations are not treated differently and that different situations

136 On the concept of "inconsistency", see Case T-512/12, Front Polisario ECLI:EU:T:2015:953 [2015], para. 153.

137 See Gauweiler, op. cit., para. 67; Weiss, op. cit., para. 72.

138 See Gauweiler, para. 69; Weiss, para. 30. See also the requirements of Article 296 TFEU, which requires legal acts to state the reasons on which they are based.

139 See, for example, Council v Commission (ITLOS), para. 61; Commission v Council (ETS), para. 69; Council v Commission (MoU), para. 32.

are not treated in the same way unless such treatment is objectively justified. When assessing possible changes to the ECB's monetary policy implementation framework that treat assets or counterparties differently based on criteria related to climate change considerations, the ECB needs to carry out a "comparability assessment", with any differences in treatment objectively justified.

Fourth, the ECB "shall act in accordance with the principle of an open market economy with free competition, favouring an efficient allocation of resources" (the "open market economy" principle).[140] This is a principle that the ECB needs to observe when pursuing its primary monetary policy objective, but also when exercising its supportive role in relation to the general economic policies in the Union and the horizontal objective of environmental protection. The principle imposes limits as to the means the ECB may use when pursuing its objectives. It is understood to imply that the Eurosystem should refrain from policy measures which would unduly disrupt the normal functioning of markets or unduly restrict competition. However, it is not an absolute prohibition of ECB interference with market functioning. If required to pursue its primary or secondary objective, ECB interference with the principle of an open market economy is possible, although more restricted in the case of considerations in pursuit of the secondary objective. In any case, the justification for such interference needs to meet proportionality standards. It is noted that the operational concept of "market neutrality" has been put forward in certain contexts as a means of operationalising the principle of an open market economy.[141] However, unlike the principle of an open market economy the concept is not a legal rule or principle described in the Treaties.

Lastly, the ECB and the national central banks are subject to the prohibition on monetary financing set out in Article 123(1) TFEU. This means they are not permitted to grant overdraft facilities or any other type of credit facility in favour of public authorities and bodies of the Union or of Member States, or to purchase their debt instruments directly from them.

Box 13
The EU taxonomy of sustainable economic activities

The EU taxonomy is a tool to help investors understand whether an economic activity is environmentally sustainable and to navigate the transition to a low-carbon economy. It does so by setting a common language to assess whether investments meet commonly agreed environmental standards and are consistent with the EU's policy commitments.

The taxonomy is established by the EU Taxonomy Regulation.[142] It defines the minimum criteria that economic activities should comply with in order to be considered environmentally

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140 See Articles 119(2) and 127(1) TFEU.

141 See Opinion of Advocate General Wathelet in Case C-493/17, Weiss and Others, EU:C:2018:815, para. 74, which refers to the ECB's and the Commission's submissions that the exclusion of the purchase of bonds with a negative yield from the PSPP would be contrary to the principle of market neutrality, which forms part of the principle of an open market economy with free competition, a condition of the ESCB's activity pursuant to Article 127(1) TFEU.

142 See Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment and amending Regulation (EU) 2019/2088 (Text with EEA relevance).

sustainable. According to the taxonomy, an economic activity qualifies as sustainable if it contributes substantially to one or more of the six EU environmental objectives: (i) climate change mitigation; (ii) climate change adaptation; (iii) sustainable use and protection of water and marine resources; (iv) transition to a circular economy; (v) pollution prevention and control; (vi) protection and restoration of biodiversity and ecosystems. Furthermore, in order to be classified as sustainable, an economic activity must not do significant harm to any of the other environmental objectives ("DNSH" principle), as well as be in compliance with minimum social safeguards.

Specifically, with respect to the objective of climate change mitigation, an economic activity is taxonomy-aligned if it "substantially contributes" to the stabilisation of greenhouse gas concentrations in the atmosphere at a level which prevents dangerous anthropogenic interference with the climate system consistent with the long-term temperature goal of the Paris Agreement. The concrete definition of what "substantial contribution" means for each economic activity is left to the technical screening criteria, which are generally designed to ensure no lock-in of assets inconsistent with the EU goals (net zero emissions by 2050 and a 50-55% reduction in emissions by 2030) and an environmental performance corresponding to the best practice in the sector or industry.

All financial market participants offering financial products and all EU companies within the scope of the Non-Financial Reporting Directive (currently all public-interest entities with more than 500 employees and that have either a balance sheet total of more than €20 million or a net turnover of more than €40 million) **will have to disclose** the share of their turnover and the share of their capital expenditures (CAPEX) and operating expenditures (OPEX) that are aligned with the EU taxonomy (Article 8 of the Taxonomy Regulation).[143]

The Regulation entered into force on 12 July 2020. It provides the general legal framework, while the concrete technical criteria to calculate and disclose taxonomy alignment are provided in separate delegated acts. A first set of delegated acts, covering the objectives of climate mitigation and adaptation and related DNSH criteria, was published on 21 April 2021, with application as of January 2022. Another set of delegated acts covering the other four environmental objectives will be adopted in the course of 2021 and applied as of 2023.

The EU taxonomy will provide the bedrock for the development of standards and labels for sustainable finance products in the EU. Most notably, the taxonomy provides the mandatory reference under the proposed European green bond standard.[144]

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143 See Commission Delegated Act specifying the content and presentation of information on Taxonomy alignment.

144 See Commission proposal on European Green Bonds.

7 Potential Eurosystem actions

Chapter 7 at a glance[145]

- In the light of the challenges for financial markets to correctly price and assess climate-related risks, these might not automatically be covered in the current Eurosystem monetary policy implementation framework at present.
- The Eurosystem could perform a supportive catalytic function in financial markets with its monetary policy measures. This would be useful in situations where effective collective action is required to achieve the European Union's binding greenhouse gas (GHG) reduction targets, but where heterogeneous market practices and standards, market inefficiencies or other obstacles need to be overcome.
- In order to more systematically reflect climate change considerations in the monetary policy implementation framework, the Eurosystem could intensify its ongoing work to prepare actions in four areas of monetary policy operations: climate change-related disclosures, risk assessment, the collateral framework and the corporate sector purchase programme (CSPP).
- The definition of alternative benchmarks in monetary policy operations should also be examined, from a legal and practical standpoint, in view of potential climate-related market inefficiencies in the market for carbon-intensive assets.

7.1 Introduction

Governments and parliaments have the primary responsibility and appropriate tools to facilitate the transition to a carbon-neutral economy. But within their mandates, central banks also need to tackle climate change, both to safeguard their ability to smoothly conduct monetary policy and deliver on their mandate, and to ensure that they remain resilient to emerging climate-related financial risks. Central banks can also act as catalysts for financial market participants, prompting them to pre-emptively enhance their analysis of, and resilience to, climate risks, which in turn could facilitate an orderly transition towards a greener economy.

This chapter discusses potential measures that the ECB could consider in the context of its monetary policy implementation framework, in line with its mandate. It reviews a number of measures, the aim of which is to ensure that climate change-related financial risk is appropriately reflected by the ECB's risk management framework, including in the field of disclosures. These actions would also enhance the catalytic role of the Eurosystem in supporting the transition. The

[145] Sections 7.2 and 7.3 largely draw on contributions by the joint work stream on climate change of the Eurosystem Market Operations Committee (MOC) and the Risk Management Committee (RMC).

chapter also looks at other measures with designs that do not necessarily rest on risk management considerations.

A preliminary evaluation of a set of measures is also conducted. At this stage, the assessment is preliminary, due especially to the need for further internal Eurosystem quantitative and qualitative analyses of the impact of climate change. Section 7.2 introduces a set of key principles that are needed to assess the potential policy measures. Section 7.3 reviews some potential measures that could be considered by the Eurosystem. Section 7.4 concludes with some considerations on the interaction between policy measures to address climate change and the monetary policy stance.

