Climate Risk with Particular Emphasis on the Relationship with Credit-Risk Assessment: What We Learn from Poland

Natalia Nehrebecka

Abstract: This research seeks to identify non-financial enterprises exposed to the climate risk relating to transition risks and at the same time use of bank loans, as well as to conduct stress tests to take account of the financial risk related to climate change. The workflow through which to determine the ability of the banking sector to assess the potential impact of climate risk entails parts based around economic sector and company level. The procedure based on the sectoral level identifies vulnerable economic sectors (in the Sectoral Module), while the procedure based on company level (the Company Module) refers to scenarios presented in stress tests to estimate the probability of default under stressful conditions related to the introduction of a direct carbon tax. The introduction of the average direct carbon tax (EUR 75/tCO$_2$) in fact results in increased expenditure and reduced sales revenues among enterprises from sectors with a high CO$_2$ impact, with the result being a decrease in the profitability of enterprises, along with a simultaneously higher level of debt; an increase in the probability of default (PD) from 3.6%, at the end of 2020 in the baseline macroeconomic scenario, to between 6.31% and 10.12%; and increased commercial bank capital requirements. Financial institutions should thus use PD under stressful conditions relating to climate risk as suggestions to downgraded under the expert module.

Keywords: climate change; scenario analysis; credit-risk assessment; financial stability

1. Introduction

Recently, the range of knowledge related to climate change and the consequences of excessive emissions of harmful gases has expanded. In this regard, there has been an increased interest in investments aimed at environmental protection. The establishment of an appropriate framework for the involvement of the financial system in environmentally and socially sustainable (as well as sustainably managed) projects is supported by a number of European initiatives. This may lead to a change in traditional financing.

In Poland, the power supply remains one of the most energy-consuming sectors, and as one of the measures taken to reduce emissions, the country participates in the EU’s Emissions Trading System (ETS). The charge for CO$_2$ emissions arises out of the ETS and constitutes an additional cost for energy producers, which they can try to pass on to end-users. The price of CO$_2$ emission allowances is corrected by the emissivity of a given technology, e.g., by 0.8 for coal—as emissions from coal units amount to approximately 800 kg of CO$_2$ per MWh of energy. Thus, if the allowance to emit a ton of CO$_2$ costs EUR 60 at present, the ETS “adds” EUR 48 to the cost of producing 1 MWh of energy from coal. This is not to mention the way in which revenues and profits fell by 30–50% among companies operating in the energy sector, as a reflection of the low oil prices characterizing most of 2020.

It is possible that enterprises will be subject to additional direct or indirect carbon taxes, tax and subsidy programs, etc. Research by [1–5] shows that carbon taxes and similar solutions aimed at increasing the price of coal represent the most powerful and effective tool by which to reduce emissions of CO$_2$ from domestic fossil fuels.
From the financial stability perspective, climate risk is the risk related with exposures susceptible to physical (the influence of extreme weather events on the value of collateral and assets) and/or transition risks (the possibility of an abrupt reassessment of asset prices in connection with a change in climate policy) caused by climate change [6]. In the case of the second type of risk, mention should be made of regulations (political measures aimed at mitigating environmental change, e.g., CO₂ pricing), or technological risk (e.g., the replacement of a CO₂-intensive production process with climate-friendly technology). The distinguishable channels by which effects in scenarios assessing the impact of transition risks can be transferred to the banking sector are: (1) credit risk related to lower profitability of high-carbon entities and higher household expenditure, (2) market risk related to asset revaluation in contaminated industries, and (3) liquidity risk related to maturity mismatching. For the IMF, it remains a priority to integrate climate risks into its risk-analysis toolkit [7].

The research carried out, which is detailed here, aimed (i) to try and identify non-financial enterprises exposed to the climate risk relating to transition risks and at the same time use bank loans, (ii) to address transition-related climate risk with a particular focus on the adaptation of credit-risk assessment (and in particular on the probability of default and the rating of enterprises), and (iii) to use climate-related stress tests to take account of financial risks. On the basis of results obtained, this article can offer guidance regarding the development of a transition-context tool for the assessment of climate risk, by reference to the costs of adjustment to a low-carbon economy.

To achieve this goal, it is necessary to answer two main questions. First, which economic sectors are in the zone of climate risk associated with the transition risk to a low-carbon economy? Second, how does the financial stress associated with the carbon tax affect credit risk through the probability of default, affecting the operating costs and profitability of the company?

The subject of the research seems interesting, given its relationship to questions of great economic and social importance surrounding the costs of programs to decarbonize the economy. The literature on this subject points to divergent short- and long-term impacts of emission reduction on the financial indicators of non-financial enterprises. Additionally, recent research suggests a positive influence on credit risk due to ESG (Environmental, Social, and Governance) factors, including the risk-changing climate [8,9]. Reference [10] also mentions microeconomic channels by which climate risk may be transmitted.

