FIRM
Frankfurter Institut für
Risikomanagement und Regulierung

Approaches to climate risk methodology as an example of ESG risk management in finance

In light of rising awareness for climate risk in the financial sector, this study addresses two questions:

1) How can climate risk be integrated into the capital requirement regulation (CRR)?
2) How can climate risk be integrated into stress tests?

The study addresses the following topics:

- Which options are currently discussed to integrate climate risk in the capital requirement regulation?
- Should climate risk be a new type of risk or a risk driver of an existing type of risk in this context?
- How could financial institutions integrate climate risk into their risk management? More concretely, how could climate risk related stress tests be designed and executed?
- What is the impact of (transitory) climate risk on the valuations of firms?
- How do the results on firm-level translate into the capital requirements of banks and asset portfolios of asset managers?

Three concrete fields of action are revealed:

- Financial institutions should establish market standards while monitoring ESG topics.
- The cross-sectoral and cross-border transformation to a carbon-free world economic system must be facilitated through adequate political frameworks and actions in a competition-neutral manner.
- ESG risks should be integrated into the established risk management cycles of credit risks and other types of risk, while showing transparently how ESG risks drive these established risk types.

Inhalt

Management Summary

The significance and consequences of climate change are more present than ever before in the public debate reflected for example in the stricter climate targets set by the EU and the German government in spring 2021. Climate risks are exemplary for the increasing significance of risks from the ecological, social and governance areas for companies, which are also referred to as ESG risks.

For some time now, this has also been reflected in various initiatives by different stakeholders in the financial sector aimed at anchoring these sustainability criteria in the risk management of banking and asset management. Two key players here are the Task Force on Climate-related Financial Disclosures (TCFD) and the Network for Greening the Financial System (NGFS), both organizations consisting of financial market players that not only drive the discussion with proposals on reporting and risk management, but also actively seek dialog with financial regulators.

Meanwhile, regulatory banking authorities in Europe are requesting financial institutions to integrate climate risk in their risk-management approaches and to run climate risk-related stress tests. In addition to the Bank of England that launched a climate stress test in June 2021 and the first climate stress test by the Bank of France released in May 2021, the European Central Bank (ECB), together with the European Banking Authority (EBA), has also taken up the issue and called on financial institutions to take action by 2022.

The need for this is supported by many studies showing considerable losses due to climate change in GDP growth or financial assets at risk if no actions are taken. Substantial risks have been derived for the financial sector, e.g. in the form of stranded, CO2-intensive assets whose value will (continue to) decline over time due to transitory climate risks, such as rising CO2 prices, or long-term losses in economic value creation.

To be at forefront of this development, the joint research project of FIRM e.V. and the Technical University of Munich addressed the following topics:

First, how could climate risks be integrated into the Basel III CRR? Since most of the existing proposals do not primarily follow a pure risk approach but often also have an economic policy effect to steer additional capital into "green lending", the recommendation is to stick with the status quo of the Basel III capital requirements.

Secondly, how can transitory climate risk be measured and integrated into stress tests and portfolio decisions? The project team analyzed the existing literature and developed a generic 6-step approach and applied this concept to measure the impact of transitory climate risk on valuations of Eurostoxx 600 firms and probabilities of default (PDs). The results are integrated into a classical stress test and applied to two investment funds of a project partner.

If a CO2 tax on Scope 1 emissions was abruptly introduced or increased up to €100 per ton over the next 1-3 years, the assets of the most CO2-intensive sectors would devaluate by 15-36%, leading to an increase of up to 5-34% in the PDs on loans to these companies for banks.

The two practical applications of this approach emphasize the significance of the results: The losses of the two investment funds, one of them purely equity based and the other being a mix of bonds and equities range, between 2.3-9.1% for the equity fund and 1.2-3.5% for the mixed fund depending on the underlying scenario assumptions while about 79.5% of the equity fund and about 45.3% of the mixed fund are covered by the model. Assuming that the Eurostoxx 600 members are representative for the borrower landscape of a European bank example, this alone would lead to a reduction of Basel III capital ratios in the magnitude of -1.2 and -1.6% while only addressing 36% of the bank's total risk-weighted assets.

The results demonstrate the significant economic consequences of climate risk for firms and financial institutions. This report gives practitioners, researches and regulators a valuable indication for further analyses on how to integrate climate risk into the decision making in the financial sector.