7.2 Principles to assess the potential Eurosystem measures

It makes sense to integrate climate change considerations into the ECB's monetary policy implementation framework, since the extent to which climate-related risks are fully incorporated in market prices and ratings is not completely clear. As the ECB's current monetary policy implementation framework relies on market prices and credit ratings for eligibility, risk control and risk assessment purposes, and since the extent to which market prices and ratings incorporate climate-related risks is still unclear, it is necessary to assess which adjustments to the framework are needed, in particular for risk management purposes. However, the Eurosystem would face the same challenges related to data availability and model limitations to calibrate the measures, for example, as any other market participant. Among other things, this points to the need for policymakers from various policy areas to work together, each within their own area of competence, to overcome the limitations and inefficiencies that are making it hard for climate-related financial risks to be reflected more fully in asset prices and credit ratings.

In addition to risk management considerations, the Eurosystem could play a supportive catalytic function in financial markets with its monetary policy measures. This would be useful in situations where effective collective action is required to achieve the EU's binding GHG-reduction targets, but where divergent market practices and standards, market inefficiencies or other obstacles need to be overcome. This catalytic role could range from sharing expertise with regulators and standard-setters and supporting certain standards through to issuing informative publications, using its own operational tools and leading by example with its own efforts.

The distinction between the risk management motive and the catalytic motive of the Eurosystem's potential action is not absolute. The same measure can often serve to pursue more than one objective, depending, among other things, on how it is designed and calibrated (see also NGFS, 2021).

A set of principles is needed to assess the potential policy measures and compare the associated trade-offs between different objectives and criteria

(Table 8). As a starting point, any measure should be in line with the ECB's mandate and other legal considerations, as explained in Chapter 6. It should not put constraints on the desired monetary policy stance. The effectiveness of the measure in supporting the EU's general economic policies should also be considered. Any measure should also be assessed for its feasibility, risk efficiency and operational complexity.

Table 8

Principles for assessing potential policy measures

1. Consistency with the ECB's mandate, including the effectiveness in supporting the EU's general economic policies	The measure should be assessed as to whether it is effective in supporting the price stability objective, including the protection of the Eurosystem balance sheet. It must be without prejudice to the price stability objective if it supports general economic policies.
2. Feasibility, risk efficiency and operational complexity	The measure must follow the principles of the monetary policy framework that are relevant for the conduct of monetary policy operations.

The principles are identified with due consideration for the interplay among the various relevant dimensions; they reflect the inevitable trade-offs that are inherent in all policy decisions. The potential actions have differing outcomes along the dimensions of effectiveness for price stability purposes, effectiveness in supporting secondary objectives, feasibility, operational complexity and risk implications for the ECB and Eurosystem balance sheets. Therefore, any policy decision would require policymakers to carefully weigh and balance these different trade-offs.

Including climate change considerations in the Eurosystem's monetary policy operations will require scrutiny of the well-established conceptual frameworks that have previously guided the implementation of monetary policy.

The Eurosystem could enhance its analyses of the extent to which its financial risk is affected by climate change and the energy transition and, where warranted, adapt its implementation framework to mitigate these risks. Improved disclosures by market participants on climate-related risks and their risk management practices would enhance market pricing and the protection of the Eurosystem balance sheet going forward. This would make it easier to implement monetary policy and hence achieve the primary objective. Moreover, it is clear that risks that are not adequately priced in the market; this may be taken into account for the requirement of "adequate collateral" under Article 18.1 of the ESCB/ECB Statute, which implies that the Eurosystem should aim at protecting its balance sheet against potential losses arising from its monetary policy credit operations and its asset purchase programmes.

These considerations need to be properly evaluated to assess whether the benchmarks employed to guide monetary policy operations need to be adjusted. The practical challenges involved should not be underestimated. Moreover, such rules need to be justified in the light of the ECB's mandate. Further work could be done within the Eurosystem to assess market allocation amid market inefficiencies and the pros and cons of modifying allocations employed to guide monetary policy operations. Furthermore, consideration could be given to policies supporting a transition path that is aligned with, at a minimum, EU legislation implementing the Paris Agreement, measured by climate change-related metrics or issuer commitments to climate goals.

Overall, the Eurosystem will assess the relevance of various conceptual frameworks when deciding on the design of its operations. This will focus on criteria based on efficient allocation considerations and consistency of portfolio composition with long-run climate change goals specified by Union law and policy. In addition, risk considerations will play a key role. Additional work is ongoing within the Eurosystem to assess the degree of overlap and complementarity between these considerations, which may inform the design of operations in the future.

7.3 A review of potential measures

This section reviews some potential actions that could be considered by the Eurosystem. The ECB could intensify its ongoing preparations in four areas of monetary policy operations: climate-related disclosures, risk assessment, collateral framework and the corporate sector purchase programme (CSPP).

Where relevant, the proposed actions and initiatives should take into account EU policies and initiatives in the field of environmental disclosure and reporting. This would ensure consistency with the ECB's mandate. The broader international regulatory agenda and lessons from the experience of other institutions could also be considered, albeit taking into account that the focus and ambition of non-EU approaches may not match those of the EU.

7.3.1 Disclosures

The Eurosystem is already playing a catalytic role in the field of enhanced climate-related disclosures. These are a public good and a key prerequisite for the Eurosystem and market participants to better assess climate-related risks. In May 2020 the Eurosystem replied to the Commission's public consultation on the renewed sustainable finance strategy and the revision of the Non-financial Reporting Directive (NFRD), calling for disclosure requirements that are comprehensive in scope and detail and rest on the principles of transparency, comparability and proportionality. The ECB also directly contributes to the work of the European Financial Reporting Advisory Group (EFRAG) on elaborating a harmonised EU non-financial reporting standard, which is currently slated for adoption in 2022. Moreover, in November 2020 the ECB published its final guide on climate-related and environmental risks for banks, explaining how it expects banks to prudently manage and transparently disclose such risks under current prudential rules.

Looking ahead, the Eurosystem could gradually step up its catalytic role and risk management practices in the area of climate-related disclosures. It could do so by implementing its own disclosures, and by introducing disclosure requirements for private assets as a new eligibility criterion or as a basis for a differentiated treatment of collateral and asset purchases, where appropriate (see below). For the latter set of measures, a timely pre-announcement in particular would be important to alert all the institutions concerned to the change and to provide sufficient time for all the necessary groundwork to be completed before the new measures actually took effect. However, it is worth noting that while better disclosure practices are key to helping market participants better understand and price climate-related financial risks, disclosures alone would not solve the problem of mispricing amid externalities. This would require corrective action in other policy areas, notably effective carbon pricing mechanisms, to internalise the environmental externalities.

Climate-related disclosures for the CSPP

The Eurosystem could start disclosing climate-related information for its CSPP and the euro-denominated non-monetary policy portfolios (NMPPs). It could use the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) as the initial framework and report, as a minimum, specific metrics and targets. Box 14 presents a discussion of the Eurosystem's approach to incorporating sustainability considerations in its NMPPs.

Disclosures as an eligibility requirement for collateral and asset purchases

The Eurosystem could introduce climate-related disclosure requirements for private sector assets as a new eligibility criterion or as a basis for differentiated treatment of collateral and asset purchases. A key purpose of these requirements would be to incentivise issuers to adopt disclosure practices for more complete and comparable information faster, and ultimately allow the Eurosystem to incorporate the information in its risk management framework.

This work should take into account EU policies and initiatives in the field of environmental sustainability disclosure and reporting, in particular the European Commission's legislative proposal for a Corporate Sustainability Reporting Directive (CSRD). The need to maintain proportionality would also be reflected using adjusted requirements for small and medium-sized enterprises, for example.[146]

The compliance requirements would have to be appropriately communicated and pre-announced to avoid cliff effects. If a new eligibility criterion is introduced, a sufficiently long adaptation period is likely to be necessary to avoid loss of eligible collateral and challenges to the feasibility of the purchase programme involved, and hence to ensure the smooth implementation of monetary policy and the achievement of the desired monetary policy stance.