The present study extends these approaches by:

1. attempting to fill a gap in the existing research, which still lacks a clearly adopted approach to assessing the impact of climate risk on the financial system;
2. offering a useful framework by which to further streamline the credit-risk assessment process with enhanced information, e.g., on ESG risks and climate risks;
3. gauging the financial impact of CO₂-taxation on enterprises;
4. including CO₂-taxes in the rating system.

The remainder of the present manuscript is organized as follows: Section 2 presents the literature review. Section 3 then presents data sources and stylized facts regarding emitter companies. The corresponding results are presented in Section 4. Discussion is then entered into, and the conclusions drawn at the end of this paper.

2. The Literature Review

The last decade has seen the development of a significant literature on the macroeconomic modeling of climate-change relationships that takes the physical risk to the economy into account [11–17]. A more recent trend in the science addresses the correlation between climate risk and financial stability. Two channels by which the (physical and transition) risk associated with climate change can be transferred on to financial stability are recognized currently [18].

Relevant regulatory bodies are accompanied by academia [6,19–30] in efforts to determine how much climate risk may affect the financial system and how the possibility of
minimal risk can be assessed. However, there remains no clearly adopted approach for assessing the impact of climate risk on the financial system. Moreover, studies attach great importance to the assessment of transition risk, because without a well-defined system by which to transition to a low-carbon economy, both the financial system and the real economy may incur major losses [22,23,28,31–34]. The strength of impact depends on the duration of climate policy [2,6,19,22,35–37], while the transition risk may be greater for countries in which high-carbon sectors of activity play key economic roles [37].

The work detailed by this paper concerns quantitative assessment of the impact of transitional climate risks on the financial system. It uses specific scenarios to analyze that impact on business, as that translates into financial statements and the derived probability of default/rating under stress where climate risk is concerned. It takes an approach that may also be used to assess responses to production costs, international price competitiveness and corporate sales revenues, e.g., [33]. Stress tests conducted in relation to climate change [36] suggest that climate policy may generate potential winners and losers among financial entities, with the relationship proving stronger where non-implementation continues for longer.

3. Data Sources

Empirical analysis for the study drew on annual data from the 2007–2020 period [38–40], as regards:

- bank borrowers’ defaults detailed in Prudential Reporting from the National Bank of Poland, NBP (reflecting Resolution of the Board of Narodowy Bank Polski No. 53/2011 of 22 September 2011, as relating to the procedure and detailed principles whereby banks would supply the NBP with data indispensable to its pursuit and periodic evaluation of monetary policy, as well as evaluation of the financial situation facing banks, and banking-sector risk), with the so-called “large exposures” regarded by banks as relating to joint-stock companies, state-run banks, and non-associated cooperative banks where sums involved exceed 2M PLN in any single enterprise [41];
- insolvencies listed on the database managed by the National Court Register (Krajowy Rejestr Sądu), i.e., the Polish Business Register;
- financial statements (sources: NOTORIA and the D&B Corporation);
- the external statistics of enterprises (source: NBP).

Of necessity, and in line with NACE Rev.2, this research excludes the economic sectors of agriculture, forestry and fishing, and financial and insurance activities, given the specifics involved. The legal forms of organization considered were partnerships (unlimited, professional, limited, or joint-stock limited), capital companies (limited liability or joint stock), civil-law partnerships, state-owned enterprises, and Poland-based branches of foreign enterprises.

Probability of Default (PD) is one of the key parameters that needs to be estimated for credit-risk modeling, and estimation proceeds in line with a definition set out in Regulation (EU) No. 575/2013 of the European Parliament and of the Council of 26 June 2013 on the prudential requirements for credit institutions and investment firms and amending Regulation (EU) No. 648/2012 (§178 CRR (Article 178 Default of an obligor 1. A default shall be considered to have occurred with regard to a particular obligor when either or both of the following have taken place: (a) the institution considers that the obligor is unlikely to pay its credit obligations to the institution, the parent undertaking or any of its subsidiaries in full, without recourse by the institution to actions such as realizing security; (b) the obligor is past due payment by more than 90 days on any material credit obligation to the institution, the parent undertaking or any of its subsidiaries. Competent authorities may replace the 90 days with 180 days for exposures secured by residential or SME commercial real estate in the retail exposure class, as well as exposures to public sector entities). The 180 days shall not apply for the purposes of Article 127.).
In the event, the sample analyzed as of January 2020 extended to 15,617 enterprises, whose overall credit obligations amounted to PLN 254,957M (see Figure 1). In total, 469 of these enterprises had already defaulted with at least one bank.

![Figure 1.](https://example.com/figure1.png)

**Figure 1.** Structure by size and section within the analyzed sample relating to non-financial operations conducted in 2020.

### 4. Stylized Facts about Emitting Entities

Climate risk is significant for Poland. Based on Eurostat data, Poland is among the top five European countries, taking into account the intensity of CO$_2$ emissions (Figure 2).

![Figure 2.](https://example.com/figure2.png)

**Figure 2.** CO$_2$ emission intensity by country.

However, it is worth noting that, as most EU Member States emit CO$_2$ beyond their allocated limits, the climate risks of the transition period to a low-carbon economy will be higher.

