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The impact of selected long-term climate scenarios on the Czech economy

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THE IMPACT OF SELECTED LONG-TERM CLIMATE SCENARIOS ON THE CZECH ECONOMY

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The Czech Republic has committed to transitioning to climate neutrality by 2050. This commitment implies a need for structural changes in the Czech economy. This article presents long-term climate scenarios mapping the transition to climate neutrality and simulations of the impacts of selected scenarios on the Czech macroeconomic environment and goes on to identify potential sources of climate risks to financial stability. The analysis indicates that the climate scenarios have a stagflationary impact, causing lower economic activity and higher inflation, although substantially less so in the Czech economy than in the global economy. The model simulations also show that the choice and timing of global climate policy will be crucial in determining the future impacts of climate change and the related costs. However, climate policy may adversely affect certain industries and sectors of the economy. We use a set of indicators to identify the potential vulnerability of real economic sectors and banks in the Czech Republic to climate risks. The CNB regularly monitors these indicators when assessing the level of climate risks and their impacts on financial stability.

I. INTRODUCTION

In 2019, the EU member states agreed on a European Green Deal[2] aimed at making the EU a climate-neutral continent by 2050 and thereby meeting its obligations under the Paris Agreement.[3] To achieve this aim, the European Commission adopted a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels (the Fit for 55 package[4]). The EU is the third biggest global emitter. The Czech Republic ranked in eighth place among the EU countries in 2019, with emissions of roughly 123,000 kilotonnes CO_2 equivalent.[5] The biggest emitter in the Czech Republic is the energy sector, with a share of around 40%, followed by manufacturing with 20%, transport with roughly 16% (car transport 9%) and agriculture with 7%. Combustion in households and waste management account for the remaining 17%. Achieving full decarbonisation by 2050 will therefore require major structural changes in various sectors, including households. Certain scenarios aimed at minimising the cost of decarbonising the Czech economy are already pointing to a need to massively reduce coal mining and the use of coal for power and heat, increase renewables capacity, make buildings less energy intensive, increase the share of electric vehicles on the roads and continue electrifying industrial processes (McKinsey & Company, 2020).

The transformation of economies – in the form of the transition to green technology and infrastructure – will require large amounts of private as well as public money. If the financial sector is to play a role in financing low-emission development and its stability is to be simultaneously safeguarded, its effect on the climate transition resulting from the change in its strategy (pricing policy) will have to be monitored and its potential vulnerability to climate risks assessed.[6] For these reasons in particular, financial institutions and their supervisory authorities are gradually incorporating climate aspects and the impacts of climate change on the financial system into their stress-testing models by means of climate scenarios.[7] These analyses are helping to provide an insight into the financial sector's ability to support the transition to a low-carbon economy and its resilience to climate risks, including under the assumption of adverse economic conditions.

The article is structured as follows. We begin by examining the significance of climate scenarios and presenting the main types of scenarios used to model macro-financial developments. The following section III analyses the impact of three selected long-term climate scenarios on the global and Czech economy and discusses the differences in the impacts of these scenarios with the aid of three macroeconomic variables: real GDP, inflation and interest rates. The results of the analysis show that the short-term costs associated with an orderly transition are lower than the costs caused by the medium

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[2] The European Green Deal is a set of political initiatives aimed at putting the EU on a path of environmental transformation culminating in climate neutrality by 2050. For details, see here, for example.

[3] The Paris Agreement entered into force in November 2016. The 196 parties committed to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Under the Paris Agreement, the Czech Republic together with the other EU member states pledged to reduce greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels. For details, see here, for example.

[4] For details, see here, for example.

[5] For details, see here, for example.

[6] There are two main categories of climate risk: the physical risks (or shocks/damage) of a changing climate, which include more frequent or severe weather events like floods, droughts and storms, and the transition risks from moving towards a carbon-neutral economy and implementing climate policy.

[7] See the *Request for a one-off scenario analysis exercise to be conducted jointly by the European Supervisory Authorities, the ECB and the ESRB in accordance with the Communication from the Commission of 6 July 2021 "Strategy for Financing the Transition to a Sustainable Economy"*.

to long-term impacts of the frequent and severe potential weather events that the Czech Republic could face in the future. Section IV presents selected indicators that can be used to monitor and assess the transmission of potential – primarily transition – climate shocks and the vulnerability of the Czech non-financial real sector and banking sector to those shocks. The final section summarises the main findings.

II. SIGNIFICANCE OF CLIMATE SCENARIOS

Climate scenarios describe the largely hypothetical evolution of future climatic conditions, taking into account current scientific data on, and projections of, greenhouse gas emissions, the energy mix, land use and other climate change factors. These scenarios typically involve assumptions regarding the reduction of CO_2 emissions, the pace of technological change, the rate of use of renewables and the introduction of carbon taxes. Given the length of the transition and the risks and uncertainties associated with it, the scenarios used to analyse climate risks can differ widely in their assumptions about the configuration of climate policies, the response of fiscal and monetary policy, the speed and degree of adjustment of the sectors of the real economy to climate change, the intensity and extent of physical shocks, and changes in business and consumer sentiment. For this reason, numerous alternative climate scenarios of various degrees of severity have been developed and analysed, ranging from a fast and orderly transition with relatively low costs in its early stages to a slow and disorderly transition with high costs in its latter stages. From the economic perspective, the scenarios are used to analyse the possible future impacts of climate change and climate policy on the macroeconomic environment, market and consumer sentiment and the financial system. From the financial market perspective, climate scenarios can also be used, under certain assumptions, to stress test the financial sector in order to evaluate how well prepared financial institutions are to manage climate risks properly. As a rule, therefore, they are used to identify the potential impacts and transmission channels of climate risks and to determine institutions' vulnerability to those risks rather than to perform standard stress testing in the sense of assessing the direct impact of climate change on the capital and liquidity of the financial institutions tested.

Climate scenarios for 30 years ahead are used most often for the purposes of macroeconomic and financial stability analysis. This length of time is considered to be an appropriate compromise between the ability to assess the long-term impact of climate risks and the requirement to construct a scenario with a sensible degree of uncertainty. Generally speaking, climate scenarios with longer horizons better map the evolution and ambitions of climate policies aimed at reducing greenhouse gas emissions, which are causing global warming. In the longer term, it is also possible to better estimate the net impact on the macro-financial environment of the opportunities and risks arising from transition policy and chronic physical risks and their interactions. However, the longer term smooths the impacts of short-term climate shocks and abstracts from their interaction with the business and financial cycles, which may exacerbate those shocks. For this reason, short-term scenarios are also used for some analyses. These are closer to classical macro-financial scenarios, since they better capture the short-term cyclical impact of climate shocks (such as frequent and severe natural disasters and changes in consumer preferences).

II.1 LONG-TERM CLIMATE SCENARIOS

It is widespread international practice to use the long-term climate scenarios developed by the NGFS[8] (NGFS, 2022) to assess the impact of climate change on the economy and financial system. The NGFS divides climate scenarios into three categories by the level of policy ambition and policy timing. The first category contains orderly scenarios, which assume that both physical and transition risks are relatively subdued over the entire horizon as a result of credible, internationally coordinated climate policies being introduced at an early stage. The second category consists of disorderly scenarios characterised by higher transition risk due to climate policies being delayed or divergent across countries and sectors. The final, "hot house world" category comprises scenarios with insufficiently ambitious climate policy or no policy at all. These scenarios assume low to zero transition risk and high to extreme physical risk due to significant assumed global warming. Within these categories, the NGFS defines six main climate scenarios (see Table 1).

[8] The NGFS (Network for Greening the Financial System) is a group of central banks and supervisors committed to sharing best practices, contributing to the development of climate and environment-related risk management in the financial sector and mobilising mainstream finance to support the transition toward a sustainable economy. For details, see here.

Table 1 NGFS climate scenarios

Category	Scenario	Policy ambition	Policy reaction	Technology change	CDR*	Policy variation
Orderly	Net Zero 2050	1.4°C	Immediate and smooth	Fast	Medium-high use	Medium
	Below 2°C	1.6°C	Immediate and smooth	Moderate	Medium-high use	Low
Disorderly	Divergent Net Zero 2050	1.4°C	Immediate but divergent across sectors	Fast	Low-medium use	Medium
	Delayed Transition	1.6°C	Delayed	Slow/fast	Low-medium use	High
Hot house world	Nationally Determined Contributions (NDCs)	2.6°C	NDCs	Slow	Low-medium use	Medium
	Current Policies	3°C +	None	Slow	Low use	Low

Source: NGFS, modified by the authors.

Note: * CDR stands for carbon dioxide removal, i.e. the process of removing carbon dioxide from the atmosphere and then isolating it by means of natural or technological processes. On the one hand, too low levels of CDR may increase transition risk, as other, more costly means will have to be used to reduce emissions. On the other hand, too high reliance on CDR in the transition scenario is also a risk, as the technology may not become as widely available as expected in the coming years. Policy variation indicates the variation in climate policies across regions. The colour coding indicates whether the factor makes the scenario more or less risky. Green indicates lower risk, blue moderate risk and red higher risk.

