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What's the Cost of "Saving the Planet" for Banks? Assessing the Indirect Impact of Climate Transition Risks on Slovak Banks' Loan Portfolios

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What's the Cost of "Saving the Planet" for Banks?

Assessing the Indirect Impact of Climate Transition Risks on Slovak Banks' Loan Portfolios*

Jozef Kalman, Ján Klacso, Roman Vasiľ[†], Juraj Zeman [‡]

September 5, 2023

Abstract

The ongoing trend of global warming is damaging not only human society but also economic activity. Central banks, supervisors, and macroprudential authorities are not immune to the climate-related risks in the financial sector. This study analyses how climate transition risks indirectly affect the banking sector through the credit risk channel for both households and non-financial corporations. We integrate Network for Greening the Financial System scenarios into conventional stress testing framework. The analysis focuses on a short-term horizon to reduce the impact of high modeling uncertainty on the outcomes. We find that a relatively smooth substitution of emission-intensive sectors results in relatively low indirect costs for banks. An uneven transition can, however, generate significantly higher credit losses, occasionally exceeding adverse scenario outcomes of conventional stress testing. The results are sensitive to an increase in energy prices or to higher defaults of firms in emission-intensive sectors.

Keywords: NGFS Scenarios, Climate Change, Climate Stress-Test, Financial Stability, Scenario Analysis, Transition Risk

JEL-Codes: C60, E50, G32, O44, Q40, Q54

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Non-Technical Summary

Climate-related physical risks, such as rising temperature or large-scale natural disasters, and transformation risks arising from policy response, may contribute to economic and financial losses worldwide for businesses, households, and governments.

Climate related risks may cascade through the financial system directly and indirectly. If the financial system is exposed to sectors with high-emissions or sectors facing high physical risks, the direct impact could be considerable. Within the Slovak banking sector, however, the direct exposure to these risks is currently perceived as negligible. Therefore, this paper aims to explore the indirect negative effects of climate transition risks on the banking sector in Slovakia. In our analysis we assess the impact of the potential negative macroeconomic development due to the transition to a carbon-neutral world on households and non-financial corporations (NFCs) credit risk.

A forward-looking analysis requires a thorough design of climate risk scenarios. Conventional stress testing scenarios do not incorporate climate-related risks hence we use the scenarios developed by the Network for Greening the Financial System (NGFS). The NGFS scenarios are based on various assumptions about climate policies, average temperature, and carbon emissions, which result in different levels of physical and transition risks. We utilize two specific NGFS scenarios - Net Zero 2050 and Divergent Net Zero — where transition risks exceed the physical risks. We then incorporate these scenarios into the stress test framework of the National Bank of Slovakia (NBS).

The impact of Net Zero 2050 scenario, where green transition is smooth, has a negligible impact on economic growth and unemployment. As a result, households and non-financial corporations experience trivial losses compared to the baseline scenario which assumes no impact of climate risks. In contrast, credit risk losses are notably higher under the Divergent Net Zero, which involves a non-coordinated approach. This is primarily due to a temporary increase in the unemployment rate and a more substantial decline in GDP, adjusted for emission production, among non-financial corporations. However, credit risk losses remain considerably below standard adverse stress testing losses even in this case.

This outcome can be partially attributed to the mild shocks driving both climate scenarios. Credit losses are salient if the substitution process to lower emission-intensive sectors is uneven, resulting in higher energy prices or increased defaults among emission-intensive firms.

While our study sheds light on the potential impact of transition risks on credit risk within the banking sector, there are numerous avenues for future research. Transition

risks also affect other financial institutions and have implications for different types of risks within the banking sector. Ongoing research at the National Bank of Slovakia aims to quantify the impact of physical risks on the real economy and the financial sector to a certain extent.

1. Introduction

Climate change is increasingly recognized as a significant risk to various aspects of society (IPCC, 2013), including economic activities (Batten, 2018) and the financial system (Rudebusch, 2021), and therefore to financial stability as well (Battiston et al., 2021). Climate change risks can be broadly divided into two categories (Batten et al., 2016). The first, physical risks, refers to the economic costs and financial losses associated with tangible climate-related adverse trends and severe weather events. The second, transition risks, refers to the uncertain pace and scope of adaptation and mitigation policies in the journey towards a zero-carbon economy.

Climate change risks include rising temperatures, sea-level rise, and more frequent and severe extreme weather events like storms, heatwaves, and droughts. Climate-related physical risks, such as large-scale natural disasters, may lead to capital misallocation, increased chances of financial losses, and reduced profitability for businesses. Tackling global warming with necessary policy responses, such as transitioning to a carbon-neutral economy, may cause economic and financial losses worldwide for businesses, households, and governments. Hence, central banks, supervisors, and macroprudential authorities closely monitor the impact of climate-related risks on the economy, financial system, and financial stability.

Climate related risks can transmit to the financial system directly or indirectly. If the financial system is exposed to sectors with high-emissions or sectors facing high physical risks, the direct impact can be considerable. In the case of the Slovak banking sector, the direct risks are currently deemed negligible (Národná banka Slovenska, 2021a). Therefore, this analysis focuses on the indirect impact. Here, the broader negative impact of climate-related risks on the real economy adversely affects financial markets and institutions through their exposure to the real economy (NGFS, 2019).

Financial authorities have acknowledged the significance of integrating climate-related risks into financial stability assessments and stressed the necessity for a more forward-looking and comprehensive analysis. Conventional stress test scenarios are inadequate for examining the external climate-related shocks financial institutions can face (Bolton et al., 2020). Consequently, integrating climate-related risks into the risk evaluation framework necessitates fundamental changes in scenario design (Baudino and Svoronson, 2021). In this regard, central banks, financial supervisors, and leading academics worldwide have developed a common reference scenario framework under the Network for Greening the Financial System (NGFS) to evaluate the impact of climate-related risks on the financial system and institutions (NGFS, 2021b).

Central banks are increasingly conducting climate risk-related stress tests on financial system using NGFS reference scenarios. Each central bank, macroprudential authority, or supervisory authority tailors its risk assessment framework to country-specific needs, incorporating different assumptions regarding the balance sheet, time horizon, and particular climate risks. Notable examples of comprehensive exercises on the impact of climate risks on financial institutions include those conducted by the Bank de France / ACPR (Allen et al., 2020), Bank of England (BoE, 2021) and the European Banking Authority (EBA, 2022). These exercises to some extent adapt NGFS scenarios and focus on both transition and physical risks over the 30-year horizon, while the Bank of England extends the horizon to 60-years in the case of physical risks and the EBA uses various time horizons.

Some central banks have conducted less demanding analyses focused solely on transition risks. Vermeulen et al. (2021) from De Nederlandsche Bank (DNB) assess risks for financial sector stemming from energy transition. Central Bank of Austria (OeNB) assesses the impact of carbon pricing on the Austrian credit institutions. They evaluate two carbon pricing scenarios over a period of five years. In one transition scenario, the carbon emission costs for the economy increase in an orderly manner, while in the other scenario, they increase in a disorderly fashion (Guth et al., 2021). Central Bank of Italy analyses the short-term effects of carbon tax on Italian households and firms. In two out of four scenarios, they use NGFS carbon pathways (Faiella et al., 2022).

In this paper, we investigate the indirect negative impact of climate transition risks on the banking sector in Slovakia, which plays a significant role in the country's financial sector. The analysis focuses on the the credit risk channel covering both households and non-financial corporations (NFCs). Our analysis utilizes high-level scenario narratives provided by the NGFS. The first scenario assumes a globally coordinated effort leading to a smooth transition to a carbon neutral economy. This scenario represents both low transition and physical risks. The second scenario considers a divergent path with suboptimal and uncoordinated actions, representing a scenario that poses comparable physical risks but at the expense of greater transition risks. The stress test framework of the National Bank of Slovakia is then employed to evaluate the impact of these scenarios. An overview of the framework for macro stress testing is described in Klacso (2014), with some updates of the satellite model used to estimate household credit risk available in Klacso (2023). The results of these scenarios are compared to a baseline scenario that represents a standard economic forecast without considering climate-related risks.

We find that if the substitution of emission-intensive sectors is smooth, without significant increases in energy prices or significant defaults in such sectors, the indirect costs to banks in terms of credit risk-related losses will be relatively small. However, these results are sensitive to changes in energy prices and the default rates of firms in emission-intensive sectors. If the transition is less smooth, leading to higher energy prices or greater adaptation challenges in certain sectors, the credit losses could be considerably higher, occasionally surpassing those from adverse scenarios in conventional stress tests.

The rest of the paper is organized as follows. Section II discusses the scenario design for financial stability assessment, and Section III introduces methodological framework. Section IV outlines findings for households and NFC and also includes sensitivity analysis to the changes in different modelling assumptions. Section V concludes.

2. Climate Risk Scenario Design

Most publicly available climate-related scenarios, such as those from the International Energy Agency (IEA), The Shared Socioeconomic Pathways (SSPs), and the International Panel for Climate Change (IPCC), were not initially designed for macro-financial analysis. In response, the NGFS has collaborated with academics to develop scenarios that provide a common reference framework for central banks, supervisors, and other stakeholders to assess the implications of climate risks on the financial system.

The NGFS scenarios consist of six theoretical future states of the world, each with different impact of climate change and climate policies (Chart 1)[1]. These scenarios are based on various assumptions about the evolution of climate policies, temperature, and emissions, resulting in different levels of physical and transition risks. Five scenario-specific design choices, called risk drivers, include policy ambition, policy timing, coordination, technological innovation, and the availability of CO_2 removal technologies (NGFS, 2021a). These choices can influence the overall level of physical and transition risks.

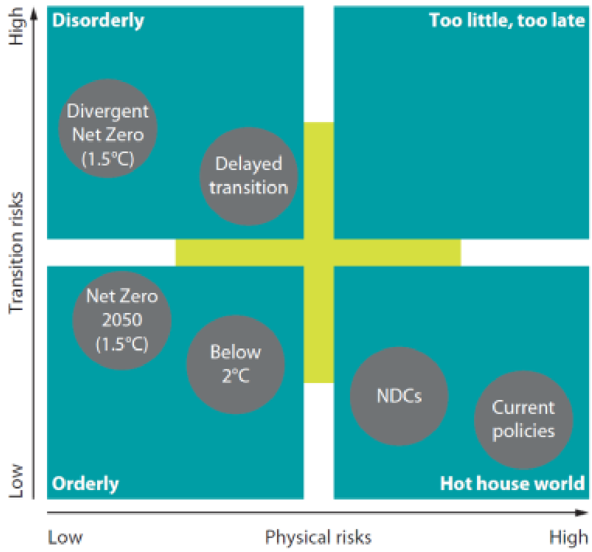
Scenario estimation involves three steps: estimating climate risk scenarios using different integrated assessment models (IAMs)[2] for specific geographical areas (with a focus

[1]Technical details of the NGFS Phase II Scenarios can be found in the NGFS documentation, see https://www.ngfs.net/sites/default/files/ngfs_climate_scenarios_technical_documentation__phase2_june2021.pdf.