Analyzing the intensity of CO$_2$ emissions by operating sector, it is water transport, energy, utilities, selected industries, agriculture, forestry and fisheries that are found to be the worst culprits (Figure 3, based on Eurostat data, 2018). Since energy supply remains one of the most energy-intensive sectors, it is worth noting the need to consider more environment-friendly policies.

Entities from the Polish economic sectors responsible for higher emissions do look important for the real economy and the banking sector (Figure 4). Emitting companies account for a significant share of the Polish economy, as they produce about 46% of all added value and employ 41% of employees. In addition, they also own 52% of all assets. At the same time, there is an increased risk of “stranded asset” during the transition to a low-carbon economy.

The companies from emission sectors in being non-sensitive from a financial standpoint. They are of higher profitability (4.5% compared to 3.9% for low-carbon entities in 2020, i.e., during the COVID-19 pandemic), have a much lower level of debt (80% versus over 100% for low carbon) and manifest a better interest coverage ratio (9.7 compared with 8.3 for other sectors) (Figure 5). These enterprises are heavily dependent on long-term bank
loans, relatively short-term, also have higher equity and additionally use more trade loans than other sectors (Figure 6).

Figure 3. CO2 emission intensity by economic sector in the case of Poland.

Figure 4. Basic statistics: emitting sectors versus other sectors.

Figure 5. Financial performance measures: emitting sectors versus other sectors.
Commercial and cooperative banks have relatively significant exposure to enterprises operating in emission industries. The portfolio of emitter entities accounts for approximately 40% of the commercial banking exposure of non-financial enterprises and 44% for the cooperative banking sector. However, it is worth noting that the scale of exposure to emitting entities is not the same as banks’ exposure to climate risk. The analysis of the impact of climate risk on the financial system requires the use of more fine-grained data.

Commercial bank exposures to the energy sector prove to be more risky (Figure 7). The above-mentioned risk for banking industry could be reduced by a significant proportion of short-term loans—most corporate loans are repaid within 2–3 years, which leaves some freedom for the banking sector in shaping exposure to climate risk and (partial) transition to “green” projects at the expense of “brown”.

Figure 6. Corporate structure liabilities: emitting sectors versus other sectors.

Figure 7. Bank loans and GVA of Poland’s emission-intensive economic sectors.

There is a high level of concentration of issuance exposures among credit institutions in Poland. The top seven banks take approximately 50% of the total exposure to the emission sectors (Figure 8). In 60% of banks, carbon exposures account for over 30% of
the entire portfolio of non-financial enterprises. Risks arising from this can shift to higher probability of default, collateral erosion, and the erosion of asset values in the event of sudden change.

Figure 8. The major exposure of Poland’s commercial banks to the country’s emission-intensive sectors.

5. The Banking Sector’s Assessed Ability to Cope with the Possible Implications of Climate-Related Risk

The workflow by which to determine banks’ capacities to assess the potential impact of climate risk is as presented in Figure 9. It consists of sections based on the levels of the sector (Sectoral Module) and the company (Company Module). The first part generates a heatmap of emission-intensive sectors. Then, once the economic sectors vulnerable in terms of GHG emissions have been determined and climate scenarios formulated via stress tests, we move to the second part of the procedure: the Company Module.

Figure 9. Workflow by which to determine the banking sector’s ability to deal with the possible implications of climate-related risk.

The procedure based on the sectoral level (Sectoral Module) is designed to identify the business sectors/subsectors most exposed to climate risk related to transition risk. The Sectoral Module consists of the following steps:

Step 1: Identification of vulnerable economic sectors [36].

In this study, the impact of transition risk for the real economy and emitting industries was assessed by reference to emissions at aggregate level, with criteria being: (i) a share in CO\textsubscript{2} emissions greater than 1% of the national total, and (ii) an affiliation within the Polish economy’s 15 largest sectors in terms of GHG emission intensity.

Step 2: Calculation of transition vulnerability factors (TVFs) [33].

After [33,34], these TVFs were generated to allow for more profound analysis of the use of stress tests applied to the climate-related transition risk. World Bank tables on
Input–Output (the Input–Output tables show the relationships between producers and consumers at national level) yield information as to CO$_2$ emission intensities at the level of each economic sub-sector, with account also taken of indirect CO$_2$ emissions from the sub-sectors with which the latter cooperate in their production process. TVF for a given economic sector $j$ is calculated using the formula:

$$TVF_j = \frac{\sum_{i=1}^{n} \frac{CO_2 \text{ emissions}_i \times GVA_j}{GVA_i}}{\frac{CO_2 \text{ national total}}{GVA_{\text{national total}}}}$$  

(1)

where $i = 1, \ldots, n$ are the economic sub-sectors.