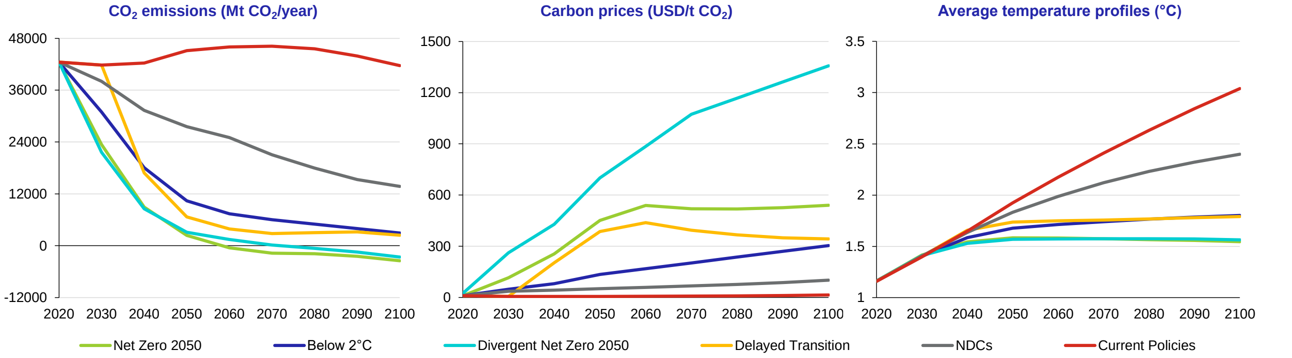
II.1.1 Scenarios for the transition to climate neutrality

A *Net Zero 2050*-consistent transition to climate neutrality (see Table 1) is considered “ideal” from both the economic and environmental perspective. In this scenario, the Paris targets are met by reaching net zero CO_2 emissions around 2050[9] amid subdued physical and transition risks, with global warming limited to 1.5°C by the end of the 21st century (see Chart 1). *Below 2°C* is a less ambitious alternative to *Net Zero 2050*. It also assumes climate policies are introduced early and become gradually more stringent, but net zero CO_2 emissions are reached after 2070 and global warming is limited to below 2°C. The transition risks are lower than under *Net Zero 2050*, but at the price of higher physical risks. *Divergent Net Zero 2050* assumes almost identical trends in CO_2 emissions and global warming as *Net Zero 2050* but differs in that climate polices have asymmetric impacts and loads across sectors. For example, the carbon price is three times higher in the transport and buildings sectors than in the energy supply and industry sectors. This scenario features the highest transition risks and lowest physical risks of all the six scenarios. *Delayed Transition* assumes climate policies are not implemented until after 2030 but are then introduced all the more forcefully in an attempt to curb further warming. This leads to higher carbon pricing. The amount of CO_2 emitted because of the delayed transition temporarily exceeds the carbon budget[10], and a faster decline in emissions is recorded after 2030. *Delayed Transition* is therefore more risky than *Net Zero 2050* due to higher transition and physical risks.

[9] Near-term (to 2030), medium-term (to 2050) and long-term (to 2100) time scales are generally considered in analyses of the impacts of climate change, adaptation to climate change and climate risks. This is because, according to IPCC (2022a), CO_2 emissions need to be reduced by 50% in 2030 relative to 2019 and net zero emissions need to be reached by 2050 if global warming is to be limited to 1.5°C. If emissions were cut by 50% in 2040 relative to 2019 and net zero emissions were reached in 2070, global warming would be limited to 2°C.

[10] IPCC (2022a) defines the carbon budget as the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given likelihood, taking into account the effect of other anthropogenic climate forcers. This is referred to as the “total carbon budget” when expressed starting from the pre-industrial period (1850 onwards) and as the “remaining carbon budget” when expressed from a recent specified date. Historical cumulative net CO_2 emissions between 1850 and 2019 amount to about four-fifths of the total carbon budget for a 50% probability of limiting global warming to 1.5°C and to about two-thirds of the total carbon budget for a 67% probability of limiting global warming to 2°C. Cumulative net CO_2 emissions between 2010 and 2019 compare to about four-fifths of the size of the remaining carbon budget from 2020 onwards for a 50% probability of limiting global warming to 1.5°C, and about one-third of the remaining carbon budget for a 67% probability of limiting global warming to 2°C.

Chart 1 Climate variables by scenario



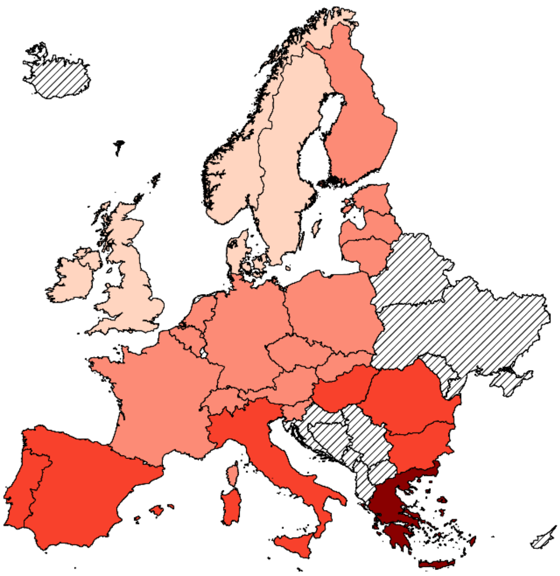
Source: NGFS Scenario Explorer.

II.1.2 Scenarios for the physical impacts of climate change

The climate change impact scenarios assume no or almost no regulation or policy action aimed at transitioning to a zero-carbon economy. The nationally determined contributions (NDCs) in the scenario of the same name are those as of March 2022,[11] and it is assumed they will be fully implemented and their objectives achieved by 2030. Between 2030 and 2100, the assumed climate policy ambition levels are comparable with those in the NDCs. This notwithstanding, the NDCs will not lead to a sufficient reduction in CO_2 emissions and, as a result, the global temperature will increase by 2.6°C. The transition risks are assumed to be relatively low. However, the absence of transition costs is more than offset by the adverse economic impact of high physical risk (implying large physical damage).

Figure 1 Impact of physical risks in Europe in 2050

(deviations from climate-neutral scenario in % of GDP)

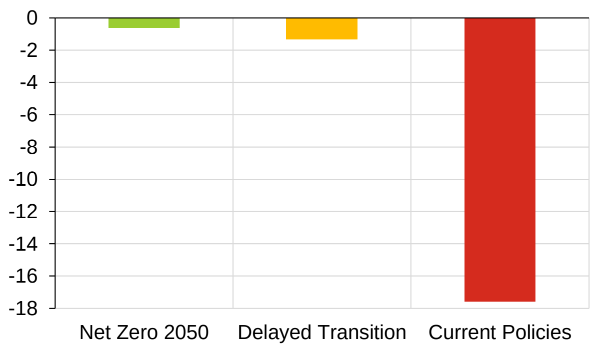


Source: NGFS Scenario Explorer.

Note: The map shows the deviations from the climate-neutral scenario obtained from the REMIND-MAgPIE model for the *Current Policies* scenario. No climate risks are considered in the climate-neutral scenario. The intervals of the categories are defined from the darkest shade to the lightest as follows: -5.5 – -4.5%, -4.5 – -3.5%, -3.5 – -2.5% and -2.5 – -1.5%. The intervals are closed from the left and open from the right. Data are not available for the hatched countries.

Chart 2 Estimate of the impact of global physical damage in 2100 by scenario

(deviations from projection of no-physical-damage scenario in % of GDP)



Source: NGFS Scenario Explorer.

Note: Given the length of the horizon and the high degree of uncertainty inherent to modelling global warming and the impacts of climate change, the value of the physical damage caused by climate change is estimated for the 95th percentile of the estimate of global warming over the entire horizon of interest in the *Current Policies* scenario, whereas the value of the damage is estimated for the median estimate in the remaining two transition scenarios.

[11] The Paris Agreement requires each party to prepare, communicate and maintain nationally determined contributions to reducing emissions and adapting to the impacts of climate change that it intends to achieve. These contributions are submitted to the UNFCCC secretariat every five years.

The *Current Policies* scenario is considered extremely adverse. It is characterised by the continuation of global climate policy in line with the current trends in the use of fossil fuels and the pace of CO_2 reduction. In this scenario, CO_2 emissions continue to follow an upward trend until 2080. This is consistent with a gradual increase in the global average temperature of at least 3°C by the end of the 21st century. This will result in extreme growth in physical damage, including irreversible changes in the climate system and ecosystem caused by tipping points being crossed.[12] This situation will have socioeconomic consequences[13] that may vary depending on different geographical factors (see Figure 1).