[2]Namely REMIND-MAgPIE model, MESSAGEix-GLOBIOM model and GCAM model. Although the models share similarities, there are some differences that can influence the results. E.g., REMIND-MAgPIE and MESSAGEix-GLOBIOM are general equilibrium models allowing for an endogenous change in con-

on the EU region in our case), downscaling the results to the country level, and using country-level data on GDP, population, primary energy consumption, and carbon taxes from each IAM model as inputs into the National Institute Global Econometric Model (NiGEM) scenarios. Key macroeconomic variables are then estimated using NiGEM (NGFS, 2021a)[3]. This means that for each NGFS scenario, the estimated development of country-specific macroeconomic variables for Slovakia is available.

Chart 1: **NGFS representative climate scenarios**

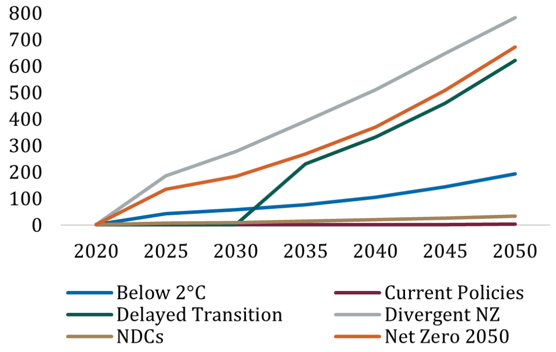


Source: NGFS

sumption, GDP and demand for energy in response to climate policies. In contrast, GCAM is a partial equilibrium model taking exogenous assumptions on GDP development and energy demands. On top of these differences, REMIND-MAgPIE additionally ran the full set of scenarios with an implementation of internalised physical risk damages. For more details, we refer to the technical documentation of NGFS (NGFS, 2021a). Further in the text we use shortened names of the models (e.g., REMID, MESSAGE, and GCAM).

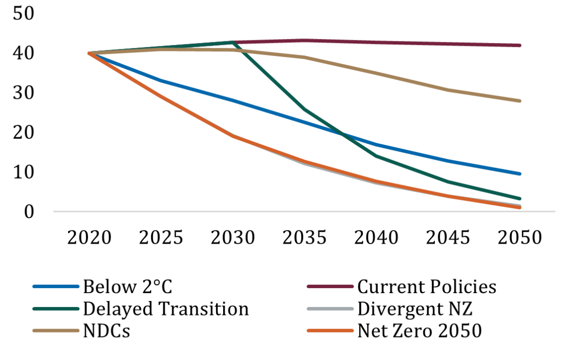
[3]Data are available in the NGFS Scenario Explorer provided by IIASA: https://data.ece.iiasa.ac.at/ngfs-phase-2/#/login?redirect=%2Fworkspaces.

Chart 2: **Carbon price development (USD, 2010 t/CO_2)**



Source: NGFS, Authors' own calculation.

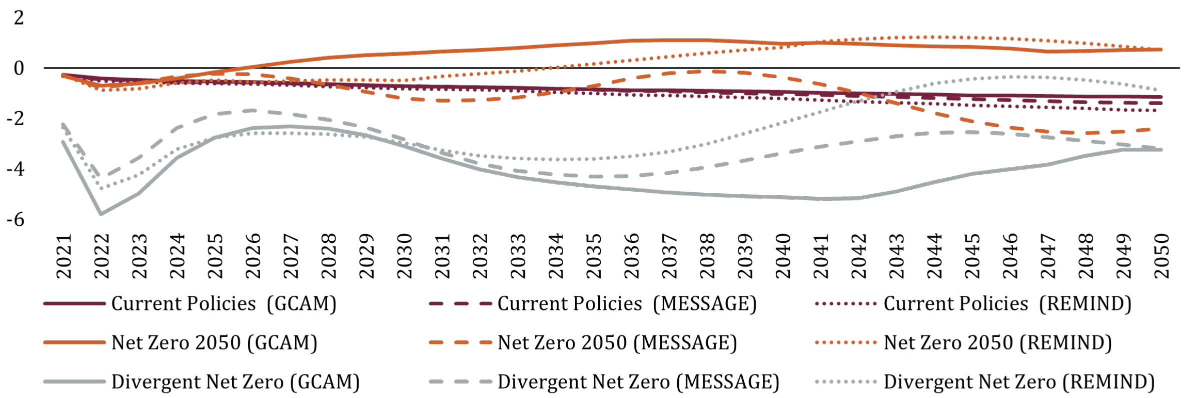
Chart 3: **CO_2 emissions by scenario (Gt CO_2/yr)**



Source: NGFS, Authors' own calculation.

This analysis focuses specifically on transition risks and the scenarios covering transition risks for several reasons. First, the impact of physical risks goes beyond the financial system and poses challenges in isolating their effects on the financial system alone. Second, the time horizon of the impact of these risks is much longer, reaching several decades. Third, while the design of scenarios related to physical risks is improving, there is still room for enhancement in the development of macroeconomic scenarios suitable for such assessments. For example, one of the scenarios with the largest impact of physical risks, the *Current Policies* scenario, yields only to a small and almost linear deviation of GDP in Slovakia from its baseline based on NGFS estimates (Chart 4). Even this deviation is significantly smaller than, e.g., the deviation under the *Divergent Net Zero* scenario.

Chart 4: **Slovakia's GDP deviation form baseline, (% difference)**



Source: NGFS, Authors' own calculation.

For the assessment of transition risks in the banking sector, we selected the *Net Zero 2050* and *Divergent Net Zero* scenarios as they best fit the purpose of our analysis. These scenarios primarily reflect different levels of transition risks, while keeping physical risks muted. They enable us to explore the impact of policy responses, available technology, and policy coordination on the financial system and the economy (Table 1). In other words, we examine the effects of different carbon prices (Chart 2), carbon trajectories (Chart 3), and innovations on the financial system. We utilize the NGFS *Baseline Scenario* as a benchmark against which to compare the results of climate stress tests. The baseline scenario represents the most likely macroeconomic projections and serves as a standard economic forecast that does not incorporate any climate-related risks (NGFS, 2021a).

Table 1: NGFS scenario assumptions

	Net Zero 2050	**Divergent Net Zero**
Physical risk	Low	Low
Transition risk	Low	High
Policy ambition	1.5°C	1.5°C
Policy reaction	Immediate and smooth	Immediate but divergent
Technology change	Fast	Fast
Carbon dioxide removal	Medium-high use	Low-medium use
Regional policy variation	Medium	Medium

Source: NBS representation based on NGFS (2021b)

The orderly scenario assumes the early introduction of climate policies that gradually become more stringent. In the *Net Zero 2050* scenario, ambitious emission reduction policies lead to rising carbon prices by 2050. The policy ambition is in line with the Paris Agreement's goal of limiting global warming to 1.5°C through rigorous climate policies and innovation, ultimately achieving net-zero carbon emissions around 2050. This mitigates the escalation of physical risks as both physical and transition risks are relatively subdued. The smooth and gradual nature of the transition minimises the costs associated with the energy transition, while limiting global warming to 1.5°C helps to mitigate the increase in physical risk (NGFS, 2021b).

The disorderly *Divergent Net Zero* scenario shares the same temperature target as the *Net Zero 2050* scenario but explores higher transition risks due to less coordinated and more fragmented approach to achieving net-zero emissions by 2050. This scenario assumes more stringent policies in the buildings and transportation sectors compared to the *Net Zero 2050* scenario. Technological availability is limited in terms of potential and up-scaling (NGFS, 2021a). Both scenarios envision a structural change in the global economy that shifts towards more carbon-neutral and less emission-intensive sectors.

However, unlike the *Net Zero 2050* scenario that assumes a smooth and efficient structural change and transition, the *Divergent Net Zero* scenario anticipates a less efficient transition, resulting in higher economic costs like lower GDP or higher unemployment.

In both scenarios, optimal carbon prices aligned with the 1.5°C target are assumed to be implemented immediately after 2020. Nevertheless, there are differences in the speed and order of the implementation and technological change policies. The immediate coordinated transition appears to have lover costs in the long run compared to inaction or a disorderly transition. Technological advancements have a profound impact on mitigation trajectories, with greater availability of innovation leading to a more gradual phase-out of liquid fossil fuels.

The scenarios related to transition risks impose shocks on the system right from the beginning. For instance, we illustrate the sudden drop in GDP in both the *Net Zero 2050* and *Divergent Net Zero* scenarios (Chart 4). After the initial shock, economic development improves gradually relative to the baseline. However, the outcomes from different integrated assessment models (IAMs) are becoming more heterogeneous for the respective scenarios after the initial years. This highlights the significant modeling uncertainty associated with longer-term projections. Therefore, to provide more comprehensive results, we focus our analysis on the shorter period of the first four years of the NGFS scenarios. In addition to the modelling uncertainty, significant changes in the structure of the banks' balance sheets could occur in the longer term, making the results even more questionable.

We have chosen two IAMs, namely the GCAM and MESSAGE. The outcome of these models represents the lower and upper bounds of the potential impact of the *Divergent Net Zero* scenario on the key macroeconomic variables in Slovakia during the covered period.[4] By examining the development of GDP in the first four years (Chart 4), we can gain insights into the range of potential impacts.

3. Methodology

In the previous section, we introduced the available NGFS scenarios and explained which scenarios and time-horizons are optimal for our assessment of transition risk. From this section on, we show how to translate the available macroeconomic variables under the respective scenarios into banking sector-specific outcomes using the NBS stress testing framework. We specifically focus on assessing the credit risk associ-

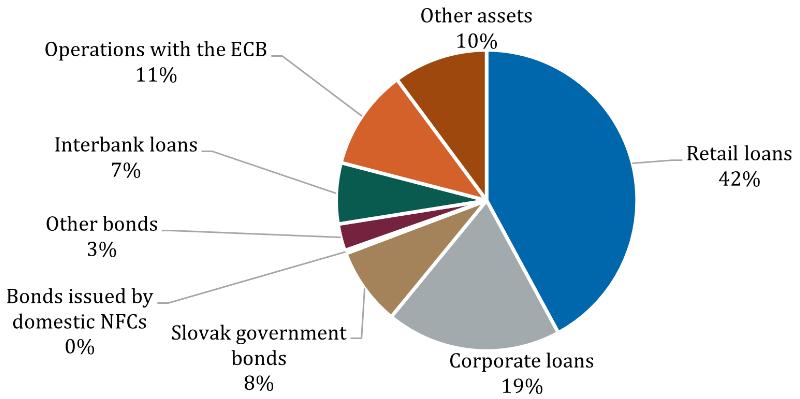
[4]While in case of the *Net Zero* scenario the lower and upper bound is represented by MESSAGE and REMIND, the overall negative impact under this scenario is significantly lower then in case of the *Divergent Net Zero* scenario. Therefore, our selection reflects the lower and upper bound of the scenario with the more important impact for the banking sector.

ated with households and NFCs.[5] Various factors drive this decision.

Firstly, when evaluating transition risks, we primarily examine the second-round effects these scenarios have on the global economy. This is similar to stress testing exercises involving macroeconomic shocks. Credit risk is considered as one of the most significant risks faced by banks within the European Union under adverse scenarios (EBA, 2018).

Secondly, the retail[6] and corporate loan portfolios constitute a substantial part of the balance sheet of the Slovak banking sector (Chart 5). Therefore, it is crucial to focus on assessing the credit risk associated with these portfolios.