The procedure based on the company level (Company Module) achieves the shift from CO$_2$ emissions at a sectoral level to company level, allowing stress tests to be carried out. The Company Module consists of the following steps:

Step 1: Transition from the sectoral to company level where CO$_2$ emissions are concerned. The calculation here relates to the share of the total CO$_2$ emissions for the given economic sector, by reference to each enterprise’s share in its sector’s sales revenues.

Step 2: The carbon tax at a company level was imposed differentially in line with the economic sector to which companies belong. The tax were thus adjusted by the so-called TVF$_j$.

Step 3: Stress-test scenarios were used to assess the behaviors of key financial indicators.

Step 4: Stress-test scenarios offer a basis for estimating Probability of Default under stressful conditions ($PD_{\text{stressed}}$).

To allow the stress tests to be performed, a general model was constructed using microeconomic module models for the probability of default in the corporate sector, as quantifying developments one year ahead where the quality of banks’ corporate loans is concerned. The statistical model in question [38–40,42] has parts that are quantitative—relating to financial factors ($F$), and based on one component considering historical data retrieved from Prudential Reporting (firm financial flexibility and the occurrence of delinquencies within a firm-bank credit relationship (credit history)), and one that uses financial-statement data for the enterprises concerned (encompassing profitability, financing structure, debt sustainability and asset types); as well as qualitative—concerning behavioral factors ($B$) (location of the entity, industry, level of employment, legal form, year of establishment, description of the owner, and payment morality).

The two parts of the model were combined via the formula:

$$y = F^\alpha B^\beta$$  

(2)

where:

$\alpha, \beta$ are coefficients ($\alpha \approx 0.7; \beta \approx 0.3$).

The statistical model is built on a logistic-regression approach and produces an estimate of the annual Probability of Default ($PD$) of a company assessed. The model is estimated by reference to categorized variables transformed using a weight of evidence (WoE) approach. The quality of the model was assessed in line with such most-popular criteria such as GINI, Kolmogorov–Smirnov (K-S), and Area Under Receiver Operating Characteristic (AUROC) statistics [43].

6. Results

6.1. Sectoral Module

It is worth mentioning that the final report on EU taxonomy, developed by the Technical Expert Group (TEG) on Sustainable Finance, provides recommendations for an overarching taxonomy design, as well as guidance on how companies and financial institutions can make disclosures using the taxonomy. The above report is supplemented by a technical annex overviewing economic activity capable of contributing substantially to
climate-change mitigation. In this study, the impact of transition risk on the real economy and CO$_2$-emitting industries was evaluated by reference to aggregate-level emissions [36], and to the criteria that: (i) the share of CO$_2$ emissions nationally is greater than 1%, and (ii) there is affiliation with the national economy’s top 15 sectors in terms of intensity of emission of CO$_2$ or other GHGs (Tables 1 and 2, based on Eurostat data, 2017).

Table 1. Emission sectors in Poland.

| NACE  | Business Sectors                                      | % Emission of GHGs |
|-------|-------------------------------------------------------|--------------------|
| A     | Agriculture, forestry, and fishing                    | 14.6%              |
|       | Crop and animal production, hunting and related       |                    |
|       | service activities                                    | 14.4%              |
| A02   | Forestry and logging                                 | 0.2%               |
| A03   | Fishing and aquaculture                              | 0.1%               |
| B     | Mining and quarrying                                 | 5.9%               |
| C     | Manufacturing                                         | 18.3%              |
| C10–C12 | Manufacture of food products; beverages and         |                    |
|       | tobacco products                                      | 1.5%               |
| C17   | Manufacture of paper and paper products               | 0.6%               |
| C19   | Manufacture of coke and refined petroleum products    | 3.7%               |
| C20   | Manufacture of chemicals and chemical products        | 4.0%               |
| C23   | Manufacture of other non-metallic mineral products    | 4.9%               |
| C24   | Manufacture of basic metals                           | 2.7%               |
| D     | Electricity, gas, steam and air conditioning supply   | 42.3%              |
| E     | Water supply; sewerage, waste management, and        |                    |
|       | remediation activities                                | 3.8%               |
| E36   | Water collection, treatment and supply                | 1.0%               |
| G     | Wholesale and retail trade; repair of motor           |                    |
|       | vehicles and motorcycles                              | 3.3%               |
| G46   | Wholesale trade, except of motor vehicles and         |                    |
|       | motorcycles                                           | 1.9%               |
| G47   | Retail trade, except of motor vehicles and            |                    |
|       | motorcycles                                           | 1.0%               |
| H     | Transportation and storage                           | 6.5%               |
| H49   | Land transport and transport via pipelines           | 3.6%               |
| H50   | Water transport                                       | 0.8%               |

In summary, Table 1 includes sectors such as energy, utilities, agriculture, mining and quarrying, manufacturing, transport and trade. On the basis of a study by [33,34], transition vulnerability factors (TVFs) were constructed to enhance the analysis of stress-test use in relation to the transition risk caused by climate change. Construction then made use of World Bank Input–Output tables, given the way these provide for a determination of CO$_2$ emission intensity at the level of the economic sub-sector, with account also taken of indirect CO$_2$ emissions from sub-sectors with which the latter cooperate in the context of the production process.