For greater clarity, we present an estimate of the impacts of the materialisation of physical risks on global GDP in 2100 for three of the scenarios described above (see Chart 2). The results show that investment in adapting economies significantly reduces the level of physical damage. A comparison of the results of the two transition scenarios reveals that the amount of investment necessary increases in the event of insufficiently ambitious and early climate policy implementation.[14]

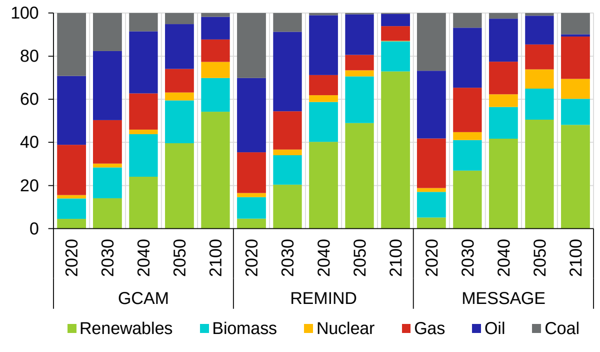
II.2 INTEGRATED CLIMATE CHANGE ASSESSEMENT MODELS

The GCAM, REMIND-MAgPIE and MESSAGEix-GLOBIOM models – known jointly as the Integrated Assessment Models (IAM) – can be used to model the transition pathways of economies based on the NGFS scenarios. These models primarily combine macroeconomic, agriculture and land use, energy, and water and climate system factors and allow for analysis of the complex, non-linear dynamics of those components and their interactions. The IAMs simply model climate change mitigation pathways by means of energy demand (such as energy efficiency improvements), energy supply (such as the share of solar in the energy mix), agriculture, forestry and other land use (such as reductions in deforestation and paddy field methane production) and CDR[15] (such as carbon absorption technologies). The transition intensity in the various models and scenarios is represented using the carbon price (see Chart 1). The carbon price is a proxy for the fiscal and regulatory policies needed to decarbonise economies, for technological change contributing to the reduction of greenhouse gas emissions or concentrations thereof in the atmosphere, and for changes in consumer preferences. It is therefore sensitive to the level of ambition to mitigate climate change, the timing of climate policy implementation, the distribution of policy measures across sectors and regions and the assumptions made about technological progress. Emissions price income constitutes additional government revenue which, depending on the scenario configuration, the government can then use to invest in the transition to climate neutrality. Given these assumptions, the resulting transition pathway should have the lowest possible economic cost.

Although the different IAMs are used for the same purpose, they differ in terms of model structure, economic agents' expectations, space and time dimension, technological progress, energy source use (see Chart 3) and so on. This needs to be taken into account, as the differences in the models lead to different outputs (see Chart 4). This naturally affects the subsequent projections of macroeconomic variables and, in turn, the simulated impacts on the financial sector.

Chart 3 Projections of primary energy source production by IAM for *Net Zero 2050*

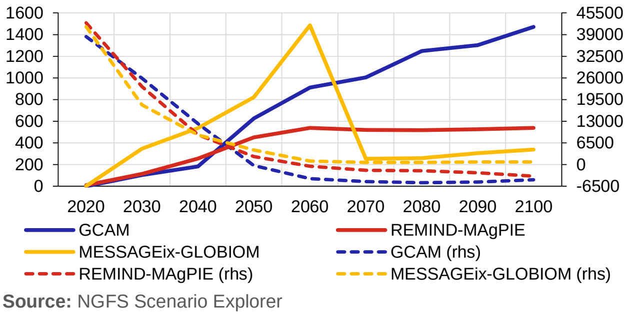
(share in total production in %)



Source: NGFS Scenario Explorer.

Chart 4 Projections of carbon price and emissions by IAM for *Net Zero 2050*

(USD/t CO_2 at constant 2010 prices; right-hand scale: Mt CO_2/year)



Source: NGFS Scenario Explorer

Note: The decline in carbon price in the case of MESSAGEix-GLOBIOM after 2060 is due to the achievement of net zero that year.

[12] According to IPCC (2018), tipping points refer to critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system, often with an understanding that the change is irreversible. A higher incidence of El Niño phenomena is an example of a potential tipping point.

[13] In addition to giving rise to property damage, climate change could adversely affect, for example, labour productivity via a negative effect on human health (Bosello et al., 2006) and tourism (UNWTO, 2008) and could cause humanitarian crises, migration and violent conflict ("social tipping points") with related negative impacts on economies (Brzoska and Fröhlich, 2015; Rigaud et al., 2018; IPCC, 2022b).

[14] The adaptation costs vary depending on the estimation methods and assumptions used. In developing economies, which, due to their geographical location, will be hit hardest, the annual adaptation costs are estimated at USD 15–411 billion for 2030, USD 47–1,088 billion for 2050 and USD 520–1,750 billion after 2050 (IPCC, 2022b; IMF, 2022a).

[15] CDR stands for carbon dioxide removal, i.e. the process of removing CO_2 from the atmosphere and subsequently isolating it using natural or technological processes.

III. MACROECONOMIC IMPACTS OF CLIMATE CHANGE

Presented below are the impacts of climate change based on three scenarios: *Net Zero 2050*, *Delayed Transition* and *Current Policies*. These scenarios were chosen to match the usual practices of supervisory authorities in analysing climate risks.[16] REMIND-MAgPIE[17] outputs were used for the analysis. Based on the chosen scenarios, the impacts on the global and Czech economy were then quantified using the NiGEM[18] macroeconomic model with an added climate block. The climate and macroeconomic variables were projected up to the end of 2050, which corresponds to the maximum projection time scale in NiGEM. The economic impacts of the simulated climate changes are tracked using three variables – GDP, consumer price inflation and interest rates. The results are presented as deviations from the values of the variables in the climate-neutral scenario. No climate risks are considered in the climate-neutral scenario.

III.1 CLIMATE RISK MODEL ASSUMPTIONS

The first group of climate risks modelled are physical shocks (physical risk materialisation), i.e. the direct impacts of climate change, which negatively affect both supply and demand. The negative supply-side effects were calibrated for the above scenarios for individual world economies on the basis of Kalkuhl and Wenz (2020) and build on the projected global temperature profiles of the selected climate scenarios (see section II.1). The global warming and increasing frequency of heatwaves assumed in the scenarios will have a negative impact on human health and hence on the availability and productivity of labour. The increasing scale and intensity of natural disasters will lead to total or partial physical destruction of capital in the affected areas. The reduction of the production factors of labour and capital will adversely affect the potential of individual economies, as overall global production capacity (supply) will be reduced. On the demand side, physical shocks will be negatively reflected primarily in private consumption and investment, the decline in which is derived from the negative effects of the supply factors on real economic activity. In the case of prices, by contrast, there are inflationary effects stemming from the supply disruptions and anti-inflationary effects reflecting the decline in demand. For all three climate scenarios, the model simulations of physical shocks assume that economic agents have limited forward-lookingness and exclude central banks' monetary policy responses.

The second group of risks modelled comprises transition shocks (transition risk materialisation), i.e. the indirect impacts reflecting the decisions of global climate policy makers. The model simulations of transition shocks assume forward-looking economic agents in all three climate scenarios. The transition shocks were calibrated for each economy for the *Net Zero 2050* and *Delayed Transition* climate scenarios (*Current Policies* does not consider transition impacts; see section II.1). As regards transition shocks, the model simulation assumes an increase in carbon tax, a decrease in the energy intensity of production, a decrease in the consumption of fossil fuels (coal, oil and gas) and an increase in the consumption of renewables. The transition scenarios assume that a reduction in air pollution due to the increase in carbon tax will lead to an increase in the costs associated with the use of fossil fuels (see Chart 5). The gradual reduction in the share of fossil inputs in production will result in lower productivity (a negative supply shock) and will therefore be an additional inflationary factor. A fall in consumption and fossil commodity prices will have the opposite effect on inflation, while the consumption of renewables preferred by global climate policy will grow over time.

Carbon tax revenue will have a positive effect on national public budgets as an additional source of revenue. The simulation of transition shocks for both scenarios assumes that central banks respond to the emerging inflation pressures and try to suppress them with monetary policy in the form of changes to interest rates. Overall, there is an inflationary mix of cost and supply shocks with negative effects on GDP. In the next step, the assumptions of the two scenarios diverge in terms of the decision on the use of the additional budget revenue. The model simulation of the *Net Zero 2050* scenario assumes that half of the revenues generated by the carbon tax increase will be reinvested in the economy by governments from the start of the forecast horizon onwards. The remaining half of the revenue from the carbon tax will be used to reduce government debt. In the *Delayed Transition* scenario, which involves a ten-year delay in the carbon tax increase and slower