Chart 5: **Asset structure of the Slovak banking sector's balance sheet**



Source: NBS

Thirdly, it is important to note that, apart from loans, the banking sector's largest share of assets consists of bonds, especially domestic government bonds. Although the NGFS scenarios indicate a mild rise in long-term interest rates, the anticipated impact on the bond portfolio is expected to be limited. Specifically, the scenarios employed in this study project an increase of 12 to 57 basis points in long-term interest rates (representing 10-year government bonds) compared to their baseline levels. The magnitude of this increase varies depending on the specific scenario and IAM utilized (NGFS, 2021a).

In the subsequent sections, we provide a concise description of how the macroeconomic scenarios are translated into estimations of credit risk using micro-data pertaining to households and NFCs.

[5]For a comprehensive overview of scenarios see: https://www.ngfs.net/ngfs-scenarios-portal/.

[6]Retail loans consists of housing loans and consumer loans provided to households, sole traders and non-profit organizations serving households.

3.1. Household Credit Risk

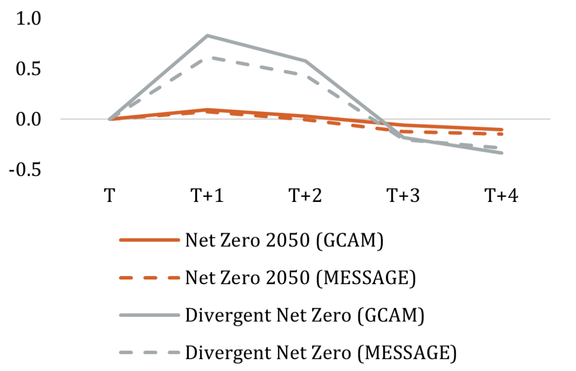
Individual, micro-level data on loans granted to households, collected by the National Bank of Slovakia (NBS) for supervisory purposes, are utilized to assess the impact of the scenarios on household credit risk. A comprehensive description of this data can be found in Klacso (2023). A table summarizing some of the key variables available in the database is provided in Appendix A.

To estimate the effects of macroeconomic scenarios using this data, it is necessary to establish a framework that links macro scenarios with micro data. Such a framework for translating macroeconomic variables, such as the unemployment rate, into micro-level household data, like income drop at a household-member level, was first developed for selected large European Union (EU) countries by Gross and Población (2017). The framework was subsequently enhanced and expanded to encompass other EU countries, as described in Ampudia et al. (2021). Jurca et al. (2020) further adapted the framework to examine the impact of borrower-based measures using data from the Household Finance and Consumption Survey (HFCS). While many of these studies rely on survey-based data, the framework can be reshaped and applied to individual-level loan data, as demonstrated in Klacso (2023) for stress testing purposes. In this paper, we employ the latest version of the framework, which is specifically designed for stress testing purposes, with minor adjustments. Details of the methodology are described in Appendix B.

The unemployment rate is the primary macroeconomic driver of credit risk in our analysis. Under the *Net Zero 2050* scenario, the increase in the unemployment rate is minimal compared to the baseline. Thus, we can expect virtually no impact on credit risk relative to the baseline scenario. Conversely, under the Divergent Net Zero scenario, the increase is more pronounced, reaching approximately 60 basis points when using inputs from the MESSAGE model and around 80 basis points when utilizing inputs from the GCAM model. In both scenarios, the increase reaches it's peak one year after the initial shock. The reason behind these figures is varying success rates of substituting emissions-intensive sectors at the onset of the transition period. The substitution process is less efficient in the short run under the *Divergent Net Zero* scenario, leading to a temporary rise in the unemployment rate (Chart 6).

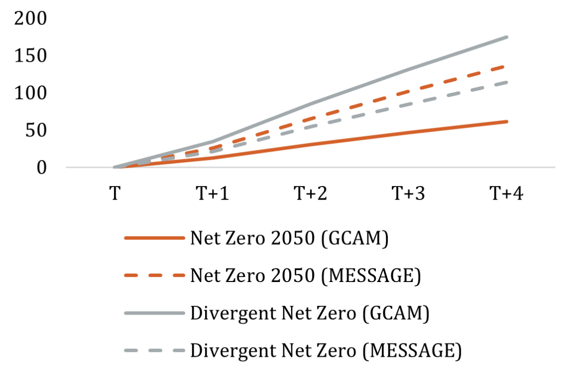
Increasing unemployment rate directly affects households with debt. When individuals within indebted households lose their jobs, their income suffers a shock. For households where this income shock is significant, meeting their monthly loan payments can become challenging, potentially leading to loan defaults. When calculating household cash flow, we consider both monthly loan payments and minimum living costs. Addi-

Chart 6: **Unemployment rate relative to baseline scenario (in p.p.)**



Source: NGFS, Authors' own calculation.
Note: IAMs used to derive the respective scenario are in brackets.

Chart 7: **Gas prices relative to baseline scenario (in %)**



Source: NGFS, Authors' own calculation.
Note: IAMs used to derive the respective scenario are in brackets.

tionally, households have the option to utilize their financial assets to meet their obligations. In cases of loan default, the value of collateral is considered, if applicable. As the scenarios used in this study do not incorporate a substantial increase in physical risks, such as floods or droughts resulting from global warming, we do not anticipate a decline in collateral value due to these factors. Further details regarding the assumptions underlying our calculations of Loss Given Default (LGD) and Probability of Default (PD) are described in Appendix B.

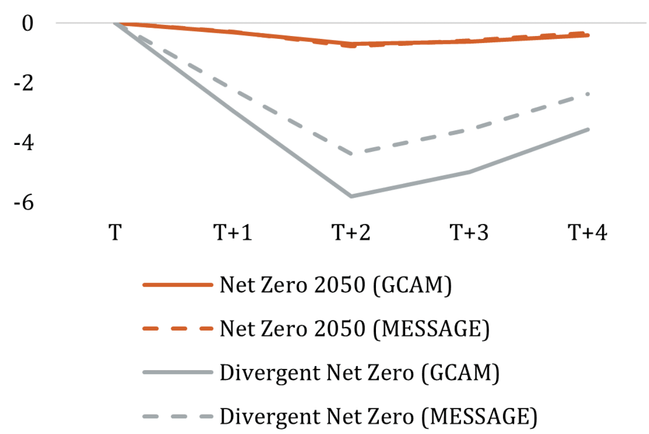
Although the scenarios generally do not contain a significant increase in inflation, we are considering the possibility of higher energy prices at the initial stages of the transition period. This serves as a sensitivity analysis to illustrate how the outcomes of the base setup could change if the transition is not smooth and households temporarily face higher energy costs. The sensitivity analysis is based on the rise in gas prices relative to the baseline scenario (Chart 7)[7]. We assume that household energy prices may increase by 20%, 50%, or 100% of the projected increase in gas prices. As the retail loan database does not contain details on households' energy-related expenditures, we calibrate these costs using data from the Household Budget Survey. We estimate energy costs through a simple regression analysis by utilizing variables available in both the retail loan database and the survey (such as the age of the reference person, number of household members, and annual income).

[7]While oil price is also available within the scenarios, in general the relative changes compared to the baseline are comparable. The price of gas is in the baseline scenario for GCAM 42.6 in the base year and 42.6, 42.7, 43.5, and 44.2 USD/barrel (eq.) in the first four years of the stress scenario.

3.2. Non-Financial Corporations Credit Risk

To evaluate the impact of the scenarios on NFCs credit risk, we utilize company-level data from AnaCredit that provides information on Slovak banks' exposures to NFCs, and FinStat that offers insights into the profitability of these companies. While the unemployment rate serves as the primary driver for assessing household credit risk, for NFCs, we assume that changes in companies' revenues will be linked to the development of GDP relative to the baseline scenario (Chart 8). The deviation from the baseline scenario under the *Net Zero 2050* scenario is relatively minor, similar to the unemployment rate, under both IAMs. However, in the case of the *Divergent Net Zero* scenario, the impact is more substantial, with the largest effect observed in the second year of the transition period. Using GCAM inputs, the impact reaches nearly -6%, whereas MESSAGE inputs result in a decrease of over -4%.

Chart 8: **GDP relative to the baseline scenario (in %)**



Source: NGFS, Authors' own calculation.
Note: IAMs used to derive the respective scenario are in brackets.

To capture the negative impact of the scenarios on GDP, which is primarily driven by the shock to emission prices, we consider that high-emitting companies and sectors will be more affected by the scenarios[8].

To incorporate this aspect, we calculate the transition vulnerability factor (TVF) for

[8] In the case of the NGFS scenarios used in this analysis, the drop in GDP is caused by an increased effective carbon tax rate. In general, the impact of increased emission costs can have both upward and downward effect on firms. The affected companies would need to increase prices of their products, which would however increase their gross revenues amid the increase of their costs of production. Normally (if companies use percentage mark-ups over costs to price products) this would actually increase net revenues (rather then decrease). At the same time, however, high prices and the availability of greener substitutes would decrease the demand for such pricey products and would lead to a decrease in sales and revenues. In the NGFS scenarios, as there is a negative initial impact of the implemented policies on the economy, the negative effect clearly prevails.

each sector following a similar methodology as outlined in Vermeulen et al. (2018). The TVF represents the emissions produced and owned by the company [9] and penalizes energy-intensive sectors more heavily. Further details about the calculation of TVFs can be found in Appendix C.

In the case of Slovakia, the three most energy-intensive sectors are the manufacture of basic metals, the manufacture of other non-metallic mineral products, and the manufacture of fabricated metal products, except machinery and equipment. The estimated TVFs for Slovak corporate sectors are provided in Appendix D.

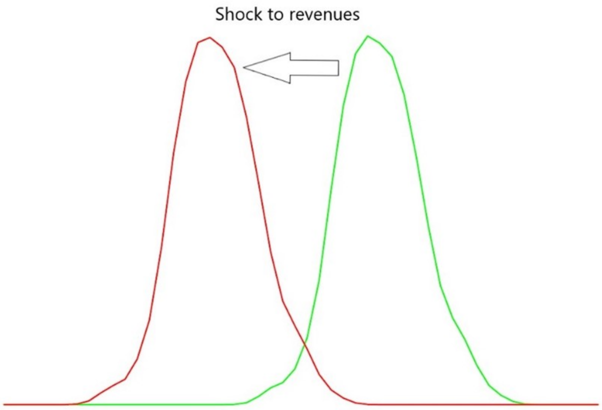
We assume that the sector-level shock, derived from the shock to GDP growth adjusted by the TVF, directly affects corporate revenues. For each sector, the annual change in corporate revenues is adjusted by the difference between the annual change in GDP under each scenario and the annual change in GDP under the baseline scenario, additionally adjusted by the TVF. The impact of the GDP shock on corporate revenues is calculated as follows:

$$\Delta Revenue_{shock,\,i,\,t} = (\Delta GDP_{scenario,\,IAM,\,t} - \Delta GDP_{baseline,\,t}) \times TVF_i \tag{1}$$

Where i represents the respective sector, $\Delta Revenue_{shock,\,i,\,t}$ denotes the shock to the annual revenue growth of sector i in year t, $\Delta GDP_{scenario,\,IAM,\,t}$ represents the annual GDP growth in year t under the respective scenario using the respective IAM, and $\Delta GDP_{baseline,\,t}$ corresponds to the annual GDP growth under the baseline in year t. This adjustment accounts for changes in the entire revenue distribution within each sector (Chart 9). Additionally, it is assumed that firms' costs will change to reflect the expected inflation under each scenario.