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[146] On 21 April 2021 the European Commission published a legislative proposal for a CSRD that revises the existing rules introduced by the Non-Financial Reporting Directive (NFRD). The proposal is ambitious, with mandatory disclosures which are assured by a third party and apply to a substantially expanded set of companies.

The Eurosystem should also continue to engage with the relevant stakeholders, most notably EU regulatory bodies. Within the Eurosystem's competence to deliver opinions, this could involve supporting the current proposal during the ongoing legislative process, as well as contributing to the work of the EFRAG on elaborating a harmonised EU non-financial reporting standard.

7.3.2 Collateral

Collateral valuation and risk control framework

Collateral rules are not intended to affect market prices in general or in a targeted manner. This contrasts with monetary policy instruments such as purchase programmes, for which the "asset valuation channel" is an important transmission channel.[147] Collateral rules implement the legal requirement to lend based on adequate collateral and are therefore calibrated so as to ensure risk protection while preserving sufficient collateral availability in different economic environments and across jurisdictions. In this context, the impact of collateral measures on prices is indirect, as it depends on their impact on bank funding and the opportunity costs associated with the collateral assets.

Collateral rules are designed to leverage on market information (e.g. market prices and credit ratings) and accommodate climate-related risks to the extent that these are included by financial markets. In that context, as a general principle the framework relies on the liquidity of markets to determine prices that embed market expectations.

Regarding collateral valuation, where deemed reliable, market prices are used to update the valuation of marketable assets used as collateral on a daily basis. For less liquid securities, theoretical prices are derived from the market prices of liquid bonds, following a methodology developed by the Common Eurosystem Pricing Hub (CEPH) that is operated by the Eurosystem.

The risk control framework is calibrated to cover various sources of risk to collateral value that could materialise between the default of the counterparty and the liquidation of the pledged collateral. Hence, it is set to cover risks generally incurred over a short period of time when the collateral is expected to be liquidated. Even within short-term horizons, however, the impact of climate-related risks should be carefully assessed.

As a consequence, the Eurosystem could consider relevant climate-related risks when reviewing the methodologies employed to calibrate its risk control framework and valuation methodologies for assets mobilised as collateral by

[147] The asset valuation channel postulates that purchases of assets by the central bank work by reducing risk premia and providing capital relief to leveraged institutions, particularly banks. Other relevant transmission channels of central bank asset purchases are: the signalling channel, which assumes that asset purchases enhance the credibility of rates staying low for long; and the reanchoring channel, where asset purchases reassure the private sector that the central bank remains committed to its long-term inflation target. See Andrade et al. (2016) for a discussion.

counterparties in Eurosystem credit operations. That would require the methodologies in place to be monitored and possibly updated as necessary.

Sustainable financial innovation

The Eurosystem has already started accepting certain new sustainability-linked instruments as collateral and for asset purchases and continues to assess financial innovation related to environmental sustainability. In January 2021 the Eurosystem started accepting sustainability-linked bonds as Eurosystem collateral and for its purchase programmes (APP and PEPP). This addition is expected to accelerate the growth of this new innovative financial instrument. Looking ahead, the ECB could continue to monitor structural market developments in sustainability products and support innovation in the area of sustainable finance within the scope of its mandate.

7.3.3 Enhancement of risk assessment capabilities for climate-related financial risks

Climate stress testing of the Eurosystem balance sheet

The Eurosystem could start conducting climate stress tests of the Eurosystem balance sheet to assess its exposure to climate risk. A pilot stress test could be performed initially for the corporate holdings in the monetary portfolios (CSPP and PEPP). The work could leverage on the methodology of the ECB's economy-wide climate stress test and should reflect changes in credit risk parameters due to both transition risk and physical risk.[148] Following the successful completion of the pilot test, the Eurosystem could focus on expanding the methodological framework for climate stress testing.

Incorporation of climate-related risks in credit ratings

The Eurosystem takes account of credit assessments from three different types of system, which likely face similar challenges to other market participants in terms of incorporating climate-related risks. To assess the credit quality of eligible assets, the Eurosystem considers the information from the credit ratings and probabilities of default issued by external credit rating agencies (ECAIs), national central banks' in-house credit assessment systems (ICASs) and counterparties' internal ratings-based systems (IRBs). The Eurosystem understands that these systems also face a lack of sufficient and robust climate change data and consistent definitions, as well as the potential misalignment between the traditional credit ratings horizon and the climate-related risk horizon.

148 See de Guindos (2021).

As climate change can be a source of credit risk, it is vital that credit assessment systems continue to incorporate and disclose climate-related risks via credit ratings in a way that is systematic, consistent and transparent. Within its mandate, the Eurosystem should maintain its efforts to foster this and collaborate with relevant public authorities. For example, as part of its due diligence on external ratings, the Eurosystem could assess the extent to which ECAIs disclose how climate-related financial risks are integrated into their rating methodologies and how transparently and consistently they present the relevance and materiality of climate-related risks for rating decisions across different sectors and asset classes.

The Eurosystem determines the credit quality of assets on the basis of any information that it deems relevant for ensuring adequate risk protection, and hence climate change should also be considered when warranted. Accordingly, the Eurosystem could intensify its efforts to duly and consistently reflect climate-related financial risks in its internal credit ratings and in this context work on minimum standards for ICAS ratings.

7.3.4 Corporate sector purchase programme

The ECB's corporate sector purchase programme (CSPP) is its asset purchase programme currently most directly exposed to transition risk; it has high potential to act as a catalyst for green finance through signalling and direct allocation of financial flows. Moreover, information disclosure of climate-related metrics and risks by corporate bond issuers is more advanced than for other types of fixed income assets. Finally, through the CSPP, the Eurosystem has direct exposure to carbon-intensive sectors (utilities, mining and materials) that are subject to transition and physical risks. This is what draws academics and practitioners to pay such close attention to this portfolio in the public discourse.

The Eurosystem has already started incorporating climate change in its due diligence process for CSPP issuers. This involves an assessment of transition risks, climate-related disclosures, carbon emissions and reduction targets. The Eurosystem could refine its process as the availability and quality of climate change metrics improves.

Going forward, the Eurosystem could adjust the framework guiding the allocation of corporate bond purchases to incorporate climate change criteria, in line with its mandate. The Eurosystem could consider the impact on financial risks, feasibility and operational implementation when making these adjustments. The adaptations might include a tilting approach, for example, that considers the alignment of issuers with, at a minimum, EU legislation implementing the Paris Agreement measured through climate-related metrics or commitments to climate goals.

The Eurosystem should seek to implement measures that reduce climate-related financial risks. These would need to support and ensure consistency with EU economic policies and laws setting climate-related goals, to the extent that they provide incentives to reduce GHG emissions, without prejudicing price stability if properly calibrated.

7.3.5 Green targeted longer-term refinancing operations

Central banks could consider extending the greening approach to refinancing operations, such as the ECB's targeted longer-term refinancing operations (TLTROs).[149] The TLTROs encourage lending to the euro area economy by allowing banks to obtain long-term loans and providing them with an incentive to increase their lending to businesses and consumers in the euro area, as the cost of borrowing is linked to how much participating banks lend. Green TLTROs could be structured to preserve the objective and modalities of standard TLTROs, while at the same time including incentives for banks to invest in green activities.

The feasibility of such operations hinges on the availability of a proper definition of "green lending". While in principle the definition of green lending could rely on the Commission's EU Taxonomy Regulation, the taxonomy is not sufficiently prescriptive at present and banks do not collect the necessary information systematically. In the absence of a consistent definition of environmental sustainability and of a reliable system of verification, it is unclear how to ensure that the fungible funds provided by banks are correctly and effectively used by individual borrowers to finance green projects.

Substantial work would be needed to improve data coverage and quality, including loan classification for debtors not subject to disclosure requirements (small firms and households), and to set up the necessary verification processes and capacities. Clear criteria and a system of (most likely self-) reporting would be necessary. In a second stage, a more prescriptive taxonomy and a change in statistical reporting could further enhance the targeting and effectiveness of the operations.