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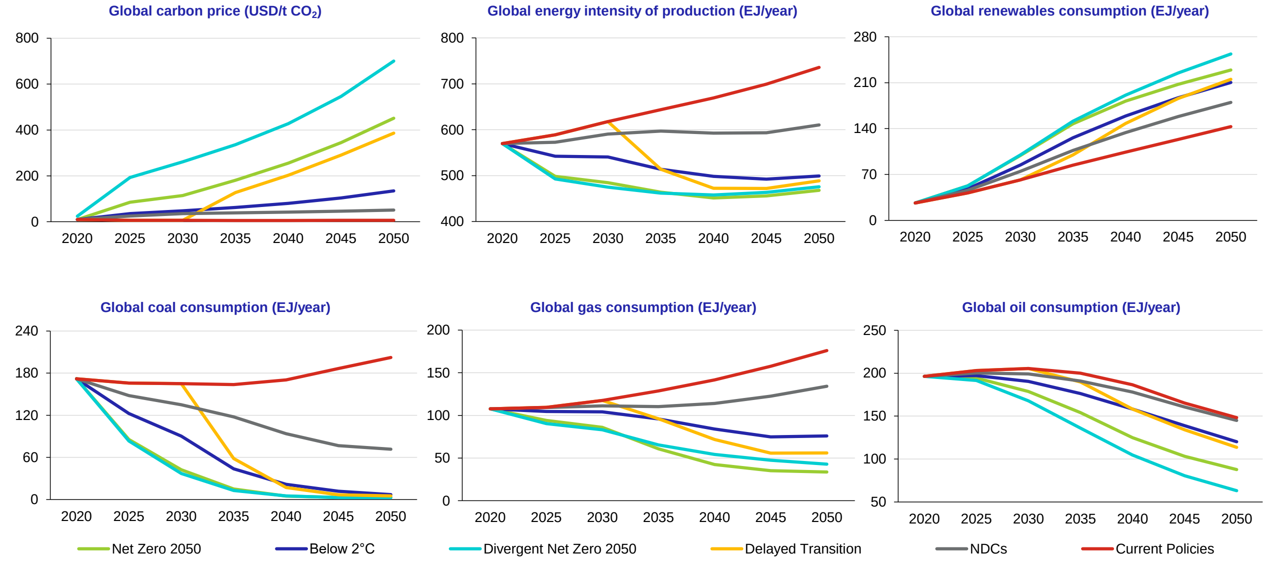
[16] According to FSB and NGFS (2022), of the total of 53 institutions surveyed, 30 had used *Current Policies*, 29 had used *Net Zero 2050*, 26 had used *Delayed Transition*, 16 had used *Below 2°C*, 10 had used *NDCs* and 6 had used *Divergent Net Zero 2050*. The first three are also used, for example, in ESRB and ECB (2022), ECB (2022a), BoC and OSFI (2022) and BoE (2022).

[17] The REMIND-MAgPIE model can be split into four components. Interpreted simply, the REMIND model itself simulates the long-run path of the global economy and energy system under different climate policy settings. It takes into account various factors – such as energy demand and supply, technological progress and policy measures – which make it possible to estimate future energy consumption, greenhouse gas emissions and the economic impacts of climate policies. Energy demand is proxied by the transport, industry and buildings sectors. The supply side of the energy system is made up of exhaustible and renewable resources. Exhaustible resources comprise coal, oil, gas, and uranium. Renewable resources include hydro, wind, solar, geothermal and biomass. The MAgPIE model simulates the impacts of climate policies on land use, agriculture, bioenergy and subsequent greenhouse gas emissions. Outputs from the LPJmL vegetation model, which simulates the impacts of climate change and changes in land use on ecosystems and the carbon and water cycles, are used for the MAgPIE simulations. The MAGICC climate model uses the emission pathways of greenhouse gas and air pollutants computed by REMIND to predict changes in climate variables such as the global temperature. In addition, REMIND can be linked to other suitable models to allow the analysis of other environmental factors not included in the components described above.

[18] NiGEM is a global econometric model that captures the interconnectedness of all the regions of the global economy. More information on NiGEM and its structure can be found in Hantzsche, Lopresto and Young (2018).

growth in the tax in subsequent years (and thus appreciably lower revenue than in the previous scenario), the additional revenue goes directly to national government budgets via endogenous modelling mechanisms. This additional budget revenue will lead, among other things, to a gradual reduction in income tax depending on the target debt levels of individual economies. After 2030, this positive demand shock will be dampened over the subsequent two years by the assumed negative sentiment of households and firms taken by surprise by the sudden change in the direction of climate policy. The delays in the implementation of climate policy will result in lower willingness of households to consume and an increase in precautionary savings. The increased uncertainty caused by the rapid introduction of new regulatory measures will also foster an increase in the risk premium and a decline in business investment activity.

Chart 5 Calibration of transition shocks for each climate scenario



Source: REMIND-MAgPIE global climate model.

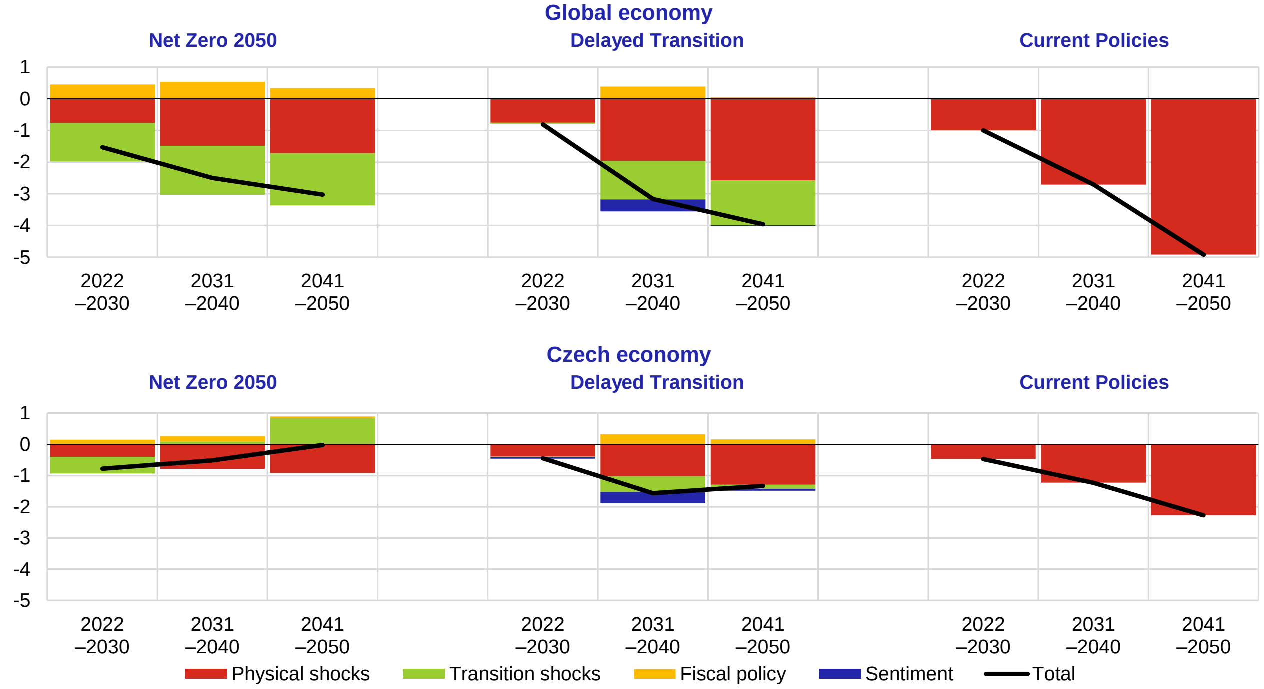
III.2 SIMULATED IMPACTS OF CLIMATE CHANGE ON REAL GDP

The resulting model simulations of the impacts of climate change on real economic activity show that the earlier global climate policy is implemented and enforced, the lower the negative impacts on economic activity should be. The overall path of GDP in the individual scenarios reflects very different impacts at the corporate sector level, with the projected growth in gross value added differing significantly depending on the carbon intensity of specific sectors (see section IV). In the case of physical shocks, climate change inevitably has direct negative impacts on GDP in all three scenarios (see Chart 6). In the *Net Zero 2050* and *Delayed Transition* scenarios, these effects are compounded by the impacts of transition shocks reflecting the implementation of climate policy. However, as can be seen from the GDP profile in the *Net Zero 2050* scenario, the negative effects are significantly reduced by timely implementation of climate policy with the use of carbon tax revenue and the partial distribution of that revenue in the form of reinvestment in the economy.[19] In the event of later implementation of climate policy in the *Delayed Transition* scenario, the negative impacts reflecting physical shocks are exacerbated by the assumed worse sentiment of households and firms. However, unlike the *Current Policies* scenario, the transition scenarios should lead to a very significant slowdown in global warming (see Chart 1) and the negative impacts on the individual world economies after 2050 should be very low in these scenarios. Conversely, in the *Current Policies* scenario, the negative impacts of climate change increase markedly further over time. This could lead to irreversible damage to the environment and human health and enormous economic costs after 2050 (see Chart 2).

[19] The difference would be greater if the entire carbon tax revenue was reinvested in the economy.

Chart 6 Impacts on the real GDP level

(deviations from climate-neutral scenario in % of GDP)



Source: CNB projections using the NiGEM model based on outputs from the REMIND-MAgPIE climate model.

Note: No climate risks are considered in the climate-neutral scenario.