[9] Scope 1 are "direct" emissions – those that a company causes by operating the things that it owns or controls. Scope 2 are "indirect" emissions created by the production of the energy that an organization buys. See: https://www.weforum.org/agenda/2022/09/scope-emissions-climate-greenhouse-business/

Chart 9: **Transmission of the GDP shock into the revenues of the corporates - scheme**



Note: Illustrative distribution shift.

There are two factors that affect the profitability of firms: an increase in input costs and a decrease in sales revenues[10]. Historical evidence indicates that companies can adjust their sales and revenues in response to rising costs. Yet, the extent of this adjustment differs among firms. The ability of companies to withstand such shocks depends on their financial situation. Profitable firms can offset these shocks through their profit margin, but those with insufficient profit margin may incur losses, leading to a decline in their equity capital. We define exposures at risk[11] as exposures to firms that may incur negative equity resulting from credit losses during the analyzed period[12]. The objective of the simulation is to identify firms at risk[13]. Defaulting firms are selected from this pool of firms at risk based on the assumed cumulative aggregate probability of default (PD) of the sector, scaled to the PD during the Great Financial Crisis. Further details on the methodology and assumptions are provided in Appendix E. Similar to households, a sensitivity analysis is carried out for the NFC sector, based on the assumed increase in energy prices.

4. RESULTS

[10]This adjustment considers only revenues from sales and input costs; other components of the Profit and Loss statement are held constant.

[11]In addition to loans, exposures include off-balance-sheet items such as undrawn credit lines, authorized overdrafts, guarantees, and loans that have been granted but are not yet drawn, with a conversion factor of 5%.

[12]Solvency-strengthening measures available to firms or provided by the government are not taken into account.

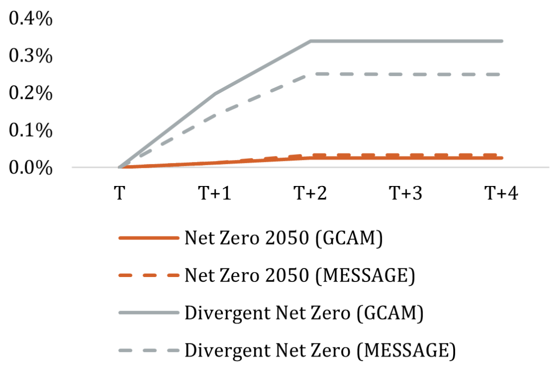
[13]Default rates are estimated from loans at risk, assuming that companies generating a profit after the shock and meeting their debt payments will not default.

4.1. Households Credit Risk

The results of the analysis confirm the anticipated mild impact of the *Net Zero 2050* scenario under both IAMs. The estimated increase in non-performing loans amounts to nearly 15 million EUR using MESSAGE inputs and approximately 18 million EUR using GCAM inputs, relative to the baseline. However, this increase remains below 0.1% of the total outstanding amount of retail loans (Chart 10).

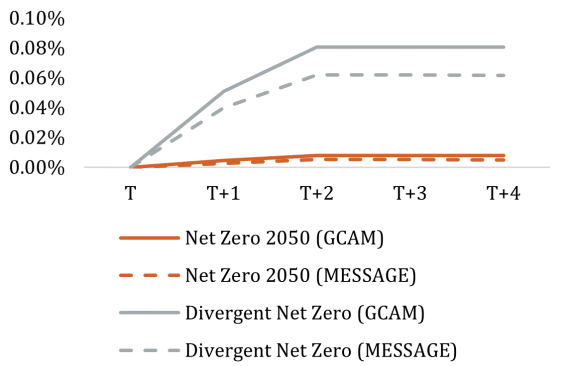
In contrast, the estimated impact is significantly higher under the *Divergent Net Zero scenario*. Non-performing loans increase by nearly 92 million EUR (0.2% of outstanding loans) using MESSAGE inputs and over 115 million EUR (0.3%) using GCAM inputs, relative to the baseline. As most retail loans are collateralized by residential real estate, assuming no change in collateral results in considerably lower credit losses compared to the volume of non-performing loans (Chart 11).

Chart 10: **Estimated development of NPLs**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

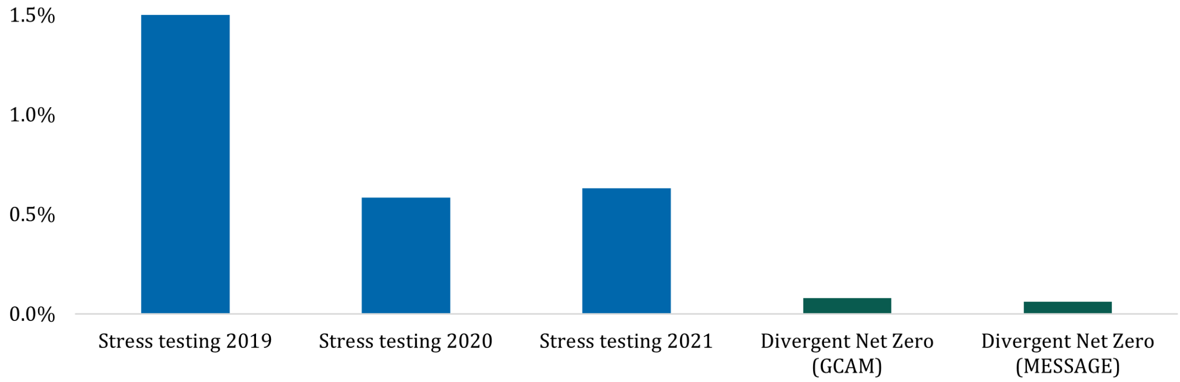
Chart 11: **Estimated development of credit losses**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

To provide context for these results, we compare them with the outcomes of conventional stress testing exercises (Chart 12). Although these exercises differ in terms of the underlying risks associated with the scenarios, they offer a broad perspective on the impact of climate scenarios. The most recent stress testing exercise unaffected by COVID or rising inflationary pressures, conducted in 2019, resulted in the highest credit losses under the adverse scenario compared to the baseline. Adverse scenarios in the 2020 and 2021 stress testing exercises resulted in significantly lower credit losses. Nevertheless, even these credit losses exceed the credit losses estimated under the *Divergent Net Zero* scenario. This finding indicates that the credit losses banks would face due to transition risks are considerably lower than those under a severe but still plausible macroeconomic scenario.

Chart 12: **Credit losses of the Divergent Net Zero scenario compared to conventional stress testing**

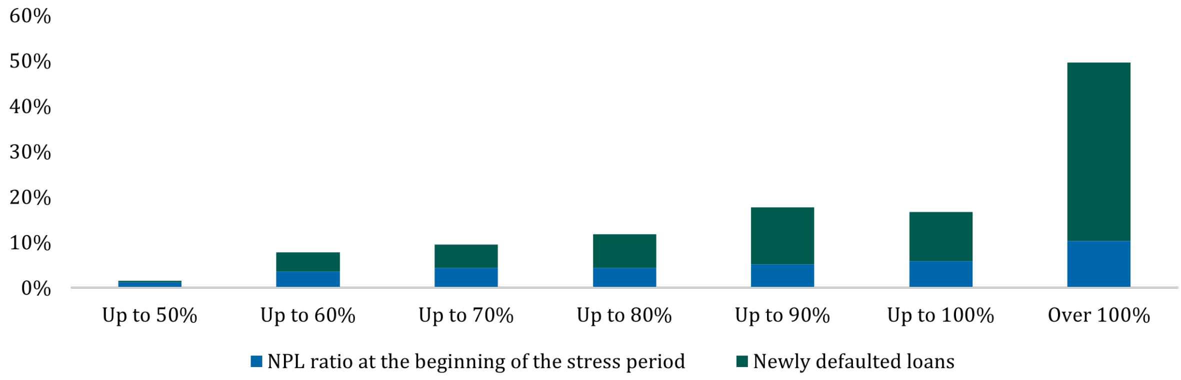


Source: NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

As there can be some heterogeneity of the credit risk among different types of households, we provide the distribution of the impact of the scenarios based on different household characteristics. We provide the breakdown of the results of the *Divergent Net Zero* scenario using MESSAGE inputs[14]. Chart 13 shows the impact of the scenario for different DSTI buckets. As expected, the impact is more severe for households having higher DSTI before the shock. These households generally have a smaller buffer from their monthly income to save, therefore even a minor drop in their income can result in default. Chart 14 shows the impact based on different level of education. Although there is a considerable heterogeneity in the stock of NPLs, there is no substantial increase in neither of the categories due to the relatively mild unemployment shock. The increase of NPLs is the lowest among households where at least one member has tertiary education (0.73 percentage points), while in case of primary and secondary education the results are comparable (0.82 vs 0.86 percentage points). The increase of NPLs is higher among single borrowers (Chart 15). In case of two or more co-borrowers, there is probably more space to loose job or to face a drop of income of some of these borrowers, while in case of a single borrower loosing a job will lead to default with a higher probability.

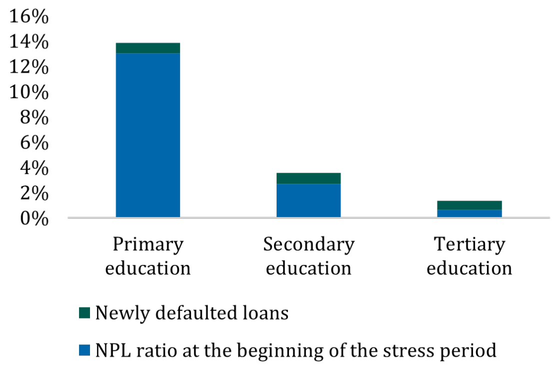
[14]The relative difference based on these distributions would be very similar for other scenarios or other IAM models, therefore we do not show them in the paper.

Chart 13: **Household NPLs - breakdown based on DSTI brackets**



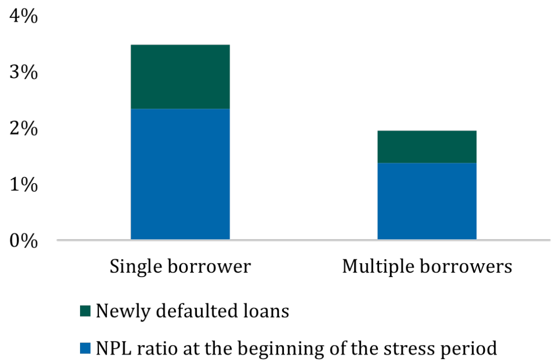
Source: NBS, Authors' own calculation.
Note: Results based on MESSAGE.

Chart 14: **Household NPLs - breakdown based on Education**



Source: Authors' own calculation.
Note: Results based on MESSAGE.