Support for the green objectives of the EU could be ensured by the fact that green TLTROs would reduce the costs related to the green transition by promoting investments in green activities (e.g. for green mortgages improving the energy efficiency of the housing stock).

At the same time, these operations could raise level playing field issues for participating banks due to their differing ability to obtain and disclose relevant information as well as cross-country differences. In particular, it may be easier for large listed companies to disclose relevant information. Also, the asymmetric distribution of potential borrowers of green loans affects the pool of eligible loans available to banks. Moreover, fiscal frameworks vary considerably across countries in terms of subsidies directed to green activities, which would exacerbate cross-country differences in the support provided by green TLTROs.

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[149] Purchases of green bonds are discussed in Box 15. A theoretical framework to shape the debate on the effectiveness of central bank purchases of green assets is presented in Box 16.

These issues, as well as those surrounding the proper definition of green lending and green collateral, need to be addressed to allow for compliance with applicable legal requirements for a possible green TLTRO to be examined.

Given the essential role of TLTROs in supporting the economy and the need to ensure the most effective targeting, and in light of the need to overcome a number of hurdles, it seems premature to concretely envisage targeted green operations at the current juncture. At the same time, progress on defining the collateral pool may make it possible to take a number of climate change considerations into account indirectly in TLTROs in a way which may be simpler operationally and without running the risk of decreasing their effectiveness.

7.4 The interaction between policy measures to address climate change and the monetary policy stance

Provided that two configurations of the instrument set are equally conducive and not prejudicial to price stability, the Eurosystem should, when incorporating climate considerations into its monetary policy implementation framework, seek to choose the configuration that best helps to mitigate the impact of climate change, with a view to contributing to the objectives of the Union. When an expansionary monetary policy is being implemented, for example, less-polluting issuers could, in principle, be overweighted for a given level of purchases, provided that the impact on the stance is unaffected by the composition of the purchases. In the case of a package of measures, as long as some “green” measures constitute a tightening of the stance, their undesired effects could be offset by fine tuning other parameters of the policy package.

For some of the measures discussed in this chapter, the timing of their introduction or phasing-out may be affected by the particular phase of the monetary policy cycle. Clear communication would therefore be needed for measures that are not permanent and would be discontinued if dictated by a change in the stance.

Finally, while very effective over a medium-term horizon, new eligibility requirements may conflict with the objective of preserving a sufficiently accommodative stance if implemented in a bulky manner in still fragile financial and macroeconomic conditions. This is because they may restrict the availability of collateral and eligible assets in asset purchase programmes. Therefore, the timing of a full phasing-in of this type of measure would have to be considered against the stipulation for the ECB to preserve favourable financing conditions as an intermediate target toward attaining and maintaining price stability. Timely communication and a sufficiently long adaptation period are expected to mitigate such potential negative effects.

Box 14
Non-monetary policy portfolios

In December 2019 the ECB's Governing Council mandated the Market Operations Committee (MOC) to work on the practical implementation aspects of climate change-related sustainable and responsible investment (SRI) principles in non-monetary policy portfolios (NMPPs) in cooperation with the Risk Management Committee (RMC). The initial focus on climate change aspects is consistent with the European Commission's Action Plan on Sustainable Finance and the work plan drawn up by the Network for Greening the Financial System (NGFS). This could be expanded in the future to encompass broader environmental aspects. From a portfolio management perspective, climate risk arises from two sources: the physical effects of climate change on investments and the impact on investments of changes associated with a transition to a low-carbon economy. In this respect, climate risk is different from environmental risk, which relates to hazards that may potentially damage the environment (such as air and water pollution, water scarcity, land contamination, reduced biodiversity and deforestation).

In 2020 a MOC task force on sustainable and responsible investment (SURI TF) analysed the SRI data providers and related metrics available at that time. The goal was to identify those that would enable consistent measurement of carbon emissions and climate change-related SRI metrics of NMPPs, the most impactful SRI strategies that could be adopted for each asset class in NMPPs and the progress of NMPPs.

The SURI TF concluded that SRI specialised data sources were crucial for effectively analysing ways to integrate climate-related SRI considerations into a portfolio. The methodological evaluation of SRI data providers identified differences in terms of data collection, estimation methodologies, modelling of unreported data, reported metrics, and coverage across asset classes and jurisdictions. The differences in the reported metrics included not only forward-looking but also backward-looking metrics such as greenhouse gas (GHG) emissions and intensity, which poses challenges for the consistent measurement of SRI metrics for any portfolio and for the comparison across NMPPs. The task force therefore recommended selecting at least two specialised SRI data providers with broad coverage for the asset classes which constitute the largest share of each NMPP investments, in order to improve the quality of the reported SRI metrics and asset-level coverage. The analysis also showed that disclosure and SRI measurement are less advanced for some asset classes which are very relevant for Eurosystem NMPPs, such as sovereign debt, sub-sovereigns, supranationals and agencies (SSAs), covered bonds and asset-backed securities. Finally, there were methodological challenges in Scope 3 reporting and a lack of market standards for forward-looking metrics which would allow a better understanding of the emission trend and the 2015 Paris-aligned commitments of issuers and counterparties. On 17 June 2021 the Deutsche Bundesbank published a public tender for climate-related SRI data on behalf of all ESCB central banks.[150]

Eurosystem members have different mandates and objectives for their various NMPPs, which makes climate-related SRI integration unique for each central bank investment portfolio. As a result, the adequacy of SRI strategies for each Eurosystem NMPP depends on their objectives, asset composition, size and investment horizons. There are also some additional limitations, given the special investor status of central banks. Besides a positive signalling effect, such SRI implementation would have two main objectives: actively contributing towards EU climate

[150] For more information, see the Deutsche Bundesbank announcement dated 17 June 2021.

targets and protecting against financial risk. Investors have to balance these objectives with the benefits of broadly diversified portfolios and consider the feasibility of potential SRI strategies for their specific portfolio characteristics (e.g. currency, size, etc.). The SURI TF analysed the main SRI strategies that investors generally follow for SRI implementation in their investment portfolios.[151] In some cases, a combination of several SRI strategies, in line with investors' best practices, may also achieve the objectives.

With regard to contributing towards EU climate targets, the SURI TF concluded that the most impactful SRI strategies differ across asset classes. For corporate investments (equities and bonds – where the investable universe is much larger than for sovereigns and SSAs), a best-in-class/tilting strategy is considered very impactful. Under this strategy, investments are guided by corporate issuers' transition commitments (using forward-looking indicators) and consequently by selecting issuers that are moving towards achieving the EU climate targets. Depending on the calibration of the parameters, this strategy could have a negative impact on the portfolio's diversification and implementation feasibility, particularly for larger portfolios. A strategy consisting of excluding high-emission corporates that are not facilitating the transition to a low-carbon economy might also be considered as an addition.

In terms of effectiveness in reducing financial risks to the ECB's and NCBs' investment portfolios, SRI integration is ranked as the most impactful SRI strategy for all the asset classes under analysis. Systematically including SRI-related information in the investment process in addition to traditional factors makes it easier to understand the climate risk exposure of the portfolio. Therefore, SRI integration would help to reduce the potential financial risks arising from climate change that are not yet taken into account by traditional risk factors.

This analysis and the conclusions served as the input for the proposals from a high- level task force comprising senior executives of all Eurosystem members for the coordination and definition of a common Eurosystem stance on the implementation of SRI in the NMPPs, which was announced in a press release on 4 February 2021.[152]

Box 15
Purchasing green bonds

One possibility that is often mentioned in the public discourse is for the ECB to purchase green financial assets in excess of those already acquired in the context of the asset purchase programme (APP) and the pandemic emergency purchase programme (PEPP) in

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151 Exclusions/negative screening is defined as deliberately excluding issuers from an investment portfolio based on the investor's values, ethics or principles. Best-in-class strategy identifies issuers that are more advanced in terms of transitioning towards a low-carbon economy or mitigating climate risk compared to their peers or that have made commitments to materially improve in the future. A somewhat softer version of best-in-class is the "tilting" strategy, which would be to overweight issuers with higher SRI scores and underweight those with lower SRI scores compared with a broad market capitalisation-based benchmark. SRI integration enhances traditional financial (risk) analysis by systematically including SRI-related information (quantitative and qualitative) in the investment process. Thematic/impact investing supports companies, organisations and/or funds in accomplishing specific goals that are beneficial to the environment and/or society. Active voting and shareholder engagement imply that investors enter into an active dialogue with issuers and/or exercise ownership rights to influence them in SRI topics.