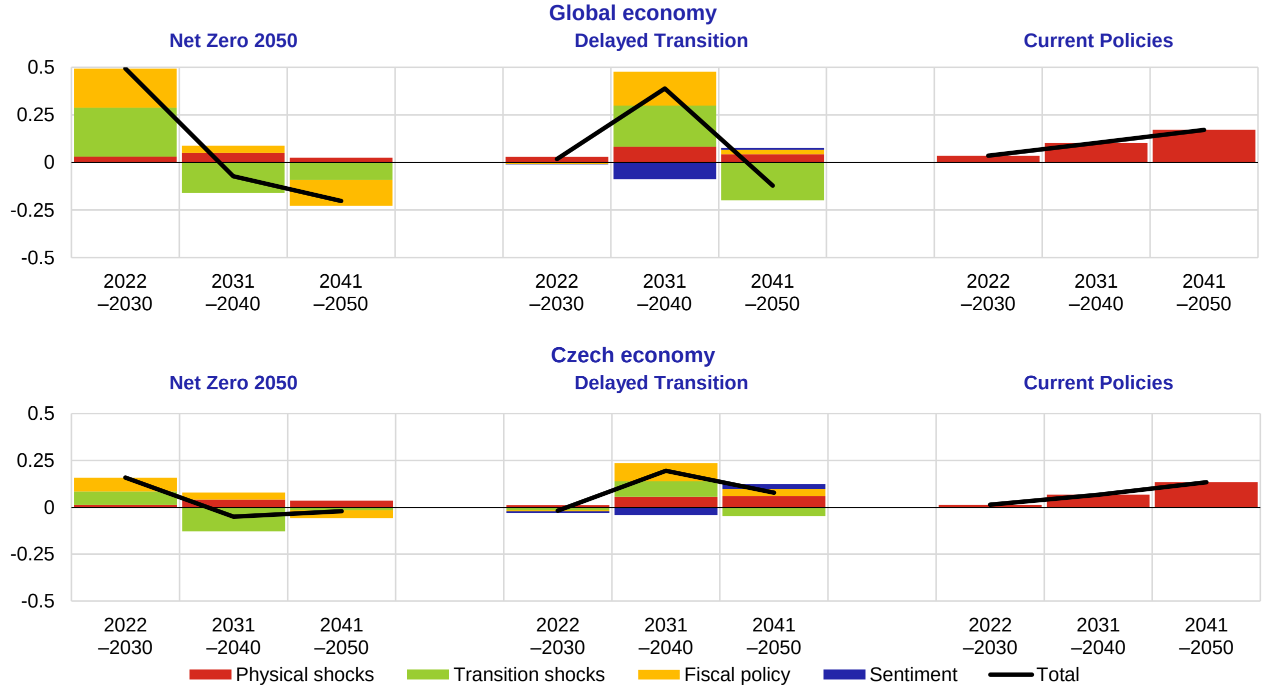
III.3 SIMULATED IMPACTS OF CLIMATE CHANGE ON CONSUMER PRICES

The simulations indicate that one of the costs of implementing global climate policy will be a temporary surge in consumer prices. This inflationary effect assumed in both transition scenarios mainly reflects the effects of introducing a carbon tax (see Chart 7). The impact on prices depends largely on the assumed scale and speed of the increase in the tax and the transmission of firms' tax costs to consumers.[20] The assumed impact of government investment to support economic growth and mitigate the negative effects of shocks will also have a short-term inflationary impact in both scenarios. The lowest inflation to the end of 2050 is implied by the *Current Policies* scenario, due to the absence of transition shocks. However, physical shocks – reflecting the prevailing negative supply factors – are the most inflationary in this scenario. These inflationary pressures are likely to strengthen further over time due to continued global warming, which will increasingly distort supply by diminishing the efficiency of use of production factors in the global economy. Anti-inflationary negative demand effects will only partially dampen this price growth.

In the *Net Zero 2050* scenario, the inflationary effects associated with physical shocks will be only modest, as the inflationary negative supply effects due to lower productivity of global factors of production will be largely dampened by anti-inflationary demand effects. In the *Delayed Transition* scenario, the slightly inflationary physical shocks are dampened overall in the short term by an anti-inflationary effect reflecting the temporary negative sentiment of households and firms (a negative demand shock) following the sudden and more forceful implementation of global climate policy after 2030.

[20] Other types of increased costs related to the decarbonisation of the economy can be considered in the scenarios. These include significantly increased financing costs and insurance premiums for climate-intensive production, which could also ultimately cause some producers to close down.

Chart 7 Impacts on annual consumer price inflation
(deviations from climate-neutral scenario in pp)



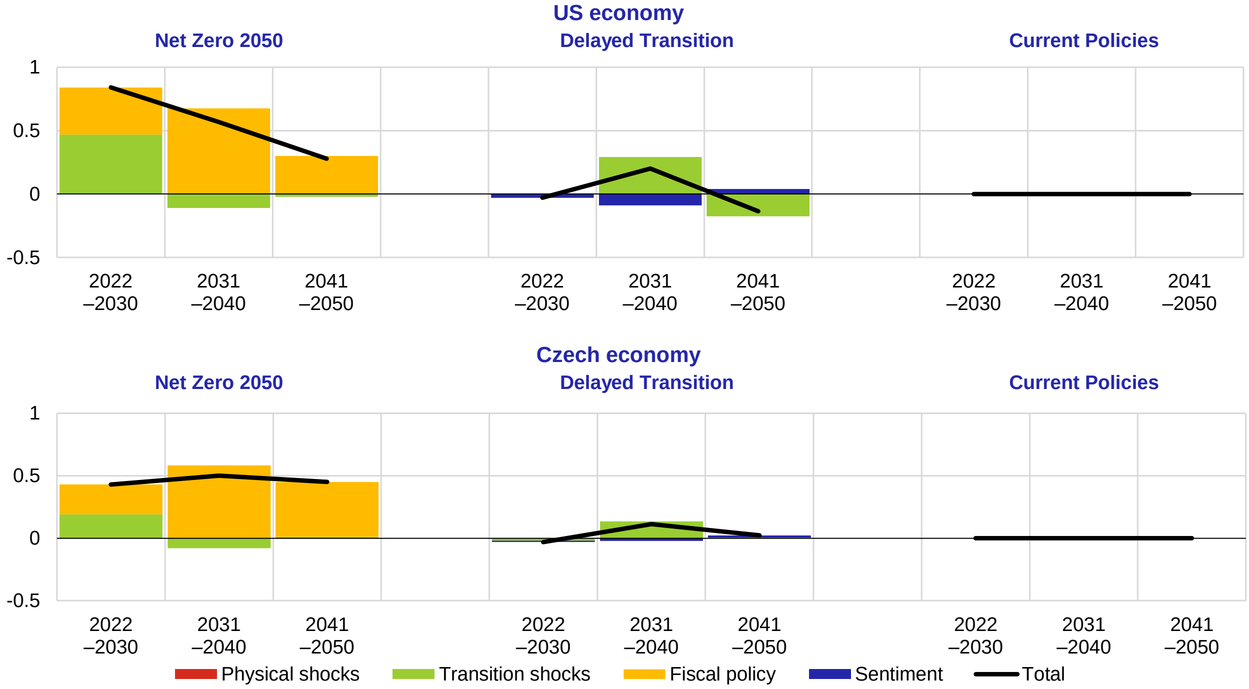
Source: CNB projections using the NiGEM model based on outputs from the REMIND-MAgPIE climate model.
Note: No climate risks are considered in the climate-neutral scenario.

III.4 SIMULATED IMPACTS OF CLIMATE CHANGE ON INTEREST RATES

The impacts of the climate scenarios suggest more subdued economic activity overall, amid upward pressure on consumer prices. This is consistent with slightly tighter monetary policies of central banks (see Chart 8). As the primary aim of this article is to explore the impact of the climate change simulated on the global and Czech economies, the monetary policy rates of the central banks of the USA (the Federal Reserve) and the Czech Republic (the CNB) were used to investigate the monetary policy response. The deviations in the central banks' responses are due to the different calibration of climate shocks, reflecting the different energy dependence of the Czech and global economies.[21] In the two transition scenarios, monetary policies respond most of all to the inflationary effects stemming from the implementation of climate policy as more expansionary fiscal policy. As stated above, this is most apparent in the *Net Zero 2050* scenario, which generates the largest fiscal revenue. In the *Delayed Transition* scenario, this positive demand shock is dissipated in the endogenous modelling mechanisms, leading to more relaxed fiscal policy. The temporarily higher interest rates also reflect the inflationary effects arising from transition shocks linked with climate policy implementation. Given the assumption of limited forward-lookingness of economic agents in the case of physical shocks, the simulation excludes the central banks' monetary policy responses. Overall, it is apparent that the effects on monetary policy rates over the time scales of the transition scenarios for both economies are relatively small.

[21] The US economy is a major exporter of fossil fuels worldwide, whereas the Czech economy is an importer. Climate policy, which puts downward pressure on the consumption of fossil fuels, the price of which will fall over time, will have stronger negative effects on the US economy. This will also be reflected in a stronger euro against the US dollar.

Chart 8 Impacts on monetary policy rates
(deviations from climate-neutral scenario in pp)



Source: CNB projections using the NiGEM model based on outputs from the REMIND-MAgPIE climate model.
Note: No climate risks are considered in the climate-neutral scenario.

IV. VULNERABILITY OF THE PRIVATE NON-FINANCIAL SECTOR

The assessment of climate scenarios is crucial for identifying the transmission channels through which climate change may affect the private non-financial sector. The next step is to use projections of financial institutions' exposures to the climate-vulnerable part of the non-financial sector and apply knowledge of their reliance on income from this part of the sector to estimate the potential impact on the financial sector as a whole. The CNB does not have enough relevant information at the level of individual firms[22] and households or about the carbon footprints of individual banks' portfolios to conduct a detailed analysis of the impacts of the simulated climate changes with robust conclusions for the Czech financial system. At the level of individual industries/sectors, however, it is possible to determine the potential impacts in at least broad terms using selected indicators[23] and so identify sources of risk to the financial sector.