1 Introduction

„In 2021, the question arises no longer whether climate change has contributed to this [flood]. The only question is how much.”[1] In light of the recent flood disaster in Germany, Dr Carl-Friedrich Schleussner, Head of Climate Science at Climate Analytics and Group Leader at Humboldt University Berlin emphasizes the devastating consequences of global warming. Climate disruption destroys homes and claims the health and lives of millions through superstorms, floods, heatwaves, droughts, and wildfires to mention only some examples[2]. If no action is taken, the damage to the global economy in the next decades will be drastic[3].

Various climate agreements such as the Paris one aim to cut Greenhouse Gas (GHG) emissions significantly within this decade in order to stabilize the global temperature in the long run[4].

Sustainability has, thus, become a highly relevant topic in all sectors of society, politics, and economy. This is reflected in the Global Compact initiative to combat global warming and the 17 Sustainable Development Goals (SDG) by the UN[5]. Moreover, polls stating climate change as by far the largest threat of the coming decades show that the issue is also deeply anchored in national societies.

Politics is acting accordingly: In Europe, the European Commission launched the so-called “Sustainable Finance” initiative as part of the “European Green Deal” and mandated a Technical Expert Group (TEG) to develop a common environmental taxonomy[6]. Another cornerstone is the

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[1] Science Media Center Germany gGmbH (2021). *Bewirkt der Klimawandel die heftigen Regenfälle?* https://www.sciencemediacenter.de/alle-angebote/rapid-reaction/details/news/bewirkt-der-klimawandel-die-heftigen-regenfaelle/#no. Accessed 7 August 2021; Translation by Carla Bleiker (2021). *Scientists predict more extreme weather events in future*. https://p.dw.com/p/3wcew. Accessed 7 August 2021.

[2] World Meteorological Organization (2021). *State of the Global Climate 2020*.

[3] Estimates of the long-run impact vary, but for example the Swiss RE Institute (2021) estimates the cost to be 18% of its GDP in the next 30 years.

[4] United Nations Framework Convention on Climate Change (ed.) (2015). *Adoption of the Paris Agreement - Final Declaration*.

[5] UN Global Compact (2021). *The world's largest corporate sustainability initiative*. https://www.unglobalcompact.org/what-is-gc. Accessed 27 May 2021; cf. note 4.

[6] European Commission (2018). *Renewed sustainable finance strategy and implementation of the action plan on financing sustainable growth: Commission action plan on financing sustainable growth*. https://ec.europa.eu/info/publications/sustainable-finance-renewed-strategy_en. Accessed 21 May 2021.

EU Emissions Trading Scheme (EU ETS) as the world's first and biggest carbon market. Meanwhile, the Federal Government in Germany strengthened its GHG reduction target until 2030[7].

Consequently, businesses face increasingly strict regulations on emissions reduction and acknowledge the relevance of sustainability. For example, the Value Balancing Alliance (VBA)[8] attempts to measure the impact of companies on society and capture it in the balance sheet[9]. In the academic stream, there is a new research agenda on the measurement of non-financial risk in a broader context[10].

Climate change in a broader context of non-financial risk actually drives financial risk through two central types of risks. While transitory risk occurs in the transition to a low-carbon economy[11], physical risks include sudden extreme weather events or evolving effects like a rise in temperature or sea level[12]. The economic damage from these two risks puts the profitability and financial health of affected companies at risk. This in turn can ultimately also hurt the financial sector as lender of capital for these companies and endanger the financial stability of the entire system. The threat environmental risk poses to companies and the financial sector is confirmed by numerous academic studies[13].

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[7] Press and Information Office of the Federal Government (2021) https://www.bundesregierung.de/bregen/issues/climate-action

[8] The VBA consists of 20 large international companies such as BMW, SAP or Deutsche Bank, the Big 4 Accounting firms, the OECD and some academic institutions.

[9] VBA (2021). *The Value Balancing Alliance Pilot Study: A leap forward towards a standardized impact valuation methodology*.

[10] Günter Franke (2020). Management nicht-finanzieller Risiken: eine Forschungsagenda. *Schmalenbachs Z betriebswirtsch Forsch* 72 (3): 279–320. 10.1007/s41471-020-00096-z.

[11] This includes for example climate policy instruments like a CO2 price or tax or a shift to more expensive, low carbon technology

[12] NGFS (2019). *A Call for Action: Climate Change as a Source of Financial Risk: First comprehensive report.*; NGFS (2020). *Guide for Supervisors: Integrating climate-related and environmental risks into prudential supervision*; NGFS (2020). *Case Studies of Environmental Risk Analysis Methodologies*

[13] Christophe McGlade and Paul Ekins (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature* 517 (7533): 187–190. 10.1038/nature14016; Robert Vermeulen, Edo Schets, Melanie Lohuis, K&ouml, Barbara lbl, David-Jan Jansen and Willem Heeringa (2019). The Heat Is on: A Framework for Measuring Financial Stress Under Disruptive Energy Transition Scenarios. *SSRN Journal*. 10.2139/ssrn.3346466; Weyzig et al. The price of doing too late too late: The impact of the carbon bubble on the EU financial system. In: *Green New Deal Series*.