152 See the press release entitled "Eurosystem agrees on common stance for climate change-related sustainable investments in non-monetary policy portfolios".

line with market capitalisation. Such a policy could allow for a proportion of an existing asset purchase programme supporting price stability to be reserved for the purchase of green bonds – in a way that departs from "market neutrality".

Green bonds are defined as bonds whose proceeds are invested to finance green projects with an environmental or climate-related benefit. However, there is no single definition of what precisely constitutes "green" or "environmental benefit". Various organisations have started to provide certifications and develop standards that grant the issuers a green label certifying adherence to particular definitions of "green" (Ehlers and Packer, 2017; Ehlers et al., 2020).[153]

Most green bond labels adhere to the "voluntary process guidelines" (Green Bond Principles) that were introduced by the International Capital Market Association (ICMA) in January 2014. These guidelines identify the key components of green bond issuance as (i) the use of proceeds for environmentally sustainable activities, (ii) a process for determining project eligibility, (iii) management of the proceeds in a transparent fashion that can be tracked and verified, and (iv) annual reporting on the use of proceeds (ICMA, 2018). These guidelines are voluntary, and the definition of "green" is confined to a broad list of green project categories.[154] Since these labels do not tally in all cases, a major step forward will be the proposed EU green bond standard, based on the EU sustainable finance taxonomy described in Box 13.

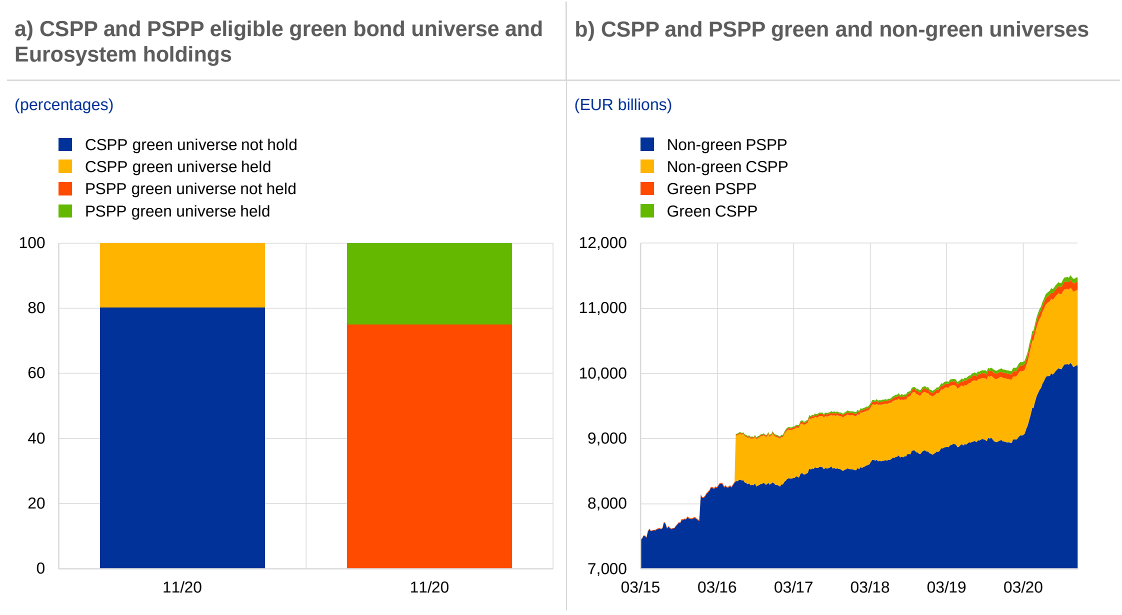
In terms of market structure, the average maturity of outstanding green bonds in 2020 was around ten years. Issuers of green bonds tend to be highly rated, with only a small fraction classed below investment grade (Chart B, panel a). Consequently, green bonds are already purchased under the ECB's APP and the PEPP, and the Eurosystem is at present one of the largest investors in green bonds issued by euro area corporates. Under the corporate sector purchase programme (CSPP) and the PEPP, the Eurosystem currently holds around 20% of the eligible green bond universe (Chart A, panel a). At the same time, the green universe represents only a very small fraction of the overall eligible universe, where the ECB makes purchases on the market in line with the current risk control framework (Chart A, panel b).

[153] Examples include the Climate Bonds Initiative (CBI), green bond indices (Bank of America Merrill Lynch, Barclays MSCI, Standard & Poor's and Solactive), CICERO Second Opinions and Standard & Poor's Green Evaluation service.

[154] Energy, buildings, transport, water management, waste management and pollution control, nature-based assets including land use, agriculture and forestry, industry and energy-intensive commercial, ICT.

Chart A

CSPP and PSPP eligible green bond universe and Eurosystem holdings



Sources: EADB and ECB calculations.

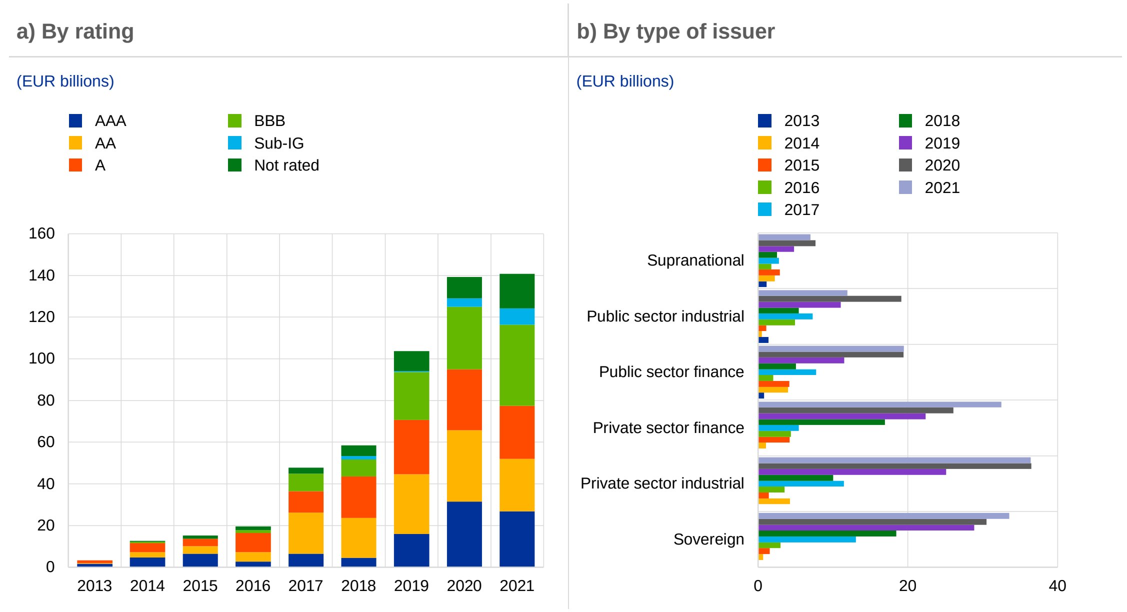
The lack of a clear definition of what is "green" is a key difficulty when implementing a strategy that reserves a portion of the purchases for green bonds. In the absence of an official and legally binding EU green bond standard, a potential starting point for the identification of green assets could be the existing labels used by the financial industry. Looking back, the green bond market only started to develop relatively recently – in 2007, with the AAA-rated issuance by the European Investment Bank and the World Bank Group. The composition of euro area green bond issuance has evolved considerably over time, with most now consisting of euro-denominated assets issued by public agencies, financial institutions and industrial enterprises (Chart B, panel b).