The latest adjustment reflects the difference between the direct intensity of CO$_2$ emissions and transition vulnerability factors (see Table 2). TVPs can determine more precisely the exposure of the economic sector to climate risk as a result of the relationship with other subsectors. The reference to the TVP coefficient allows for the identification of sectors/sub-sectors displaying high susceptibility to transition risks (as with various categories in the industries producing chemicals and chemical products, products from other non-metallic minerals or basic metals).
of $40/t\text{CO}_2$ [5]. The current price of \text{CO}_2 emission allowances per tonne—of more than
airlines) by which the latest 2030 climate target may be met.

Reduced carbon taxes of between USD 14 per t\text{CO}_2 in Portugal and USD 127 per t\text{CO}_2 in
reduced carbon taxes of between USD 14 per t\text{CO}_2 in Portugal and USD 127 per t\text{CO}_2 in

ent solutions (including the said tax and the abolition of free \text{CO}_2 emission permits for airlines)
by which the latest 2030 climate target may be met.

A World Bank publication reveals how some European countries have already intro-
duced carbon taxes of between USD 14 per t\text{CO}_2 in Portugal and USD 127 per t\text{CO}_2 in
Sweden [26]. Six scenarios considered (see Table 3) were thus the 1a, 2a, and 3a scenarios,
assuming a carbon tax of EUR 50/75/100 per t\text{CO}_2, and the 1b, 2b, and 3b scenarios
assuming the introduction of a \text{CO}_2 tax of EUR 50/75/100 per t\text{CO}_2, as supplemented by
a 5% reduction in sales revenues constituting a correction of consumer preferences. All scenar-
ios confined themselves to first-round effects.

Table 2. The heatmap of emission-intensive sectors.

| NACE  | CO\textsubscript{2} Intensity (t/M EUR) | TVF 1 |
|-------|---------------------------------|-------|
| A01   | 2277.68                         |       |
| A02   | 484.85                          |       |
| A03   | 5597.21                         |       |
| B     | 267.27                          |       |
| C10–C12 | 380.14                      |       |
| C17   | 1015.55                         |       |
| C19   | 3834.83                         |       |
| C20   | 3897.52                         |       |
| C23   | 3393.24                         |       |
| C24   | 6817.59                         |       |
| D     | 13,660.47                       |       |
| E36   | 1052.20                         |       |
| G46   | 173.10                          |       |
| G47   | 85.63                           |       |
| H49   | 801.88                          |       |
| H50   | 17,159.05                       |       |

1 Low impact TVF: \( \leq 1 \), Moderate impact TVF: \( > 1 \& \leq 5 \), High impact TVF: \( > 5 \).

6.2. Scenarios and Stress Tests

Researchers considered scenarios in stress tests relating to increases in the price of
\text{CO}_2 emissions, with [44] considering carbon prices of $50–75/t\text{CO}_2 [45] of $100/t\text{CO}_2, or
of $40/t\text{CO}_2 [5]. The current price of \text{CO}_2 emission allowances per tonne—of more than
EUR 60—is well above the global average of $2 but still within the $50–100 range the IMF
deems necessary if Paris Agreement targets are to be met [37].

This study’s assessment of the impact of transition risks considered the introduction
of a direct carbon tax, in line with European Commission findings on a number of different
solutions (including the said tax and the abolition of free \text{CO}_2 emission permits for airlines)
by which the latest 2030 climate target may be met.

Table 3. Scenario for stress tests.

| Scenario | Tax (EUR per t\text{CO}_2) | Diff (Sales) |
|----------|--------------------------|-------------|
| 1a       | 50                       | 0%          |
| 1b       | 50                       | −5%         |
| 2a       | 75                       | 0%          |
| 2b       | 75                       | −5%         |
| 3a       | 100                      | 0%          |
| 3b       | 100                      | −5%         |

By reference to data on the carbon tax (see Table 3), the tax amount under stressful
conditions \((\text{TAX}_{\text{stress}, j})\) was determined at enterprise level, in line with the sector to
which the entity belongs, and as adjusted for the transition vulnerability factor \((\text{TVF}_j)\) for
the given economic sector:

\[
\text{TAX}_{\text{stress}, j} = \text{TAX} \times \left[\frac{\text{Sales}_i}{\text{Sales}_j}\right] \text{TVF}_j 
\]
where:
\[ i = 1, \ldots, N - \text{id for company}, \]
\[ j = 1, \ldots, S - \text{id for sector/subsector}. \]

Where Polish enterprises are concerned, it is worth noting that domestic entities emit more CO\(_2\) than their foreign units. This is due to the high share of fossil-fuel energy in the mix, as well as a specialization in high-emission and high-carbon products. As viewed from an international perspective, Polish corporations still pay relatively less for these. A higher and more widely used carbon tax addresses the problem at the source, directly incentivizing reductions in emissions and associated social costs.