Chart 15: **Household NPLs - breakdown based on the number of borrowers**

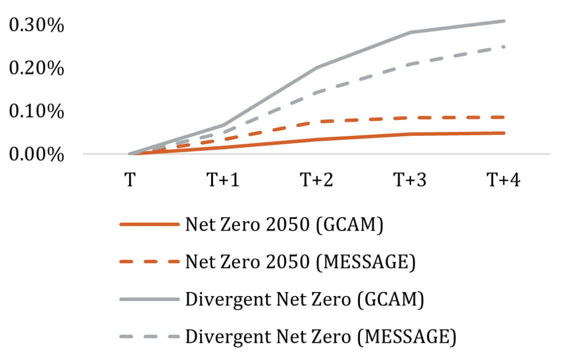


Source: Authors' own calculation.
Note: Results based on MESSAGE.

4.2. Non-Financial Corporations Credit Risk

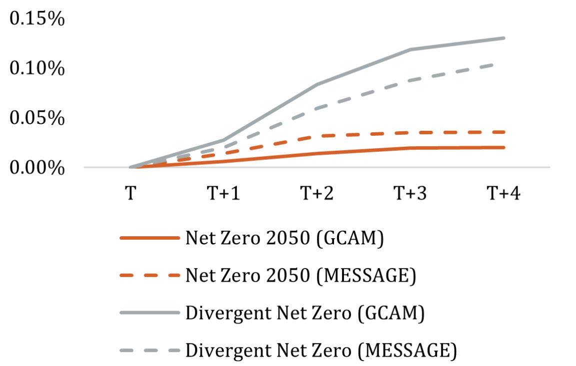
The results of the NFC loan portfolio largely align with those of the retail loan portfolio. Under the *Net Zero 2050* scenario, non-performing loans exhibit only a modest increase relative to the baseline, amounting to up to 9 million EUR using GCAM inputs (less than 0.1% of the outstanding loan amount (Chart 16) and more than 16 million EUR using MESSAGE inputs (0.1% of the outstanding loan amount). In the case of the *Divergent Net Zero* scenario, the increase is considerably higher, reaching 60 million EUR (0.3%) using GCAM inputs and nearly 48 million EUR (0.2%) using MESSAGE inputs. Credit losses resulting from non-performing loans align with the assumed Loss Given Default (LGD) of 45% for non-guaranteed loans and 10% for guaranteed loans (Chart 17).

Chart 16: **Estimated development of NPLs**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

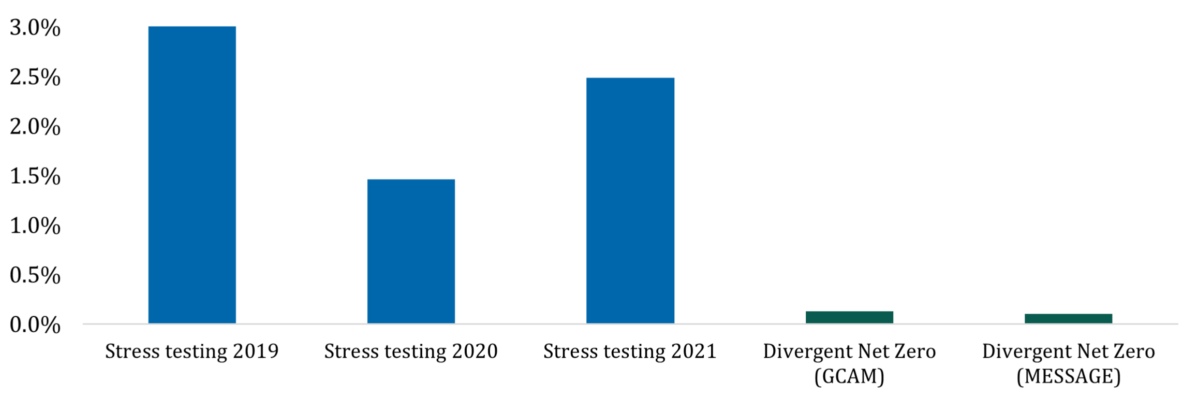
Chart 17: **Estimated development of credit losses**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

Again, we can compare the results to those of conventional stress testing (Chart 18). Relative to the baseline, credit losses estimated under the adverse scenario are considerably higher in conventional stress testing (from 2019) and in stress testing affected by COVID (2020) or increasing inflationary pressures (2021). Considering our focus on transition risks, we can perceive this outcome as positive. It is important to note that ideally, to reach net zero emissions, the global economy should be on the transition path. Therefore, this path or scenario should be integrated into any economic forecast, and therefore, the results of such exercise should be incorporated even into the baseline scenario of conventional stress testing.

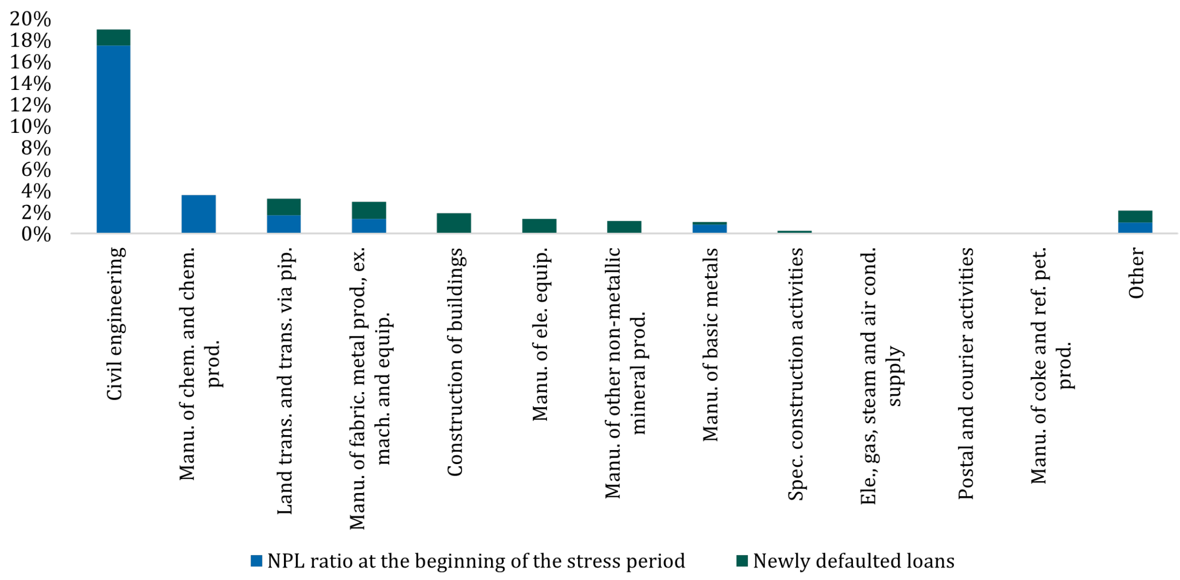
Chart 18: **Credit losses of the Divergent Net Zero scenario compared to conventional stress testing**



Source: NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

There can be substantial heterogeneity of the impact of the shock accross various NPL sectors. One obvious reason is the differentiation of the GDP shock between the sectors based on their emission intensity captured by the TVF. Chart 19 and Chart 20 show the distribution of NPLs among the first 12 emission intense sectors for large and medium firms as well as for small and micro-enterprises, respectively. The charts display the result of the *Divergent Net Zero* scenario using MESSAGE inputs. In general, these more emission intense sectors face higher NPL increases in comparison to the remaining NFC loan portfolio. The increase of NPLs is higher for small and micro- compared to large and medium enterprises, as they are in general more risky and face higher probabilities of default even in case of conventional stress testing.

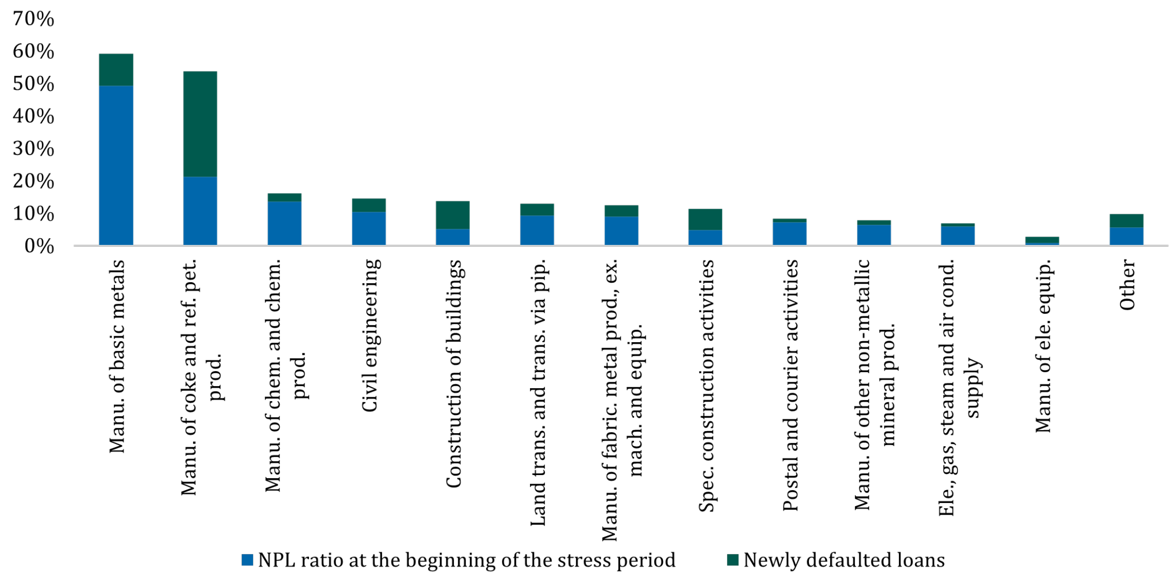
Chart 19: **NPLs ratios of NFC sectors with the highest TVFs - large and medium enterprises**



Source: NBS, Authors' own calculation.

Note: Results based on MESSAGE.

Chart 20: **NPLs ratios of NFC sectors with the highest TVFs - small and micro enterprises**



Source: NBS, Authors' own calculation.

Note: Results based on MESSAGE.

4.3. Sensitivity Analysis

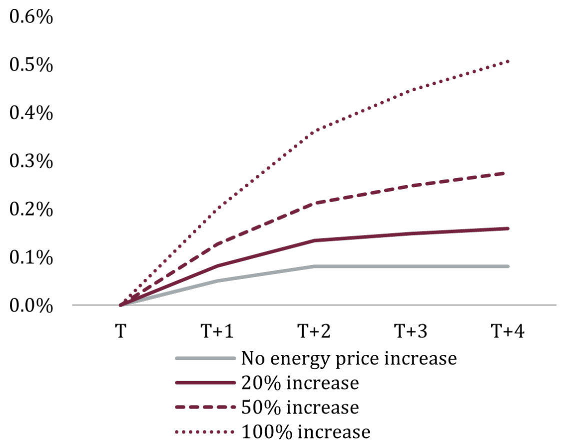
Scenarios that focus on transition risks typically anticipate short-term negative shocks at the global economic level. However, these shocks tend to dissipate relatively quickly, facilitating a smoother overall transition. Nevertheless, there may be obstacles at the regional level that impede the desired smoothness of the transition process. Some states or regions may suffer more significant impacts on local businesses, and some energy suppliers may need more time to adapt efficiently. Consequently, these factors can contribute to potentially increased economic losses at the local level. In the following subsections, we will explore several possible causes behind these increased economic losses and discuss their implications for credit risk.