In addition, the volume of purchases should match the development of the market. The share of investment grade green bonds is still very small compared to the wider global bond market, despite the expansion of the market and surge in investor demand. Furthermore, some evidence suggests a lack of market depth, making it particularly difficult to purchase in some sectors. For instance, EU governments do not currently issue enough green bonds to allow existing programme targets to be met.

Within the context of a purchase programme established to maintain price stability, purchases of green bonds would indirectly support the environmental objectives of the EU, mainly by lowering the cost of capital for companies issuing green bonds. A green corporate bond purchase programme would support the transition to carbon neutrality across sectors, including those issuers that, as a starting point, have large emissions but would contribute to the objective through investments which over time reduce such emissions, provided they remain in line with the taxonomy criteria. While the pace of greenhouse gas reduction is determined by the European Commission, a green bond purchase programme could lower the adjustment costs for firms during the transition.

Chart B

Outstanding amounts of green bonds



Source: Dealogic.

Recent empirical studies provide mixed evidence on whether such action would lead to these companies moving towards climate neutrality at a much faster pace. On the one hand, recent analysis by the Bank for International Settlements (Ehlers et al., 2020) concludes that there is no strong evidence for green bond issuance being associated with a reduction in carbon levels over time at firm level. By and large, this may be due to the prevailing uncertainty around what qualifies as a green activity, meaning that "greenwashing" is still prevalent. On the other hand, Flammer (2020) finds that public companies issuing green bonds may improve their environmental performance through signalling – publicly announcing commitments which are then difficult not to follow up on. As the commitment towards the environment materialises, companies reduce their CO2 emissions and achieve higher environmental ratings. This is inconsistent with the greenwashing argument. If companies were to issue green bonds to portray themselves as environmentally aware, but without any intent to deliver, tangible improvements in environmental performance would not be observed post issuance. Zhou and Cui (2019) reach similar conclusions by looking at the corporate social responsibility of listed Chinese companies issuing green bonds.

A clear definition of what constitutes a green bond is essential to allow the operational feasibility and ensure the proportionality of the measures. Moreover, the impact of such measures on Eurosystem financial risks would need to be assessed, as it would depend on the credit risk profile of the green bonds to be purchased and how they affect the concentration profile of current outright portfolios. As the green bond market segment matures, the existing operational difficulties should become progressively less binding.

Box 16
Macroeconomic effects of tilting the central bank monetary policy portfolio in an extended DSGE model

A number of academics, columnists and advocacy groups are pushing central bankers to implement policies that have a direct impact on climate change. De Grauwe (2019), for instance, believes that the ECB should replace the corporate bonds that mature with new green bonds: such a policy would not change the money supply, so it would be inflation-neutral. Similarly, Schoenmaker (2021) suggests greening monetary policy by tilting central bank balance sheets towards low-carbon sectors. A debate has emerged among central bankers regarding whether these policies are effective and compatible or not with the mandate of independent central bankers.

In a recent paper, Ferrari and Nispi Landi (2020) provide a theoretical framework to shape the debate on the effectiveness of central bank purchases of green assets. For a given amount of purchases of private bonds purchased, which the central bank sets in line with its mandate and consistent with price stability considerations, the paper asks whether a tilting of central bank purchases in favour of green assets could, while keeping the overall amount unchanged, be effective in reducing pollution without affecting price stability.

The paper argues that such a programme can only be effective in reducing pollution if there is a market segmentation between green bonds and polluting bonds and it does so without prejudice to the price stability objective. The paper also shows that this policy has only short-term effects, meaning that in principle it is not well suited to affect slow-moving variables, such as atmospheric carbon concentration. The reason is that conventional and unconventional monetary policies are neutral in the long run – a permanent "green quantitative easing (QE)" does not change the steady state of macroeconomic and environmental variables. The argument behind this result is that if a market segmentation between green bonds and polluting bonds exists, it must be short-lived and therefore the price of the polluting and non-polluting bonds in the long run cannot be affected by the composition of the central bank balance sheet. However, the short-terms effects should not be disregarded, as they could help to reduce the transition costs of firms that invest to cut emissions, which may make it easier for the EU to become carbon neutral. Indeed, while monetary policy alone cannot determine the structural changes needed to tackle climate change, it can help accelerate the transition process to a green steady state achieved through fiscal policy or regulation.

These results are based on a DSGE model, calibrated on the United States, that bridges the work of Gertler and Karadi (2011) in analysing the macroeconomic effects of central bank asset purchase programmes of public or private bonds, with the environmental model of Heutel (2012) designed to study environmental policies over the business cycle.

Unlike the previous economic-environmental literature, the production side is characterised by two sectors: the polluting sector, whose production generates damaging emissions that affect total factor productivity (TFP) of the economy, and the green sector, whose production is not polluting. This assumption creates a distinction between bonds issued by green firms (green bonds) and bonds issued by polluting firms (polluting bonds). Bonds can be bought by commercial banks or the central bank. A leverage constraint prevents banks from fully exploiting the arbitrage opportunity between bonds and deposits from households: in equilibrium, there is a spread between the loan and the deposit interest rate. The spread is an increasing function of bank leverage. At the same time, the central bank is not subject to the leverage constraint, meaning that an expansion of its balance sheet has macroeconomic effects. The existence of this leverage constraint therefore violates the “Wallace neutrality”.[155]

In order to capture the production effects on climate change, the paper adopts the set-up from Heutel (2012), which merges the baseline Real Business Cycle (RBC) model with a simplified version of the Dynamic Integrated model of Climate and the Economy (DICE) devised by Nordhaus (2008).[156] In the DICE model, the pollution externality affects the economy only through TFP. As set out in Angelopoulos et al. (2013) and Barrage (2020), pollution can directly affect the utility function of households. As argued by Nordhaus (2008) and Heutel (2012), a utility externality could be more appropriate for conventional pollutants that directly affect health. Instead, CO2 and other greenhouse gases are more likely to affect the productivity of physical capital and labour inputs. The model is then used to analyse the impact of green QE – a policy that tilts the central bank’s balance sheet towards the green sector.

The first finding is that production in both sectors is not affected if green and polluting assets are perfect substitutes. This is the case where there is no market segmentation between the two bonds, when the central bank temporarily tilts the portfolio composition to green bonds and keeps constant total assets. The argument relies on a no-arbitrage condition. If bonds issued by the green and the polluting sectors are perfect substitutes for banks, their returns must be identical as well. In this case, the portfolio rebalancing of the central bank determined by green QE is fully offset by a rebalancing of commercial banks in the opposite direction, with no macroeconomic or environmental effect.

Regulation forcing banks to hold a certain amount of green bonds is a possible source of market segmentation between the two bonds. Household preferences could be another source, as households could make portfolio choices looking at the impact that their choices have on the climate and this could force banks to do the same. Without taking a stand on the source, a certain degree of imperfect substitutability between the two bonds is assumed in the model, such that banks are not able to fully exploit arbitrage opportunities between green and polluting bonds.[157]

Then a temporary green QE shock is simulated (Chart A). When the central bank temporarily increases its share of green bonds while keeping total assets constant, the interest rate paid by green firms experiences downward pressure. Banks are not able to fully exploit the arbitrage opportunity, because changing the asset composition is costly. A spread opens up between polluting and green interest rates. Green firms face a lower interest rate, increase capital and raise production. Polluting firms face higher interest rates and cut production. Detrimental emissions fall and the stock of atmospheric carbon decreases. The production externality is reduced and TFP increases. From a quantitative perspective, however, all these effects are small, even given low substitutability between green bonds and polluting bonds. Our calibration, which we borrow from Nordhaus (2008) and Heutel (2012), implies that atmospheric carbon follows a highly persistent process: emissions are lower for a limited period and bring about only a tiny reduction in the stock of pollution. Moreover, we model an open economy (the United States) where a significant portion

[155] As Wallace (1981) points out, the equilibrium path of output and prices is independent from central bank balance sheet policies, unless there is something special in central bank intermediation. The mechanism of the model is the same as in Gertler and Karadi (2011).