IV.1 NON-FINANCIAL CORPORATIONS SECTOR

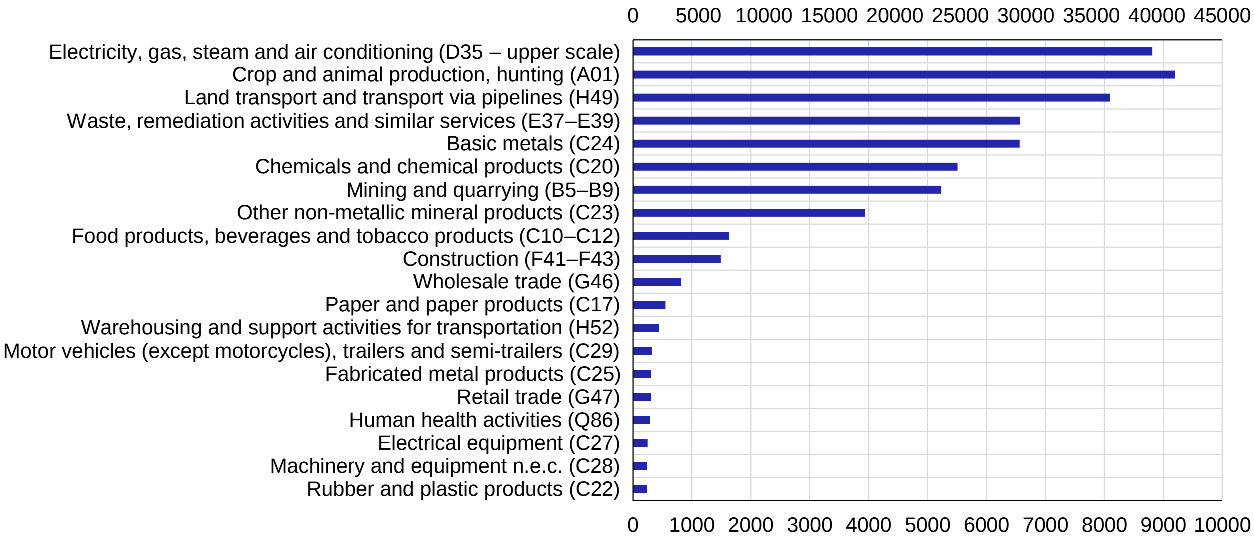
The present emissions intensity of the Czech economy is comparatively high, due to a heavy concentration of economic activity in industry and a relatively large share of fossil fuels in the energy mix (see Chart 9 and Chart 10). The Czech Republic's average emissions intensity is above the EU average (Box 4, CNB 2021). Given its structure, the Czech economy is therefore comparatively vulnerable to risks associated with the transition to climate neutrality. The expected growth in climate policy intensity – in the form of rising prices of emission allowances[24] and a stricter regulatory framework[25] – will gradually increase the transition risk for the part of the corporate sector that does not have credible enough climate transition plans and is unable to adapt its business model to the new sustainable business environment. As the above scenarios suggest, such companies will gradually lose competitiveness,[26] see their profits decrease or go out of business

[22] For example, information about firms' production technology linked with the development of renewables, about the national geographical breakdown of exposures to firms (the location of tangible assets in risky regions), about firms' credible plans for a green transition and about the number of indebted households employed in industries at risk from climate change.
[23] Some of the indicators presented here are used in the CNB's approach to setting the systemic risk buffer rate (forthcoming, https://www.cnb.cz/en/financial-stability/macroprudential-policy/the-systemic-risk-buffer/).
[24] The total amount of emission allowances is decreasing every year, which is causing their prices to rise. Moreover, a second separate emissions trading system for road transport and buildings (ETS II) is to start up in 2027. A Carbon Border Adjustment Mechanism (CBAM) will also enter into force. It aims to maintain the price competitiveness of the EU by levying a tariff on products imported from countries with less stringent regulations and by preventing companies from moving production to those countries.
[25] An example of this is the Farm to Fork Strategy, which sets out agricultural objectives. These include reducing by 50% the use of more hazardous pesticides and achieving 25% of total farmland in the EU under organic farming by 2030.
[26] Both price competitiveness (a higher share of renewables leads to lower costs) and competitiveness by producing in conformity with the change in consumer preferences towards more sustainable products.

entirely. If the banking sector continues to lend to vulnerable firms despite this risk, it may be exposed to the risk of default, which will increase in likelihood. The related growth in banks' losses may be exacerbated by a decrease in the value of the assets used by these companies as collateral ("stranded assets"). In the medium to long run, the value of the corporate sector's assets will also be negatively affected by physical risks and probably a related relatively sharp rise in insurance premiums (Box 6, CNB, 2022a).

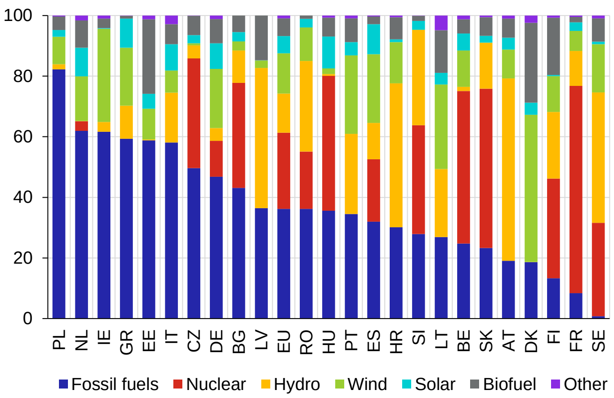
Climate policy-relevant sectors (CPRS) can be divided into the following categories: energy-intensive (mostly manufacturing), agriculture, fossil fuels (e.g. mining and quarrying), buildings, transport and utilities (EBA, 2021). This breakdown is largely consistent with the direct emissions levels[27] of the sectors of the Czech Republic (see Chart 9). It is clear from these that the biggest greenhouse gas emitters in the Czech Republic are utilities, materials and chemicals processing, transport, waste management and agriculture.

Chart 9 Direct greenhouse gas emissions by sector in the Czech Republic
(kt CO_2e)



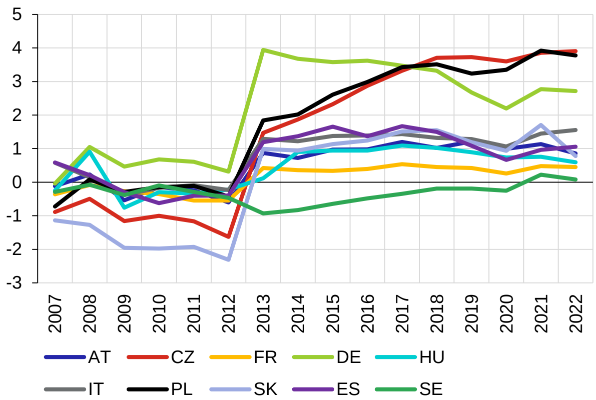
Source: Eurostat
Note: NACE level 2 sections in parentheses.

Chart 10 Electricity production by source in selected EU countries
(share in gross electricity production in % in 2021)



Source: Eurostat

Chart 11 Balance of emission allowances surrendered and received for free in selected EU countries
(t CO_2e per capita)



Source: EEA, European Commission

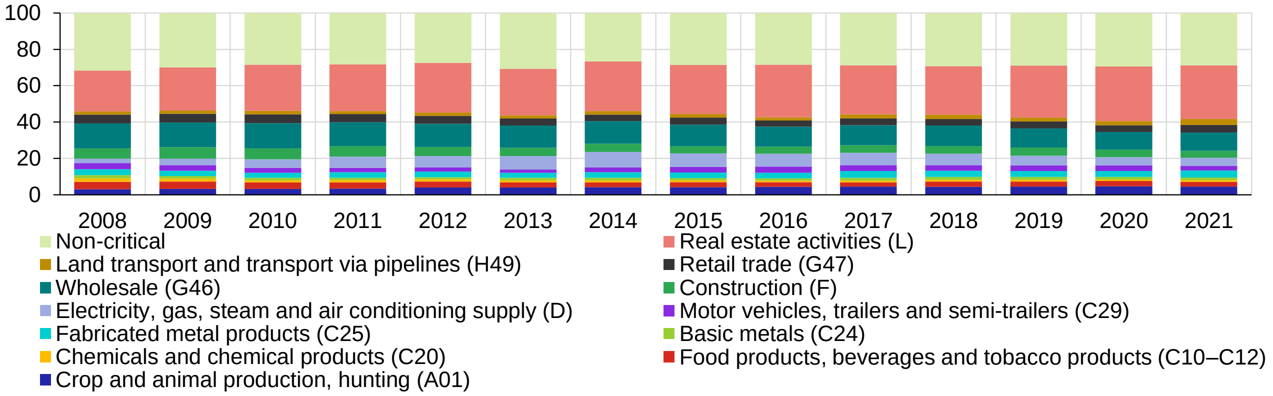
Changes in the energy sector are vital for ensuring the transition of the Czech Republic to a sustainable economy while maintaining the competitiveness of firms. This is evident from the balance of emission allowances surrendered and received for free (see Chart 11), which indicates greater vulnerability to transition shocks in the form of rising emission

[27] To analyse the impacts of transition risks, it is also appropriate to take into account indirect emissions, which are generated along the entire value chain. For details, see Box 4, CNB (2021).

allowance prices and higher input costs. Without major investment in renewables[28] and changes to the Czech Republic's energy mix, continued growth in the cost of energy from emissions-intensive sources would lead to further growth in costs and hence to a gradual decrease in competitiveness. Investment in renewables is more than just an opportunity for the Czech Republic to become more energy self-sufficient.[29] Bank financing of such investment will also generate a substantial reduction of climate risks in the Czech Republic, risks to which banks themselves are potential exposed.