4.3.1. Increase of energy prices

Although transition risk scenarios anticipate higher emission prices, the overall inflation remains low due to the substitution with alternative energy sources. However, in the short term, such substitution may not occur quickly or effectively enough. Therefore, in this section, we conduct a sensitivity analysis to explore the potential impact of energy price increases on households and NFCs. As outlined in the methodology section, we assume energy prices to increase by 20%, 50%, and 100% of the expected gas price increase, respectively. It is important to note that although an increase in energy prices leads to higher overall inflation, this paper does not estimate the exact impact of energy price increases on inflation. We use different energy price increase scenarios instead to broadly understand how credit risk is affected by rising prices.

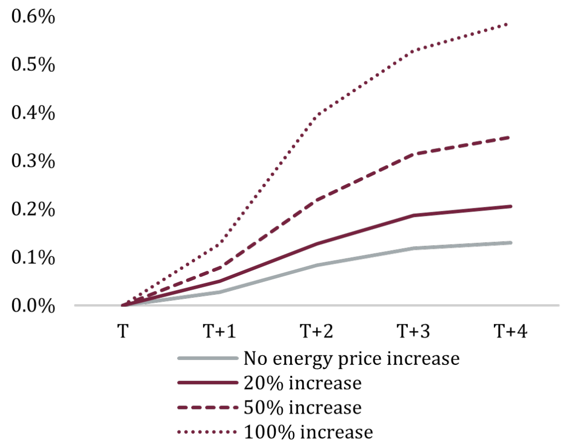
We present the results for the *Divergent Net Zero* scenario using GCAM inputs, as this specification leads to the most substantial credit losses. The findings are remarkably similar across sectors. Both households (Chart 21) and NFCs (Chart 22) demonstrate sensitivity to energy price increases. While under the base scenario of no energy price increase, the share of credit losses relative to the baseline is approximately 0.1% for both sectors, considering a complete transmission of gas price increase to energy prices (100% scenario) raises this share significantly, to almost 0.6% for both sectors.

Chart 21: **Increasing energy prices - credit losses from loans to households**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

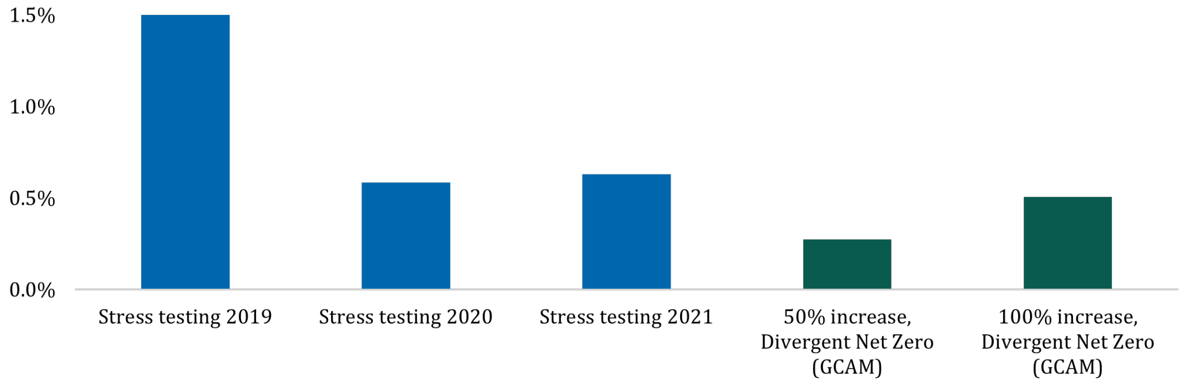
Chart 22: **Increasing energy prices - credit losses from loans to NFCs**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

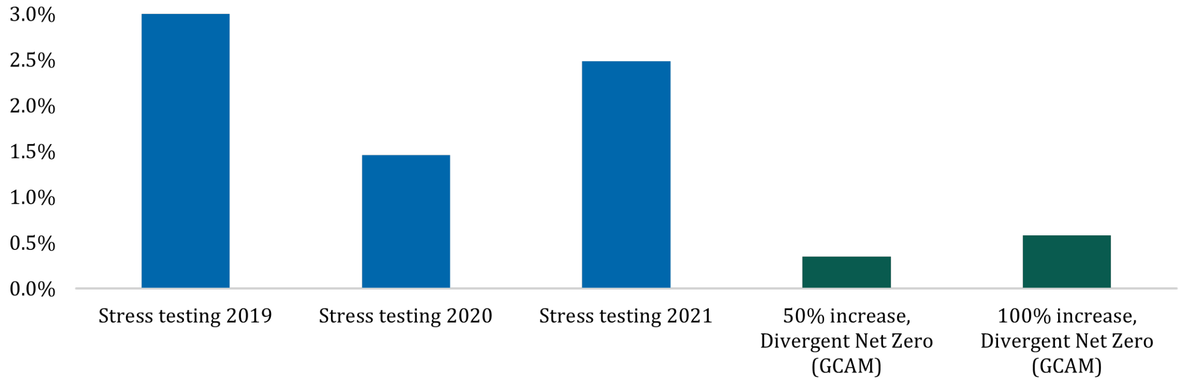
Despite still being lower compared to the results of conventional stress testing, these credit losses are much closer to the most recent stress testing outcomes, particularly for households (Chart 23). Concerning corporates, conventional stress testing still results in significantly higher credit losses (Chart 24). There could be several reasons for this discrepancy. First, conventional stress testing generally encompasses a broader range of risks. Second, while the direct exposure of banks to energy-intensive firms (which are also the most vulnerbale to energy price increases) is relatively low (Národná banka Slovenska, 2021b), the household sector demonstrates a more homogeneous response to different shocks.

Chart 23: **Increasing energy prices vs. conventional stress testing – credit losses from loans to households**



Source: NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

Chart 24: **Increasing energy prices vs. conventional stress testing – credit losses from loans to NFCs**

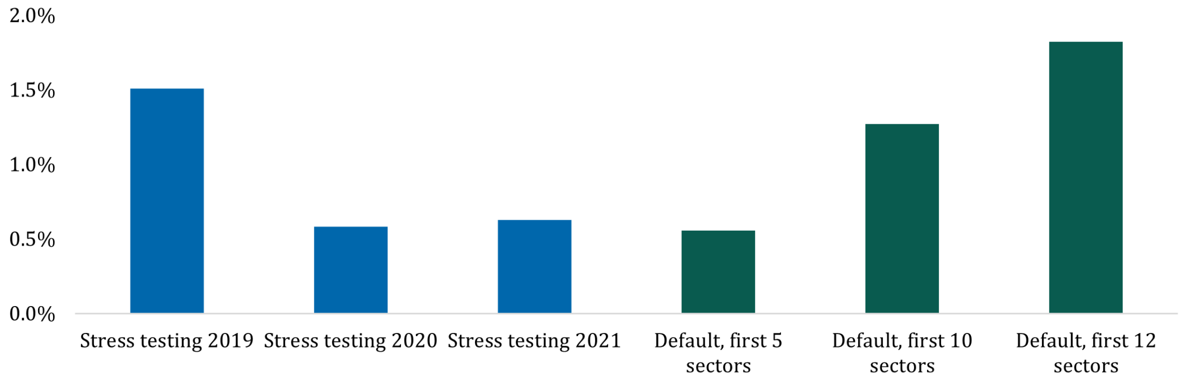


Source: NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

4.3.2. Problems in emission-intensive sectors

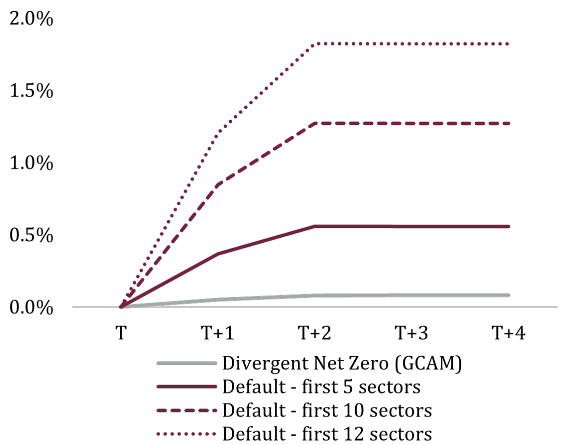
The substitution between brown and green sectors may appear smooth at the global level, but this can mask discrepancies at the local level. Therefore, in this subsection, we provide a sensitivity analysis of potential loan losses due to higher defaults in more emission-intensive sectors.

Chart 27: **Default of emission-intensive sectors vs. conventional stress testing – credit losses from loans to households**



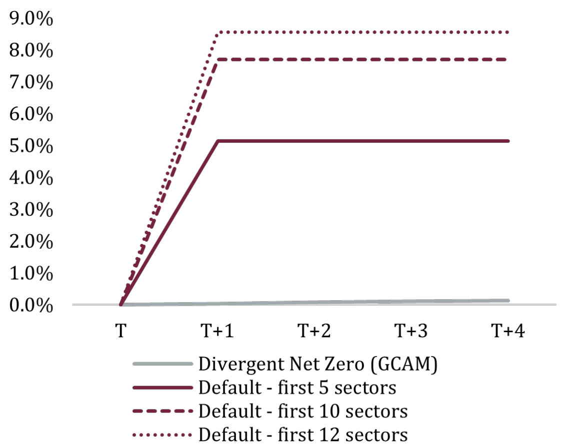
Source: NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

Chart 25: **Default of emission-intensive sectors - credit losses from loans to households**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

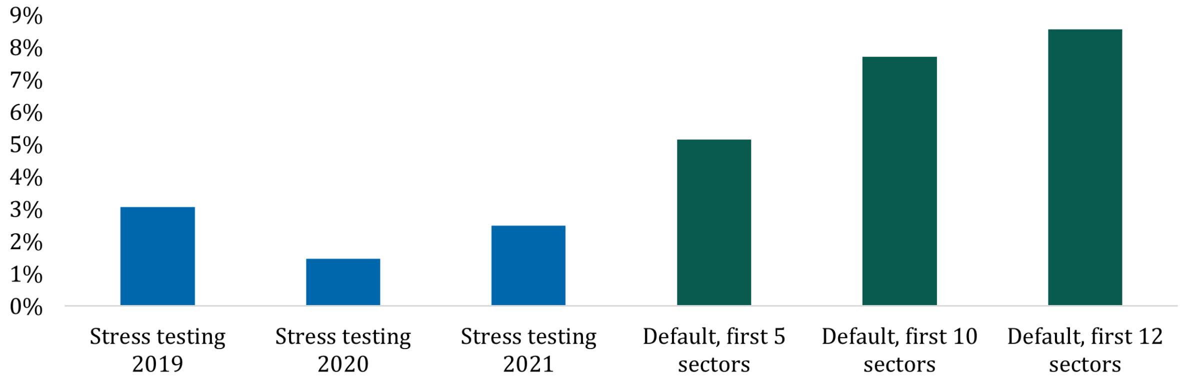
Chart 26: **Default of emission-intensive sectors - credit losses from loans to NFCs**



Source: Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

The selection of sectors for analysis is based on their scope 1 and scope 2 emission-intensity, which is translated into a transition vulnerability factor provided for Slovak economic sectors in Appendix D. The share of the five most energy-intensive sectors in the banks' NFC loan portfolio is 17.0%, while their share in total employment is 6.7%. The corresponding shares for the top ten sectors are 24.0% and 14.4%, respectively, and for the top twelve sectors, they are 26.7% and 21.1%, respectively (including the Special construction activities sector). It is important to note that not all loans in these sectors will default, and not all employees will become unemployed. However, there is a

Chart 28: **Default of emission-intensive sectors vs. conventional stress testing – credit losses from loans to NFCs**



Source: NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans.

risk of contagion that may affect firms in other sectors linked to these emission-intensive sectors. Therefore, in this subsection, we present the results as a default risk equivalent to the share of these emission-intensive firms in NFC loans for corporate credit risk and as a default risk equivalent to the share of these sectors in total employment for household credit risk[15].