[156] See Chapter 3 for the presentation of the DICE model and Box 5 for a discussion of including the environment in a DSGE framework.

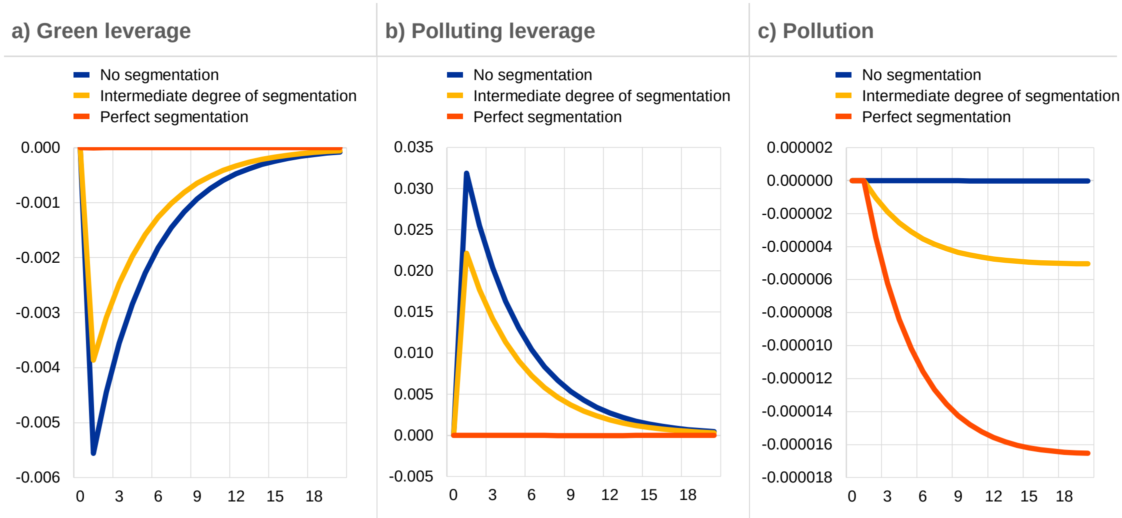
[157] They do so by introducing a quadratic cost whenever a bank changes the composition of its portfolio. This friction is used extensively in DSGE models in order to make different assets imperfect substitutes (see, for instance, Benigno, 2009, and Cúrdia and Woodford, 2011).

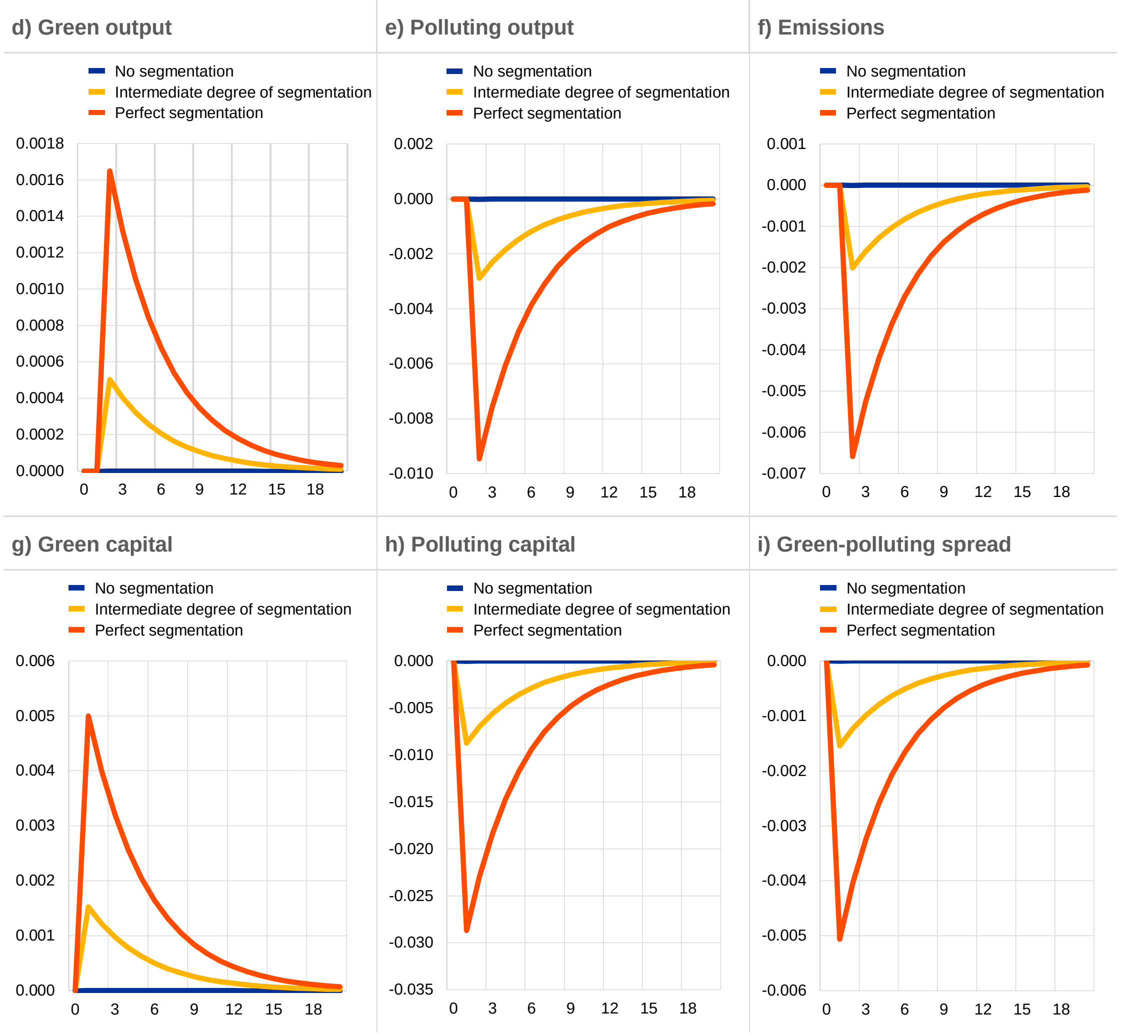
of the emissions comes from abroad, meaning that the policy does not affect the foreign production. Coordinated action at the global level in the context of a global emission-reduction path, such as in the Paris Agreement, could be more effective in lowering the overall stock of pollution.

The analysis has some relevant policy implications. First, a certain degree of imperfect substitutability in the bonds market is needed for green QE to be effective in reducing pollution. There are several factors that can segment the market, some under the control of central banks and others beyond their control (e.g. banking regulation, collateral framework, household preferences). Second, even with an extremely low degree of substitutability between green and polluting assets, green QE cannot guarantee a transition towards a low-emission economy. The main reason for this is that climate change and pollution are structural problems, while green QE is an instrument that, like other monetary policy tools, only plays a role along the business cycle. Third, regardless of the degree of substitutability, a portfolio tilting towards green assets does not affect inflation, meaning that the policy would be consistent with the price stability objective. Finally, the short-lived effects of the policy on emissions can be beneficial in the context of coordinated action to reduce greenhouse gas emissions. During the transition to a low-emission equilibrium with a higher share of "green production" driven by an emissions cap or a carbon tax, a tilting of the central bank balance sheet towards carbon-free assets can have positive effects in lowering the cost of capital for green firms, reducing emissions in the short term and accelerating the transition process.

Chart A

Impulse response functions to a 5% positive green QE shock for different levels of financial market segmentations between green and polluting bonds





Source: Ferrari and Nispi Landi (2020).
Notes: "Green QE" is defined here as a rebalancing of the composition of the central bank's portfolio towards gren assets. Responses are in log-deviations from the steady state, except for inflation and spreads, where the response is in quarterly percentage deviations from the steady state reported at annual rates. Under the blue line there is no market segmentation. Under the yellow line there is an intermediate level of market segmentation. Under the red line the market segmentation is perfect (i.e. the two bonds are not substitutes).