The financial sector has been integrating sustainability in risk assessments for some time. Two interest groups consisting of financial practitioners and central bankers respectively, The Task Force on Climate-related Financial Disclosures (TCFD) and the Network for Greening the Financial System (NGFS), have recently published various guidelines, potential approaches, or case-studies on how to measure and simulate the impact of environmental risk on financial stability[14].

These initiatives have been complemented by regulatory authorities particularly in the EU. The European Banking Authority (EBA) announced to include ESG risks in the supervisory review process and expects financial institutions to disclose climate risks, mitigating actions, and their Green Asset ratio[15]. The European Central Bank (ECB) required financial institutions in two letters in 2020 to establish a climate risk-management approach and develop suitable climate-related stress tests approaches by 2022[16] . The ECB also published guidelines and aggregated sector-level results on a first climate stress test execution in March 2021[17].

Due to the rapidly advancing regulation in the financial sector and the substantial environmental risk, companies and financial institutions need to develop climate risk assessment tools to measure their risk. One question is in particular to what extent environmental risk poses additional risk for financial institutions that is not yet adequately reflected in the CRR. One approach would be for example to integrate environmental risk as a new type of risk into the CRR. This question is addressed in the first part of the report.

Another question is the impact of transitory climate risk on firms and portfolios of financial institutions. This report focuses on transitory climate risk for three reasons: First, increasing CO2 prices or carbon taxes are required to reduce GHG emissions and combat climate change[18]. Second, data availability regarding CO2 emissions as a foundation for any CO2 price/taxation scheme has been and still is improving considerably in light of ESG ratings or the EU taxonomy. Third, regulatory efforts to integrate climate risk in the CRR appear to be more pronounced for transitory risk than for physical risk[19]. The analysis illustrates the impact of transitory climate risk

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[14] TCFD (2019). *Task Force on Climate-related Financial Disclosures: Status Report: 2019 Status Report*. Accessed 27 May 2021; cf. note 12; cf. note 12.

[15] EBA (2019). *EBA Action plan on sustainable finance*. Paris.

[16] ECB (2020). *Guide on climate-related and environmental risks: Supervisory expectations relating to risk management and disclosure*: European Central Bank.

[17] See the ECB Blog-Post by Luis de Guindos, Vice President of the ECB, in March 2021: https://www.ecb.europa.eu/press/blog/date/2021/html/ecb.blog210318~3bbc68ffc5.en.html

[18] World Bank (2017). *High-Level Commission on Carbon Prices: Report of the High-Level Commission on Carbon Prices*. Washington, DC.

[19] See for example the two ECB reports from 2020

on valuations of firms, on credit risk of banks and finally on asset management portfolios in the second part of the report. In this structure, the study belongs to the very first ones to combine the impact of transitory climate risk on valuations of a cross-European firm-level sample ("bottom-up") with a common stress test of application of a large European. Last but not least, this study also illustrates the impact of transitory climate risk on two investment fund portfolios.

2 Integration of climate risk in the CRR of financial institutions

This chapter illustrates potential options how climate risk could be integrated into the CRR. Most of them rely on two opposing paradigms about the role of the financial sector towards a carbon-free economy. Afterwards, the options are assessed with a detailed set of criteria to analyze their suitability to adequately reflect climate risk in the CRR.

2.1 Two opposing paradigms – risk approach and economic policy approach

Two major paradigms exist in literature regarding the integration of environmental risk into the regulation of financial institutions:

The risk-based approach focuses purely on the inherent environmental risk of each asset that drives financial risk for the holder of the asset. These financial risks shall then be considered in the capital requirements of financial institutions to make them resilient against potential environmental shocks. In other words, environmental risk would be either a driver of the current risk types (credit risk, market risk etc.) or a new risk type as such in the regulation of financial institutions. This risk-based approach shifts the focus on the measurement of risk away from past data to forward-looking measures for each asset to measure short- and long-term environmental and thus financial risk. As climate-related risk and its effects are highly uncertain, attaining robust risk measures represents a significant challenge.[20]