### 6.3. Company Module

The scenarios used in the stress tests reveal how the introduction of a direct carbon tax of between EUR 50 and 100/tCO\(_2\) reduces the profitability of non-financial entities significantly, even as it raises the levels of debt. This is indicated by the probability of default increasing from 3.6% (default rate from 3.1%), at the end of 2020 in the baseline macroeconomic scenario, to between 6.31% and 10.12% (see Table 4).

| Scenario | Tax (EUR per tCO\(_2\)) | Diff(Sales) | PD stressed |
|----------|-------------------------|-------------|-------------|
| 1a       | 50                      | 0%          | 6.31%       |
| 1b       | 50                      | -5%         | 6.30%       |
| 2a       | 75                      | 0%          | 9.80%       |
| 2b       | 75                      | -5%         | 9.50%       |
| 3a       | 100                     | 0%          | 10.12%      |
| 3b       | 100                     | -5%         | 10.10%      |

Where the direct carbon-tax stress scenario involves EUR 75/tCO\(_2\), the observation for the above case is of a drop by at least one notch in non-financial enterprises ratings, with just a quarter of companies able to remain in the same credit rating class (see Figure 10).

**Figure 10.** PD and rating in stress scenarios 3a and 3b.

### 7. Discussion

As part of the discussion of the results obtained, it is worth referring to and comparing the effect of COVID-19 on the probability of default [40] and decarbonization to credit risk in the case of non-financial enterprises. The pandemic-induced crisis has clearly contributed to an increase in non-performing loans. On the other hand, state aid programs, as well as regulations forming elements of anti-crisis shields, have helped mitigate the negative effects of restrictions (while the default rate in 2020 was at a level of 3.1%, our stress tests...
suggest an increase in PD to approximately 6% by June 2020). Nevertheless, the gradual withdrawal of this funding may increase non-performing loans further. Consequently, the numbers of bankruptcies and insolvencies in Poland can still be expected to reflect the impact of COVID-19, albeit after some delay.

Where decarbonization is concerned, the response in terms of PD is actually stronger than that anticipated for the pandemic where the average direct carbon tax is as high as EUR 75/tCO$_2$. Highly correct estimation of the size of the climate risk can limit negative effects. Conversely, timely action could reduce potential losses to the banking sector and the real economy caused by the transition to a low-carbon economy.

8. Conclusions and Implications

Last year—2020—brought a pandemic and the launch of the Green Deal by the EU. The reaction to the first phenomenon was the activation of domestic fiscal and monetary instruments. The transition to a green economy with associated funds and promised policy presents a new and long-term challenge, as, by achieving full implementation of the concept of the European Green Deal, the EU intends to become the first continent able by 2050 to remove as many CO$_2$ emissions as it generates. In consequence, the research detailed here has inter alia sought to identify non-financial enterprises that are exposed to climate risk of a transitional nature and at the same time use bank loans, as well as to conduct stress tests that account for the financial risk relating to climate change.

Summing up the results of the study, the following conclusions can be drawn. Economic sectors that are in the zone of climate risk associated with the risk of transition to a low-carbon economy are energy, utilities, agriculture, mining and quarrying, selected manufacturing, transport and trade. High-carbon industries play an important role both in the real economy and in the banking sector. Therefore, a timely transition to a low-carbon economy is important.

The quantitative assessment of the impact of transitional climate risks on the financial system has shown that the introduction of a direct carbon tax has an impact on credit risk. The probability of default (PD) of non-financial enterprises in the economic sectors associated with CO$_2$ emissions increases from 3.6% (default rate from 3.1%) at the end of 2020 in the basic macroeconomic scenario to 6.31–10.12%, depending on the scenario in stress tests. The resulting situation entails an increase in the capital requirements of commercial banks.

The transition to a low-carbon economy thus contributes to declining creditworthiness on the part of enterprises, with a domino effect created, in which participants are financial and credit institutions, and the financial system as a whole. Likely effects would be on the transmission of monetary policy, as assets become stranded and the financial risks associated with the climate are reassessed.

This study suggests that a gradual transition to a low-carbon economy should encompass a number of policy measures in which public and private sectors participate. Having first studied the situation, the central bank needs to control for climate risks and assess credit risk using stress tests. Climate risks also need to be added to the prudential framework.

Attention needs to be paid to the limitations present as stress tests are run to take financial risks associated with climate change into account. The first such limitation concerns the dataset on CO$_2$ emissions currently available at the level of the business sector. Next comes the fact that all scenarios are limited to first-round effects. The introduction of a carbon tax in the economy increases high energy costs, contributing to a reduction in energy consumption or a switch to alternative sources in the medium and long terms. In the absence of alternative products or services, it is low-income consumers that suffer above all.