Chart 12 Carbon-critical sectors in the Czech Republic identified for 2021

(share in credit portfolio in %)

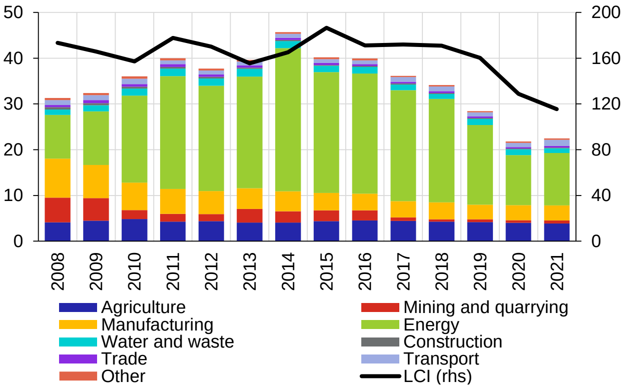


Source: Eurostat, CNB

Note: NACE level 2 sections in parentheses.

Chart 13 Loan-weighted emissions intensity by sector and LCI

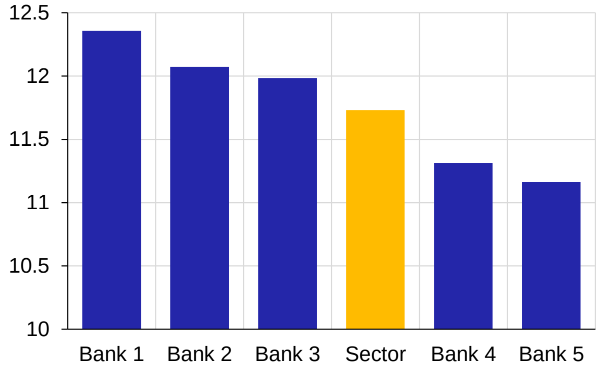
(t CO_2e/CZK million of value added by sector; right-hand scale: t CO_2e/CZK million of loans)



Source: Eurostat, CNB

Chart 14 Concentration of the banking sector's loans in emissions-intensive sectors

(natural logarithm of carbon-weighted HHI)



Source: Eurostat, CNB

Various indicators can be used to measure the banking sector's vulnerability via exposures to emissions-intensive sectors (ESRB and ECB, 2022). The concept of carbon-critical sectors (CCrS, Faiella and Lavecchia, 2020) can be used to identify and monitor climate policy-relevant sectors. CCrSs are identified by ranking sectors according to their shares of total greenhouse gas emissions and total bank loans. The fifth of sectors that have the lowest average of these two ranks are defined as carbon-critical. A total of 78% of greenhouse gas emissions and 71% of loans to non-financial corporations were concentrated in CCrSs in the Czech Republic in 2021[30] (see Chart 12). These figures are in line with the long-term average for 2008–2021. Loans to these sectors accounted for approximately 70% of the banking sector's interest income as of mid-2023; the figure for the top fifth of sectors emitting the most greenhouse gases was 34%. The CCrS structure is

[28] Deloitte (2023) discusses investment in renewables in the Czech Republic and its economic benefits in detail. However, investment in renewables is linked to the operation of, and investment in, the power grid. ČEPS (2023) presents potential coal phase-out scenarios for the grid. Of the four scenarios considered, the most ambitious – Decarbonisation – is the most costly, owing to the need to import electricity from abroad, invest in renewables and generate large amounts of electricity from gas sources.

[29] This should be aided by the REPowerEU plan, created in response to Russia's aggression in Ukraine and the EU's dependence on Russian fossil fuels, the aims of which include achieving greater diversification of the energy mix of EU Member States. The Czech Republic should receive roughly CZK 16.7 billion under the instrument. Further investment in renewables could be financed, for example, from the EU Modernisation Fund (up to CZK 500 billion). Despite the reduction in dependence on Russian fossil fuels, it should be noted that the EU is dependent on other economies, especially China, in the area of production of solar panels and the minerals it needs for the transition to climate neutrality. The Commission has responded by presenting a Net-Zero Industry Act and a Critical Raw Materials Act to support the circular economy, reduce the administrative burden, monitor supply chains and so on.

[30] Faiella and Lavecchia (2020) state that in Italy, CCrSs cover 80% of greenhouse gas emissions and 50% of bank loans.

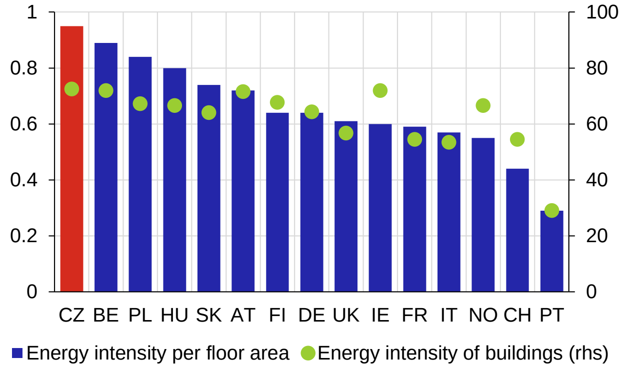
changing over time. In 2008–2016, the CCrSs included mining, for example, but since 2017, this sector has been classed as non-carbon-critical due to the winding down of the industry and the generally reduced willingness of banks to lend to it. The decrease in the significance of this economic activity is also evident from the sectors' emissions intensity weighted by their share in banks' loan portfolios (see Chart 13). According to this metric, the aggregate carbon intensity of banks' loan portfolios has been decreasing since 2014, especially in the energy sector.[31] The average loan carbon intensity (LCI) – the emissions of a sector over the bank loans provided to it – has been showing a similar trend (see Chart 13).[32]

Another relevant indicator is the risk of concentration of loans provided to high-emitting firms at the bank portfolio level (see Chart 14[33]), which can be computed using the carbon-weighted Herfindahl-Hirschman Index (ECB, 2022b). Banks with higher concentrations of loans to firms at risk from transition policy are potentially more vulnerable to transition risk.

IV.2 HOUSEHOLD SECTOR

Chart 15 Energy intensity of residential buildings in selected European countries

(GJ/m^2; right-hand scale: GJ/building)



Source: IEA

Climate risks can also affect the financial situation of households in many ways. As the above climate scenario simulations indicate, households may be exposed during the climate transition to a decrease in their real disposable income due to growth in the price level (see section III.3). Another potential burden on households is expenditure on energy efficiency, such as investment in building insulation, intelligent systems for effective energy management in buildings, and solar panels. Climate policy implementation may also affect house prices. The market value of more energy-intensive buildings may decrease in relative terms due to the greater investment needed to modernise them and reduce their energy intensity. The energy intensity of buildings is a highly relevant issue in the Czech Republic, as the country has one of the highest levels in Europe (see Chart 15). The market value of property may also be negatively affected by physical risks, in the form of direct damage with knock-on effects on household expenditure on repairs and higher insurance premiums.[34] In localities that are highly susceptible to physical risks, property could become uninsurable and hence unsuitable for use as collateral. The materialisation of physical risks and the transition to climate neutrality may therefore generally lead to a decrease in the real value of households' property and an increase in their real debt levels. This in turn may affect not only the probability of default of indebted households, but also the size of banks' total losses given such defaults due to potential increased volatility in the market prices of property used as collateral.