Due to the considerable share of these sectors in both the volume of NFC loans and total employment, losses from both corporate (Chart 26) and household credit risk (Chart 25) would be substantially larger compared to the basic results presented earlier in this section. Credit losses from loans granted to households would increase proportionally with each additional potentially affected sector. For instance, under a default equivalent to the top twelve most emission-intensive sectors, credit losses from household loans would reach nearly 2% of the total loan amount (compared to the baseline), surpassing even the credit losses estimated in conventional stress testing (Chart 27).

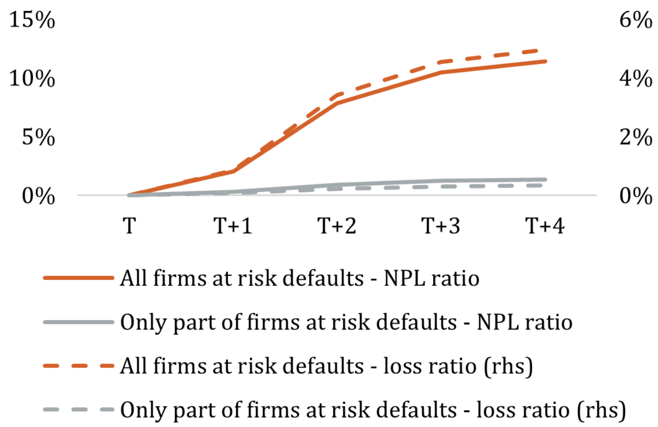
Regarding corporate loans, credit losses would be substantial even under a default equivalent to the top five sectors (Chart 28). As the number of affected sectors increases, credit losses would naturally escalate, with the outcome of even the top five sectors scenario exceeding the typical credit losses estimated under adverse stress testing scenarios.

[15] As we do not have data about exposures within NFCs at the individual level, we are not able to model the contagion between firms in case of a default. Therefore, possible non-linear contagion effects are not captured.

4.3.3. Higher default rate of firms with negative equity

According to the methodology, it is assumed that not all firms at risk will default. However, as all these firms would experience negative equity due to increasing costs and declining revenues, they represent significant risks to the banks even if they do not default. To illustrate the overall exposure at risk of default due to negative developments, we present the development of the non-performing loan (NPL) ratio and credit losses relative to the loan volume if all exposed loans ended up defaulting. These results are shown for the *Divergent Net Zero* scenario using GCAM inputs and the 100% increase scenario for energy prices, as this combination results in the highest credit losses. Overall, both the NPL ratio and credit losses would be significantly higher (Chart 29). The NPL ratio would soar from 1.4% to 11.4% (relative to the baseline), and the ratio of credit losses to the loan volume would surge from 0.3% to 5.0%.

Chart 29: **Sensitivity analysis – all firms at risk default**



NBS, Authors' own calculation.
Note: All results are provided relative to the baseline, as a percentage of the outstanding amount of loans. We represent GCAM climate scenarios.

Although the overall outcome of the basic setup appears to be relatively benign, the sensitivity analysis reveals that this conclusion is highly dependent on the assumption of a smooth transition to less fossil-fuel-intensive energy sources. If this assumption proves inaccurate at the local level, with rising energy prices or increased defaults in energy-intensive sectors, banks will face higher credit risk associated with loans extended to households and firms.

This finding is crucial as it emphasizes the necessity of integrating risk analysis based on transition paths even into the baseline scenarios of conventional stress testing. The credit risks faced by banks can escalate significantly under a non-coordinated transition towards a sustainable global economy.

5. Conclusion

Global warming and the necessary transition towards a carbon-neutral economy pose an ever-growing risk to human society, economic activities, and financial stability. Central banks and regulatory authorities are increasingly focusing on understanding the impact of climate risks on the financial sector.

We assess the indirect impact of transition risks on the Slovak banking sector through the credit risk channel, with a specific focus on households and non-financial corporations. We utilize two scenarios provided by the Network for Greening the Financial System (NGFS), which encompass different assumptions regarding the policy response to climate change. Furthermore, we incorporate these scenarios into our internal conventional stress testing framework.

The expected impact on economic growth and unemployment is negligible under the *Net Zero 2050* scenario characterized by a smooth transition. As a result, households and non-financial corporations encounter negligible losses compared to the baseline scenario. In contrast, credit risk losses are significantly higher under the *Divergent Net Zero*, which involves a non-coordinated approach. This is due to temporarily higher unemployment rate and a larger decline in GDP adjusted for emission production among non-financial corporations. Nonetheless, it is important to note that credit risk losses remain significantly lower than those observed in adverse scenarios derived from conventional stress testing even in this scenario. This outcome can be partially attributed to the mild shocks driving both climate scenarios.

Assumptions regarding the smooth substitution to lower emission-intensive sectors affect the results significantly. Credit losses would be substantially higher if the substitution process is less smooth, resulting in higher energy prices or increased defaults among emission-intensive firms. Although it is feasible to estimate loans at risk for non-financial corporations, accurately predicting defaulted loans poses challenges. Credit losses faced by banks would significantly increase if all loans at risk defaulted.

Although we provide insights into the potential impact of transition risks on credit risk in the banking sector, there are numerous avenues for future research. Transition risks affect other financial institutions as well and have implications for different types of risks within the banking sector. Ongoing research at the National Bank of Slovakia is aimed at quantifying the impact of physical risks on the real economy and the financial sector to a certain extent.

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A. Appendix

Table 2: Main variables available in the retail loan database

Type of information	Data item	Description
Information at the granted date	Aim of the loan Granted and drawn amount of the loan Granted date Original maturity date Initial interest rate Initial monthly instalment	Information about whether it is a new loan, refinancing loan or renegotiated loan
Information at the reporting date	Outstanding amount of the loan Actual maturity date Actual interest rate Actual monthly instalment Actual interest rate fixation Date of the next re-fixation Days overdue Volume of provisions Default flag Forbearance	Dummy indicating whether the loan is at default at the time of reporting Dummy indicating whether any changes in the loan contract have been realised due to the credit quality (forbearance)
Information about the debtor / household at the granted date	Education of the first and second (if exists) debtor Minimum subsistence amount Income of the debtors Income source of the debtors Financial assets of the debtors Overall debt of the debtors at the granted date Overall monthly instalment of the debtors at the granted date DTI at the granted date DSTI at the granted date	Primary, secondary or higher level of education Minimum subsistence amount of the household that is used for the calculation of DSTI 3 (consumer loans) or 6 (housing loans) month average of net income Employee, self-employed or other Financial assets of the debtor at the reporting bank or at the asset management company held by the bank The volume of all loans granted to the debtors
Information about the collateral (if exists)	Number of collateral Region Collateral value entering the calculation of LTV Different measures of the collateral value LTV at the granted date LTV at the reporting date Date of the last revaluation of the collateral	Region of the collateral Market value, internal value (set by the bank), external value (external appraisal)

Source: NBS

B. Appendix

The macro-level increase in the unemployment rate is translated into individual retail loan data using a similar approach as in Klacso (2022). Specifically, a logit model is employed to estimate the probability of employment or unemployment for each debtor annually, based on socio-demographic factors such as sex, education, marital status, type of activity (employed or self-employed), and age. To ensure consistency with the respective scenario's unemployment rate, the model's intercept is adjusted so that the average probability of becoming unemployed each year in the sample matches the end-of-year unemployment rate. Using these adjusted probabilities, debtors' job losses are simulated using Monte Carlo simulations.

When debtors lose their jobs, they experience a negative income shock. However, since the retail loan data only provides information about debtors' income at the time of loan origination, the first step is to update all debtors' income to reflect the year 2021. Aggregate data from the Social Insurance Agency in Slovakia is utilized for this purpose. Since 2013, annual data has been available on income changes by age and income cohorts, including income changes at the decile level within each cohort. The data is further segmented into individuals employed in both the given year and 2021, and those employed in the given year but unemployed in 2021. By doing so, the analysis captures the magnitude of the negative income shock for those who become unemployed, as well as potential income fluctuations at the individual level. This is important because household income generally increases at the macro level, with the exception of periods of stress like the Great Financial Crisis or the Covid pandemic, when net income can decline due to reduced working hours or lack of bonuses. However, income can fluctuate significantly at the individual debtor level.

To assess debtors' ability to meet monthly installment payments and expected minimum living costs, a household-level cash flow analysis is conducted. Since the retail loan database does not include information about households, approximations are made based on co-debtor information. The updated monthly income of all co-debtors, along with the value of their financial assets (limited to those held in the bank where debtors have a loan), are considered. On the cost side, monthly installment payments and minimum living costs, represented as 1.5 times the subsistence minimum for household members, are taken into account. This reflects the assumption that households can reduce their expenditure during financial stress, aligning with the way the Debt Service-to-Income (DSTI) limit is set by the National Bank of Slovakia[16].

[16] The DSTI limit uses as a denominator the income decreased by the subsistence minimum: https://nbs.sk/en/financial-stability/fs-instruments/dsti.

Overall, a household defaults on its debt when its monthly outflow exceeds its monthly inflow. This is expressed by the following equation:

$$\begin{aligned} PD_{\mathrm{t}} = 1 <=> \sum_{All\,loans} & Monthly\,instalments_{\mathrm{t}} + 1.5 \times Subsistence\,minimum \\ \geq \sum_{All\,household\,members} & Monthly\,net\,income_{\mathrm{t}} \\ + \sum_{All\,household\,members} & \frac{Financial\,assets_{\mathrm{t}}}{12} \end{aligned} \tag{2}$$

As is clear from the above formula, we assume the household can use its financial assets to compensate for the decrease in income. Based on the experience from the Great Financial Crisis, we assume if a household can withstand the shock for 12 months, it will not default. Moreover, this is also in line with the temporary nature of the increase in unemployment rate expected under the Divergent Net Zero scenario.

As shown in the equation, it is assumed that households can utilize their financial assets to compensate for the decrease in income. Drawing from the experience of the Great Financial Crisis, if a household can withstand the shock for 12 months, it is assumed that it will not default. This duration aligns with the temporary nature of the expected increase in the unemployment rate under the Divergent Net Zero scenario.

When a household is unable to meet its obligations, it is assumed that it defaults on the loan with the smallest outstanding amount. If other loans can still be paid, the household will do so. However, if there are insufficient funds to repay all loans, the household defaults on the loan with the second smallest outstanding amount, and this process continues until there is enough liquidity to repay the remaining loans or no loan remains. If a household has multiple loans in one bank, defaulting on any of these loans results in defaulting on all loans within that bank.