The research detailed here has the potential to contribute to the debate on climate risk and financial stability. In particular, this current study fills gaps in the literature when it comes to: (i) the quantification of the impact of transient climate risks on the financial
system, and in particular on probability of default/rating under stress conditions; (ii) the estimation—based on specific scenarios (e.g., regarding CO₂ emissions)—of impact on business, as translated into financial statements and derived probability of default/rating under stress for climate risk (with analysis here performed at the level of firms also quite possible at sectoral level); and (iii) the understanding as to if and how transition risks are reflected in credit-risk measures, as a matter of considerable importance to companies, banks, investors, and regulators.

Overall, climate risk has a negative medium- and long-run effect on both the real economy and the financial system. Equally, the correct estimation of the size of the climate risk can allow for a reduction of negative effects. The results of this study therefore contribute to awareness raising in regard to possible consequences of the transition to a low-carbon economy.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The author declares no conflict of interest.

**References**

1. Akerlof, G.; Greenspan, A.; Maskin, E.; Sharpe, W.; Aumann, R.; Hansen, L.P.; McFadden, D. Economists' Statement on Carbon Dividends. *Wall Street J.* 2019, A13.

2. Battiston, S.; Dafermos, Y.; Monasterolo, I. Climate risks and financial stability. *J. Financ. Stab.* 2021, 54, 100867. [CrossRef]

3. CAE—Conseil d’Analyse Économique; GCEE—German Council of Economic Experts. A Uniform Carbon Price for Europe; Report 2019; CAE: Montreal, QC, Canada, 2019.

4. Farid, M.; Keen, M.; Papaioannou, M.; Parry, I.; Pattillo, C.; Ter-Martirosyan, A. After Paris: Fiscal, Macroeconomic, and Financial Implications of Climate Change. IMF Staff Discussion Note 2016, SDN/16/01, 2016. Available online: https://www.imf.org/external/pubs/ft/sdn/2016/sdn1601.pdf (accessed on 5 November 2021).

5. Mercer. Optrust. Portfolio Climate Risk Assessment; Report 2017; Mercer: New York, NY, USA, 2017.

6. ECB. *Financial Stability Review: Climate Change and Financial Stability*; Report 2019; ECB: Dhaka, Bangladesh, 2019.

7. Georgieva, K. Remarks by IMF Managing Director at the Climate Adaptation Summit; International Monetary Fund: Washington, DC, USA, 2021.

8. Cantino, V.; Devalle, A.; Fidandrino, S. ESG Sustainability and Financial Capital Structure: Where they Stand Nowadays. *Int. J. Bus. Soc. Sci.* 2017, 8, 116–126.

9. Sassen, R.; Hinze, A.-K.; Hardeck, I. Impact of ESG factors on firm risk in Europe. *J. Bus. Econ.* 2016, 86, 867–904. [CrossRef]

10. Baudino, P.; Svoronos, J.-P. Stress-testing banks for climate change—A comparison of practices. In *FSI Insights Policy Implement*; BIS: Basel, Switzerland, 2021; p. 34. Available online: https://www.bis.org/fsi/publ/insights34.htm (accessed on 5 November 2021).

11. Burke, M.; Hsiang, S.M.; Miguel, E. Climate and conflict. *Annu. Rev. Econ.* 2015, 7, 577–617. [CrossRef]

12. Burke, M.; Hsiang, S.M.; Miguel, E. Global non-linear effect of temperature on economic production. *Nat. Cell Biol.* 2015, 527, 235–239. [CrossRef]

13. Mooij, R.; Keen, M.; Parry, I. Fiscal Policy to Mitigate Climate Change, a Guide for Policymakers; International Monetary Fund: Washington, DC, USA, 2012.

14. Diffenbaugh, N.S.; Burke, M. Global warming has increased global economic inequality. *Proc. Natl. Acad. Sci. USA* 2019, 116, 9808–9813. [CrossRef] [PubMed]

15. Hallegatte, S.; Rozenberg, J. Climate change through a poverty lens. *Nat. Clim. Chang.* 2017, 7, 250–256. [CrossRef]

16. Hsiang, S.; Kopp, R.; Jina, A.; Rising, J.; Delgado, M.; Rasmussen, D.J.; Muir-Wood, R.; Wilson, P.; Oppenheimer, M.; et al. Estimating economic damage from climate change in the United States. *Science* 2017, 356, 1362–1369. [CrossRef]

17. Noy, I. The macroeconomic consequences of disasters. *J. Dev. Econ.* 2009, 88, 221–231. [CrossRef]

18. de France, B. Climate-Related Scenarios for Financial Stability Assessment: An Application to France. *Work. Pap.* 2021, 774.

19. de France, B. Evaluating Climate Change Risks in the Banking Sector. Report Required under Article 173 V° of the Energy Transition and Green Growth Act No. 2015-992 2015. Available online: https://www.afi.es/webAfi/descargas/1857306/125280 0/Evaluating-Climate-Change-Risks-in-the-Banking-Sector.pdf (accessed on 5 November 2021).

20. BIS. *Climate-Related Financial Risks—Measurement Methodologies*; Bank for International Settlements: Basel, Switzerland, 2021.