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Annex

A.1 Key features of the DICE (2016R) model

For illustrative purposes, this annex outlines key features of the Dynamic Integrated model of Climate and the Economy (DICE-2016R). An equation for the externality (greenhouse gas or CO2 emissions) as a function of economic activity,[158] a system of simplified climate model equations that translates cumulative emissions into a change in temperature and a function that translates the increase in temperature into economic damages are essential components of integrated assessment models (IAMs) in this category. As set out by Nordhaus (2017), DICE optimises a global social welfare function which is the discounted sum of the population-weighted utility of per capita consumption. Net global output Y_t is gross economic activity $F(\bullet)$ net of climate damages and abatement costs:[159]

$$Y_t = \left(1 - D(T_t)\right) \cdot (1 - \mathrm{A}_t) \cdot F(TFP_t, K_t, L_t)$$

where K_t and L_t denote the capital stock and the labour force, A_t represents the abatement cost function and TFP_t is total factor productivity of Hicks-neutral technical change. Simple IAMs like DICE feature a highly reduced-form of externalities, where damages solely affect current output net of abatement costs. Nordhaus assumes the damage coefficient D to be quadratic in the global surface temperature anomaly, T. None of capital stock, labour force and productivity are affected.[160] In other words, total factor productivity increases exogenously and is independent of temperature. Labour is a constant proportion of the total population which grows at an exogenous rate. Representative households – who own all production factors – are rewarded with net global output and allocate it to consumption and investment according to an endogenously optimised savings rate. Investment net of capital depreciation determines the accumulation of the capital stock. Carbon emissions E_t are projected as a function of gross economic activity, the emissions control rate ECR_t, a carbon intensity σ_t which declines at an exogenous rate, and exogenous land-use emissions:

$$E_t = \sigma_t \, F(\bullet) \cdot (1 - ECR_t(P_t)) + Land\_use_t$$

158 The negative externality of greenhouse gas emissions can be introduced in economic models in various ways: in the utility function of representation agents, in the production function, in the production factors (capital and labour) or in their productivity. Instead, the externality can be introduced as a simple constraint, e.g. as a limit to the temperature increase. In this case, climate damages can be ignored in the model analysis.

159 In DICE, gross economic activity is modelled as a Cobb-Douglas production function.

160 For extensions of DICE which incorporate damages to capital stock and total factor productivity, see Dietz and Stern (2015). For the impact of climate change on labour productivity, see Kahn et al. (2019).

The emissions control rate $ECR_t \in [0,1]$ is determined by climate policy, as it increases with the carbon price P_t. The cost of emission reductions is parametrised by a log-linear function.

From emissions to global warming

The speed and magnitude of global climate change are determined by radiative forcing, climate feedbacks and the storage of energy by the climate system. While there is no detailed representation of processes of the Earth system, DICE employs a system of equations to model the carbon concentrations in three reservoirs: a one-pool atmospheric layer (with atmospheric carbon stock $S_{AT,t}$) and a two-pool ocean (deep oceans; biosphere/shallow oceans). The carbon concentrations of these reservoirs are linked to carbon emissions and past concentrations as follows:[161]

$$S_{AT,t} = \varepsilon E_t + \phi_{AT\to AT} \cdot S_{AT,t-1} + \phi_{SO\to AT} \cdot S_{Shallow\ Oceans,t-1}$$

$$S_{Shallow\ Oceans,t} = \phi_{AT\to SO} \cdot S_{AT,t-1} + \phi_{SO\to SO} \cdot S_{Shallow\ Oceans,t-1} + \phi_{DO\to SO} \cdot S_{Deep\ Oceans,t-1}$$

$$S_{Deep\ Oceans,t} = \phi_{SO\to DO} \cdot S_{Shallow\ Oceans,t-1} + \phi_{DO\to DO} \cdot S_{Deep\ Oceans,t-1}$$

where carbon emissions enter the atmosphere at rate ε in the first round. Referring to lagged carbon concentrations, the carbon cycle parameters ϕ determine the flows between the three reservoirs per period. This representation can be understood as an attempt to capture the decay of atmospheric carbon.[162] Nordhaus (2017) starts with an atmospheric carbon concentration in 2015 amounting to $S_{AT,t} = 851\ Gigatonnes\ of\ carbon\ (GtC)$ (compared to 588 GtC in the pre-industrial reference period), $S_{Shallow\ Oceans,t} = 460\ GtC$ in the biosphere/shallow oceans (compared to a pre-industrial level of 360 GtC) and $S_{Deep\ Oceans,t} = 1{,}740\ GtC$ in deep oceans (compared to 1,720 GtC). Surface temperature $T_{AT,t}$ is assumed to respond to concentrations in the atmosphere and deep oceans. Higher radiative forcing warms the atmospheric layer, which then warms the upper ocean, thereby gradually warming the deep ocean. The energy budget model embedded in DICE is intended to reflect inertia of the different layers in the form of a gradual adjustment to the new equilibrium temperature:

161 See the DICE Manual.

162 Other reduced-form models of the carbon cycle represent the stock of atmospheric carbon concentrations as a function of cumulative past emissions, a lasting share φ_L and two parameters that determine the decay over time; see Golosov et al. (2014).

$$S_{AT,t} = \sum_{s=0}^{\infty} E_{t-s} \cdot \left\{ \varphi_L + (1-\varphi_L) \cdot \underbrace{\varphi_0}_{share\ that\ stays\ in\ the\ atmosphere\ for\ more\ than\ one\ year} \cdot \underbrace{(1-depreciation\ rate)^s}_{geometric\ decay} \right\}$$

$$T_{AT,t} = T_{AT,t-1} + \lambda \cdot \left\{ 3.7 \cdot \left[\frac{\ln\left(\frac{S_{AT,t}}{S_{AT,preindustrial}}\right)}{ln\ 2} - \frac{T_{AT,t-1}}{c} \right] - \xi_1 \cdot \overbrace{\Delta T_{t-1}}^{T_{AT,t}-T_{Deep\ Oceans,t}} + exog.forcing_t \right\}$$

$$T_{Deep\ Oceans,t} = T_{Deep\ Oceans,t-1} + \xi_2 \cdot \Delta T_{t-1}$$

where λ denotes the speed at which the global surface temperature converges to its equilibrium level, being equal to $c \cdot \left[ln(\frac{S_{AT,t}}{S_{AT,preindustrial}})/ln(2) + exog.forcing_t \right]$ for a given atmospheric carbon concentration. The climate transition parameters ξ_1 and ξ_2 denote the heat loss from atmosphere to oceans and the heat gain by deep oceans, respectively. A critical parameter is the equilibrium climate sensitivity c. This describes how the temperature responds to a change in energy flux per time per area. Adding energy amounting to a radiative forcing of 3.7W/m² corresponds to a doubling of carbon concentration in the atmosphere. The best current estimate for an additional energy influx of 3.7W/m² is an equilibrium temperature response $c = 3°C$ for an equilibrium CO2 doubling in the atmosphere. At the same time, probability density functions of c tend to exhibit a large positive skew (Dietz and Stern, 2015). While equilibrium temperature is a near-logarithmic function of atmospheric carbon concentration, the transient response is close to linear.[163]

[163] See Dietz et al. (2020), Matthews at al. (2009) and MacDougall (2016). The linear relationship arises from (i) the saturation of carbon sinks leading to a higher airborne fraction of CO2, which cancels out the reduction in radiative forcing per unit change in atmospheric CO2 (due to the near-logarithmic relationship between CO2 concentration and radiative forcing), and (ii) the uptake of heat and carbon by the ocean being linked to the same deep-ocean mixing processes. Matthews et al. combine the concepts of carbon sensitivity (increase in atmospheric carbon concentration from the emission of CO2) and climate sensitivity, and the feedbacks between these two processes, in a single metric, known as the transient climate response to cumulative emissions (TCRE). These authors estimate the TCRE at 1-2.1°C per 1,000 GtC. Nordhaus (2018) assumes a transient increase of 1.7°C for a doubling of the atmospheric CO2 concentration after 70 years.

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