The loss given default is determined based on the collateral value, if available. Typically, Slovak households use real estate property as collateral for mortgage loans, making it the only type of collateral recorded in the retail loan database. When a household defaults on a mortgage loan, losses are calculated using the following formula:

$$Loss\ Given\ Default_{\mathrm{t}} = max(0, L_t - CV_t) + 0.1 \times L_t \tag{3}$$

Here, L_t represents the outstanding amount of the defaulted loan at the time of default, and CV_t denotes the indexed value of the collateral. The collateral value needs to be indexed since up-to-date values may not be available in all cases within the database.

Whenever possible, regional real estate price developments are taken into account. Additionally, a fixed cost of foreclosure, equivalent to 10% of the outstanding loan amount, is assumed. In cases where collateral value information is absent, the loss is estimated at 20% for mortgage loans and 80% for other types of loans. These values are derived from banks' internal reporting on provisioning.

C. Appendix

Energy transition risks will have a more significant impact on industries that heavily rely on fossil fuels. As a result, financial institutions' vulnerability to energy transition risks will vary depending on their exposure to industries with different levels of vulnerability. To capture this effect, a transition vulnerability factor (TVF) is calculated for each industry, as shown in Table 1. The TVF is based on the amount of CO_2 emissions associated with the production of final goods and services in each industry, considering both the industry's own emissions and the emissions of its suppliers, known as "embodied CO_2 emissions."

The World Input-Output Database (WIOD) provides annual input-output tables for 56 industries in 43 countries, covering the period from 2000 to 2014. Alternatively, the Trade in Value-Added (TiVA) database offers information on 36 industries in 64 countries for the period from 2005 to 2015. These tables are utilized to calculate the value-added content of final goods produced by each industry. To estimate the CO_2 emissions embodied in final goods, data from the EXIOBASE 2015 database of Eurostat, which provides information on industry-specific CO2 emissions, is employed. The transition vulnerability factor for sector *i* is calculated as follows:

$$TVF_{\mathrm{i}} = \left(\frac{\frac{CO_2\, total\ in\ final\ product}{VA_i}}{\frac{CO_2\, total}{VA\ total}} \right) \tag{4}$$

where VA_i represents value added in each industry while VA_{total} display total production. Same analogy applies for CO_2 variables.

This approach penalizes final goods and services that require substantial CO_2 emissions for their production, as it considers not only direct emissions but also emissions by firms upstream in the value chain.

For simplicity, it is assumed that the industry-specific TVFs are identical across countries. While this is a simplifying assumption, calculating TVFs at the country level could result in more volatile estimates when industries represent a relatively small share within certain countries.

The weighted average of TVFs for the global economy is equal to 1, with weights determined by the relative share of value added in each industry. This property ensures that the transition vulnerability factors are consistent with the aggregate stock market return, assuming that the composition of the stock market index aligns with the industry composition in the real economy.

D. Appendix

Table 3: Estimated Transition vulnerability factor for Slovak corporate sectors

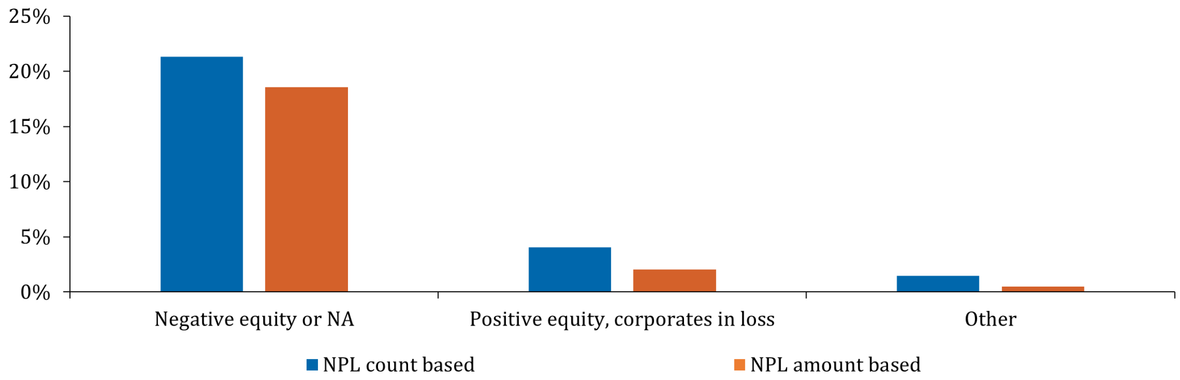
Sector	TVF
Manufacturing and basic metals	7.52
Manufacture other non-metallic mineral products	4.52
Manufacture of fabricated metal products, except machinery and equipment	3.54
Electricity, gas, steam and air conditioning supply	3.47
Manufacture of chemicals and chemical products	3.38
Manufacture of coke and refined petroleum products	2.41
Land transport and transport via pipeline	2.38
Manufacture of electrical equipment	2.37
Postal and courier activities	2.23
Construction	2.07
Manufacture of machinery and equipment n.e.c.	1.95
Manufacture of rubber and plastic products	1.91
Manufacture of other transport equipment	1.83
Air transport	1.79
Manufacture of motor vehicles, trailers and semi-trailers	1.70
Manufacture of basic pharmaceutical products and pharmaceutical preparations	1.47
Manufacture of paper and paper products	1.44
Manufacture of furniture; other manufacturing	1.34
Water transport	1.16
Sewerage, waste management, remediation activities	1.14
Manufacture of computer, electronic and optical products	1.14
Activities of extraterritorial organisations and bodies	1.10
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.97
Printing and reproduction of recorded media	0.97
Repair and installation of machinery and equipment	0.96
Manufacture of textiles, wearing apparel, leather and related products	0.96
Manufacture of food products; beverages and tobacco products	0.93
Water collection, treatment and supply	0.91
Mining and quarrying	0.91
Warehousing and support activities for transportation	0.80
Crop and animal production, hunting and related service activities	0.70
Legal and accounting activities; activities of head offices; management consultancy activities	0.68
Accommodation and food service activities	0.63
Other professional, scientific and technical activities; veterinary activities	0.59
Other service activities	0.52
Human health and social work activities	0.52
Administrative and support service activities	0.51
Public administration and defence; compulsory social security	0.51
Fishing and aquaculture	0.49
Wholesale and retail trade and repair of motor vehicles and motorcycles	0.46
Forestry and logging	0.46
Scientific research and development	0.45
Wholesale trade, except of motor vehicles and motorcycles	0.42
Advertising and market research	0.40
Telecommunications	0.40
Education	0.40
Architectural and engineering activities; technical testing and analysis	0.39
Retail trade, except of motor vehicles and motorcycles	0.36
Computer programming, consultancy, and information service activities	0.34
Real estate activities	0.31
Motion picture, video, television programme production; programming and broadcasting activities	0.30
Publishing activities	0.30
Financial service activities, except insurance and pension funding	0.25
Activities auxiliary to financial services and insurance activities	0.24
Insurance, reinsurance and pension funding, except compulsory social security	0.24
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.05

Source: Authors' own calculation based on Vermeulen et al. (2021)

E. Appendix

The estimation of firms defaulting on their loans is based on the projected pool of firms that are expected to have negative equity as a result of increased costs, decreased revenues, and loan payments. Historical data indicates that reporting negative equity does not necessarily imply loan default for non-financial corporations. However, firms with negative equity have a significantly higher default rate compared to other firms (Chart 30).

Chart 30: **NPL ratio in different categories of corporates**



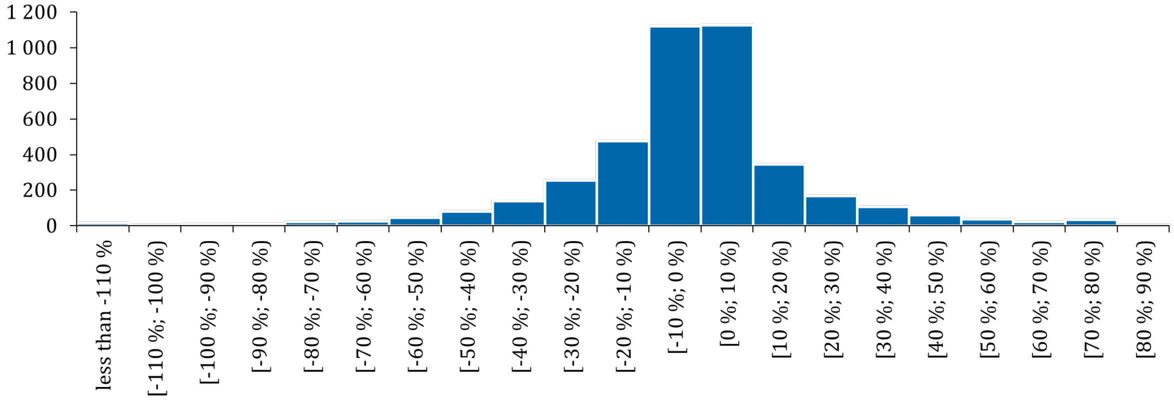
Source: NBS, Authors' own calculation.
Note: Figures based on data as of end 2021.

When estimating the number of firms with negative equity, it is assumed that firms can adjust their revenues in response to changes in costs. However, this adjustment is not a one-to-one relationship (Chart 31), and the exact adjustment cannot be determined for all firms since the distribution of past adjustments is only available for a subset of firms.

The distribution of past adjustments is utilized to estimate the magnitude of adjustments at the firm level. To map the distribution to individual firms, 1,000 Monte Carlo simulations are conducted, randomly assigning a size of adjustment to each firm in each simulation. Then, the median exposure at risk is calculated.

The cumulative aggregate default rate within the simulation horizon is assumed to be similar to the rate observed in 2009 during the peak of the Global Financial Crisis in Slovakia, which exceeded 3%. Under the baseline scenario, the cumulative aggregate probability of default (PD) is assumed to be 3%. Default rates vary across firm size categories and are scaled based on the baseline scenario. The estimated default rate for micro enterprises is approximately 40%, around 15% for small and medium-sized enterprises (SMEs), and approximately 6% for large enterprises. In the event of firm default, all its loans are considered in default. The scaling is based on PD differences

Chart 31: **Distribution of the difference between the relative increases in sales and costs during the second half of 2021 (number of firms)**



Source: NBS and SO SR, Authors' own calculation.
Note: The horizontal axis shows the ranges of the difference between the relative change in sales and relative change in costs. The vertical axis shows the number of firms. The chart shows only firms that reported an increase in costs.

among different corporate size categories available from AnaCredit. Using these default rates, the aggregate cumulative PD is estimated to be 4.5% for the Divergent Net Zero scenario using GCAM inputs under the 100% scenario.

After estimating the exposure at risk and the aggregate default rate, the exposure at default is calculated by adjusting the exposure at risk according to the default rate. For the Divergent Net Zero scenario using GCAM inputs under the 100% scenario, the share of firms at risk is 27%, and the share of firms defaulting is set at 4.5%. This implies that approximately 16.5% of firms at risk will default, resulting in the exposure at default being estimated as 16.5% of the exposures at risk. Loss given default (LGD) is set at 45% (based on the parameter of the Basel Standardized Approach) and 10% for state-guaranteed loans (as, on average, 90% of the loan is secured by the government).