21. BIS. *Climate-Related Risk Drivers and Their Transmission Channels*; Bank for International Settlements: Basel, Switzerland, 2021.
22. De Nederlandsche Bank. *Time for Transition: An Exploratory Study of the Transition to a Carbon-Neutral Economy*; Report 2016; De Nederlandsche Bank: Amsterdam, The Netherlands, 2016.

23. Dunz, N.; Naqvi, A.; Monasterolo, I. Climate sentiments, transition risk, and financial stability in a stock-flow consistent model. *J. Financial Stab.* 2021, 54, 100872. [CrossRef]

24. EBA. *Mapping Climate Risk: Main Findings from the EU-Wide Pilot Exercise*; Report 2021; EBA/Rep/2021/11; EBA: Paris, France, 2021.

25. IMF. *Global Financial Stability Report*; Report 2019; IMF: Washington, DC, USA, 2019.

26. IMF. *Using Taxes for Climate Action; Fiscal Monitor* IMF: Washington, DC, USA, 2019.

27. IMF. *Climate Change; Annual Report 2020*; IMF: Washington, DC, USA, 2020.

28. Network for Greening the Financial System (NGFS). *Climate Scenarios for Central Banks and Supervisors*; Report 2020; NGFS: Paris, France, 2020.

29. Parry, I.W.H.; Morris, A.; Williams, R.C. *Implementing a U.S. Carbon Tax: Challenges and Debates*; Routledge: New York, NY, USA, 2015.

30. Roncoroni, A.; Battiston, S.; Escobar-Farfán, L.O.; Martinez-Jaramillo, S. Climate risk and financial stability in the network of banks and investment funds. *J. Financ. Stab.* 2021, 54, 100870. [CrossRef]

31. Dafermos, Y.; Gabor, D.; Nikolaidi, M.; Pawloff, A.; van Lerven, F. Greening the Eurosystem collateral framework: How to decarbonise the ECB’s monetary policy. *New Economics Foundation*. 2021. Available online: https://neweconomics.org/2021/03/greening-the-eurosystem-collateral-framework (accessed on 5 November 2021).

32. Dafermos, Y.; Kriwoluzky, A.; Vargas, M.; Volz, U. *The Price of Hesitation: How the Climate Crisis Threatens Price Stability and What the ECB Must Do about It*. Greenpeace Germany; German Institute for Economic Research; SOAS University of London: London, UK, 2021.

33. De Nederlandsche Bank. *The Price of Transition: An Analysis of the Economic Implications of Carbon Taxing*; Report 2018; De Nederlandsche Bank: Amsterdam, The Netherlands, 2018.

34. De Nederlandsche Bank. *An Energy Transition Risk Stress Test for the Financial System of the Netherlands*; Report 2018; De Nederlandsche Bank: Amsterdam, The Netherlands, 2018.

35. de France, B. *Carbon Tax a Production Network: Propagation and Sectoral Incidence*. Working Paper. 2020. No. 760. Available online: https://publications.banque-france.fr/en/carbon-tax-production-network-propagation-and-sectoral-incidence (accessed on 5 November 2021).

36. Battiston, S.; Mandel, A.M.; Monasterolo, I.; Schuetze, F.; Visentin, S.B.G. A climate stress-test of the financial system. *Nat. Clim. Chang.* 2017, 7, 283–288. [CrossRef]

37. IMF. *World Economic Outlook*; Report 2019; IMF: Washington, DC, USA, 2019.

38. Nehrebecka, N. Sectoral risk assessment with particular emphasis on export enterprises in Poland. *Proc. Rij. Fac. Econ. J. Econ. Bus.* 2018, 36, 677–700. [CrossRef]

39. Nehrebecka, N. Credit risk measurement: Evidence of concentration risk in Polish banks’ credit exposures. *Proc. Rij. Fac. Econ. J. Econ. Bus.* 2019, 37, 681–712. [CrossRef]

40. Nehrebecka, N. COVID-19: Stress-testing non-financial companies: A macroprudential perspective. The experience of Poland. *Eurasian Econ. Rev.* 2021, 11, 283–319. [CrossRef]

41. Eurostat. *European System of Accounts ESA 2010*; Report 2013; ECB: Luxembourg, 2013.

42. King, G.; Zeng, L. Logistic Regression in Rare Events Data. *Political Anal.* 2001, 9, 137–163. [CrossRef]

43. Nehrebecka, N.; Walczak, A.D. Construction measures of bankruptcy: Case study of Polish enterprises. *Glob. Bus. Econ. Rev.* 2016, 18, 420. [CrossRef]

44. BNP Paribas. *Stress-Testing Equity Portfolios for Climate Change Impacts: The Carbon Factor*; Report 2016; BNP Paribas: Hongkong, China, 2016.

45. University of Cambridge Institute for Sustainability Leadership. *Unhedgeable Risk: How Climate Change Sentiment Impacts Investment*; University of Cambridge Institute for Sustainability Leadership: Cambridge, UK, 2015.