The Czech Republic's transition to climate neutrality will certainly also affect the structure of its labour market. Employees from the aforementioned emissions-intensive sectors are most at risk of losing their jobs. Given timely and credible climate policy, the number of new jobs created should exceed the number destroyed on aggregate.[35] The impact on structural unemployment will depend largely on factors such as the reskilling capacity of the potentially unemployed, employment policy and the education and training system. These factors should enable the effective reallocation of workers currently engaged in polluting economic activity and foster greater adaptability to the new demands on the labour market. Low adaptability to the new skills required on the labour market and low labour mobility thus imply a risk of higher structural unemployment.[36]

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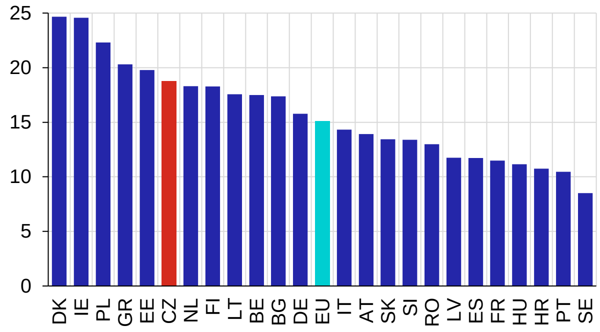
[31] The energy sector is also a significant issuer of the bonds held by the banking sector in its balance sheets. Companies in the energy sector had around CZK 95 billion of bonds issued as of the end of 2022. These are not taken into account in the indicators interpreted here.
[32] Given the absence of data on greenhouse gas emissions at the level of the individual companies to which loans have been provided, the LCI value is misleading, as, for example, it overestimates the LCI value for sectors with low loan volumes.
[33] Given the absence of company-level data on greenhouse gas emissions, however, the resulting figures should be treated with caution.
[34] According to an illustrative analysis conducted by the CNB, the most favourable option is the full pass-through of the rise in reinsurance prices to premiums for insurance companies (Box 6: *Illustrative analysis of the potential channels of the impact of climate risks on insurance companies*, CNB 2022a).
[35] According to an ILO simulation (ILO, 2019) on a sample of 32 countries, the transition could lead to the creation of almost 25 million jobs and the loss of nearly 7 million. Five million workers who lose their jobs because of contraction in specific industries will be able to find jobs in the same occupation in another industry within the same country. This means that the remaining 2 million workers are likely to be in occupations where jobs will be lost without equivalent vacancies arising in other industries, and will require reskilling into other occupations. In the EU, the impact of the Fit for 55 initiative on the change in the employment rate would be somewhere around -0.3% and 0.5% by 2030 (Vandeplas et al., 2022).
[36] However, higher mobility may be closely linked with high emissions intensity in transport, which also needs to be transformed to reduce emissions. This will lead to a further increase in household expenditure (or an additional burden on public finances via subsidies) in the form of purchases of electric (and possibly green-hydrogen-powered) vehicles, which are currently more expensive than internal combustion engine vehicles.

Chart 16 Emissions intensity per worker in selected European countries

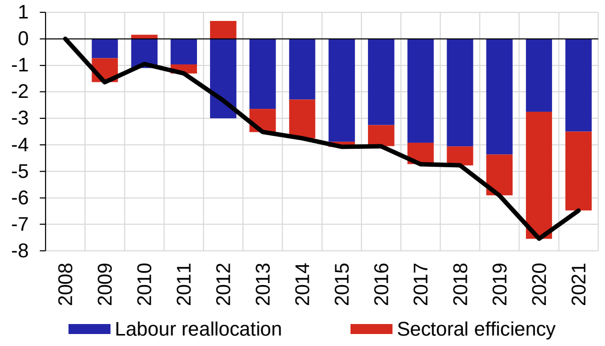
(t CO_2e per worker in 2021)



Source: Eurostat

Chart 17 Change in the weighted average emissions intensity per worker in the Czech Republic

(t CO_2e per worker w.r.t. 2008)



Source: Eurostat

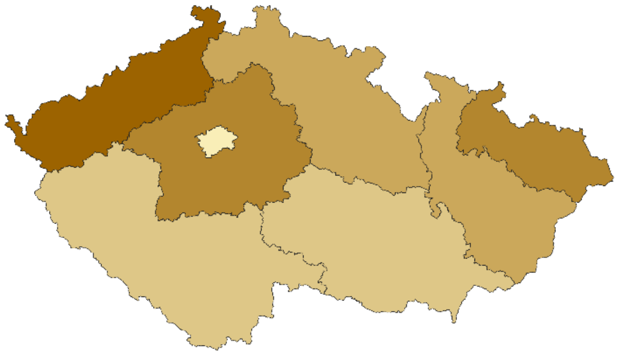
Note: The calculation method is described in an on-line annex to IMF (2022b).

The Czech Republic is above the international average in terms of emissions intensity per worker (see Chart 16). However, the evolution of the weighted average emissions intensity per worker shows that labour is already being steadily reallocated to sectors with lower emissions intensity (see Chart 17). Localities with high concentrations of polluting activities and low mobility levels may be subject to higher structural unemployment rates if new jobs are not created in those localities. The sectors highly likely to disappear in the future are linked primarily to coal and lignite mining (Vandeplas et al., 2022). In the Czech Republic, those sectors are particularly prevalent in the Moravian-Silesian, Ústí nad Labem and Karlovy Vary regions (see Figure 2).

As the scenarios presented above have already indicated, unemployment in the Czech Republic will be affected to a large extent by how climate policy is implemented (see Chart 18), specifically whether it is implemented in a timely and synchronous fashion or not. Given the excess demand for labour in the long term (CNB, 2023) and the fact that low-skilled and low-income workers[37] working in the secondary labour market are the ones most at risk (European Commission, 2019), the risk to financial stability seems quite limited. This is due not only to the negligible projected impact of climate change on the aggregate unemployment rate in the Czech Republic (see Chart 18), but also to banks' very low credit exposures to low-income households (CNB, 2022b[38]).

Figure 2 Emissions intensity per worker by NUTS 2

(t CO_2e per worker in 2021)

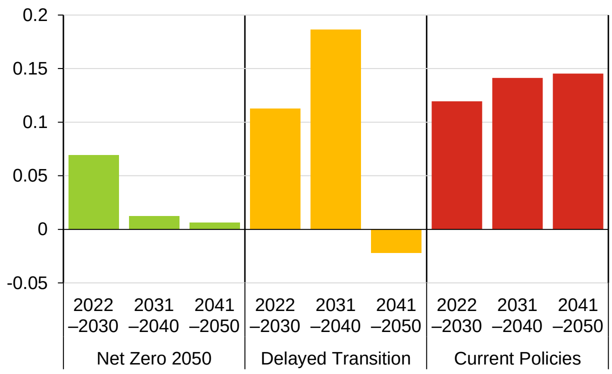


Source: Eurostat, EDGAR (2022)

Note: The intervals of the categories are defined from the lightest shade to the darkest as follows: 0–6.4, 6.4–17.2, 17.2–19.3, 19.3–26.9 and 26.9–75.6. The intervals are open from the left and closed from the right.

Chart 18 Impacts on the unemployment rate in the Czech Republic

(deviations from climate-neutral scenario in pp)



Source: CNB projections using the NiGEM model based on outputs from the REMIND-MAgPIE climate model.

Note: No climate risks are considered in the climate-neutral scenario.

[37] Lower-educated and lower-skilled workers generally have a higher probability of loss of employment and a lower probability of reemployment (OECD, 2013; Kuhn, 2002).

[38] The default rate on consumer loans secured by residential property is particularly sensitive to growth in the unemployment rate, while growth in interest rates and energy prices does not have a systemically adverse effect. Although low-income households are most exposed to default, they account for only a small proportion of bank loans to households (see the household stress test in CNB, 2022b).

V. CONCLUSION

The Czech Republic has committed to cutting greenhouse gas emissions and becoming climate neutral by 2050. Besides offering economic opportunities and benefits for society as a whole, this transformation will involve significant spending and is likely to be accompanied by the materialisation of related climate risks.

The main part of this article presents possible long-term macroeconomic pathways of the global and Czech economy under three climate scenarios: *Net Zero 2050*, *Delayed Transition* and *Current Policies*. The model simulations show that the growing long-term partial shock associated with climate change will foster lower economic growth and higher inflation overall by comparison with the standard business cycle and hence give rise to a need for tighter monetary policy of central banks. The impacts on the countries and regions of the global economy differ widely in intensity. Despite being industrial and heavily coal-dependent, the Czech economy seems relatively resilient to climate shocks by international standards when the scenarios presented - including the model's assumption regarding the optimal redistribution of carbon tax revenues through government investment back into individual economies - are met. The results of an analysis of selected scenarios nonetheless imply that delaying the implementation of climate policy will result in substantially larger economic costs. This finding is relevant to the Czech Republic, too. Despite the limitation of the model horizon to 2050, the analysis suggests that, unlike the *Current Policies* scenario, the remaining two transition scenarios should lead to a very significant moderation of global warming, with very low negative impacts on individual economies of the world after 2050. In contrast, under the *Current Policies* scenario, which has a minimal effect on the reduction of CO_2 emissions, the negative impacts of climate change will increase significantly over time, with the potential for irreversible environmental and human health damage and huge economic costs after 2050.

The article also studies indicators of the vulnerability of domestic real economic sectors and banks to potential climate risks. These indicators include the sectors' direct emissions, carbon-critical sectors, loan-weighted emissions intensity, the concentration of bank loans in emissions-intensive sectors, the energy intensity of residential buildings and emissions intensity per worker. The indicators were used to identify, among other things, climate risk-relevant sectors accounting for a significant proportion of the Czech banking sector's loan portfolio. The evolution of the indicators also suggests that the aggregate carbon intensity of banks' loan portfolios has already begun to decrease, especially in the energy sector. This sector is the largest contributor to the production of greenhouse gases.

The CNB also intends to use macroeconomic model simulations based on various NGFS climate scenarios to stress test financial institutions. One of the aims of this article was to raise awareness of the modelling system the CNB will use for preparing scenarios. Some of the indicators presented here, along with others created as new information comes in, will be used to assess climate risks in the Czech Republic and will be included regularly in the CNB's Financial Stability Reports.

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