Opposed to the risk-based approach, the economic policy approach focuses on macro-prudential considerations such as lower climate footprint and higher "green" investments while maintaining capital neutrality and controlling the capital requirement impact. In order to achieve capital neutrality, additional recalibration on a micro-level would be required. Additionally, it should be accounted for changing capital structures in the long run. For example, if the share of green assets in portfolios rises, banks' capital base may decrease (in the short-run), leading to potential vulnerabilities in stress situations in the short-run. To counter such a development, additional capital buffers may need to be granted on a case-by-case analysis. Another task is to ensure real impact on lending. As it is often suggested that reduced capital requirements would only benefit credits that are already classified as low risk by traditional risk metrics, the effectiveness of capital adjustments in terms of fostering green lending remains doubtful. Additionally, closing the green financing gap remains a key question. Currently, many proposals do not address the issue that innovative green technologies are relatively unattractive assets due to their higher risk and lower

[20] Maria Berenguer, Michel Cardona and Julie Evain (2020). *Integrating Climate-related Risks into Banks' Capital Requirements*. Paris.

collateral capacity. The most likely solution to this problem is a provision of public guarantees, alleviating private investment concerns, instead of supporting factors adjusting their capital requirements[21]. The next chapter presents some of the options from the literature how to integrate environmental risk particularly into the CRR.

2.2 Climate risk as new type of risk

One approach to account for climate risk in the Basel III framework is to add a new risk type "environmental/climate risk" to the current risk types in the capital requirements of Basel Pillar 1 (credit risk, market risk, operational risk and CVA risk). Since environmental risk can be regarded as a material risk similar to the existing four risks and may currently be undercapitalized, a new risk type could be justified.[22] Figure 1 shows the existing Basel III capital requirement relations together with a proposed amended Pillar 1 that includes climate risk. As for the other risk types, assets would consequently require a climate risk measurement and adjustment of the RWA to reflect the inherent risk of climate change on the entire economy.

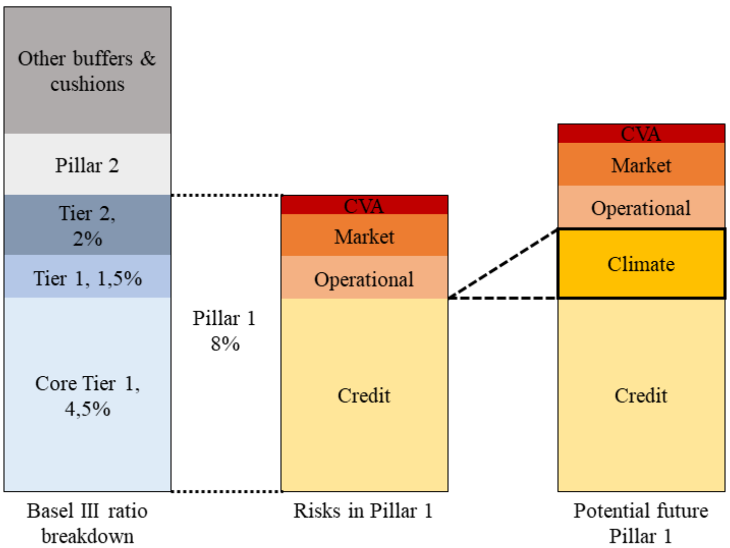

Figure 1: New climate risk methodology in Basel III.[23]

Several proposals exist how to implement or complement "climate risk" as a new type of risk that are outlined in the following.

[21] ibid.

[22] Benoit Genest (2020). *7 Proposals to Integrate Climate Risk into Capital Requirements: From Basel III To Basel IV: Accelerating Banks' Integration Of Climate Risk*. Climate Risk Series. London.

[23] ibid.

Climate stability fund

After the introduction of this new risk type "climate risk", a climate stability fund could be established financed by the banks' new capital buffer against climate risk. The banks would contribute part of these capital requirements, e.g. 50%, to the fund which is supervised by the respective regulator. The remaining part of the capital will remain on the balance sheet of the bank. The fund could then serve as a protection for contributing banks against unexpected losses sustained from green lending.[24]

Climate risk progression factor

To better account for the potential increase in climate risk over time for example due to further increasing CO2 emissions and ongoing temperature rise, a dynamic scaling factor could be added to the climate risk computation. The factor could be tied to reference climate scenarios such as the ones by the Intergovernmental Panel on Climate Change (IPCC). The capital requirement would increase for example with cumulative CO2 consumption or temperature rise. If the IPCC RCP 4.5 scenario (i.e. maintaining a temperature increase of less than 2 degrees) is used as benchmark, a scaling factor with a base of 100 in 2015 – when the Paris Climate Accord was enacted – could be applied to the capital charge[25]:

The factor could be added to the CRR calculation yielding an additional capital charge over time depending on the climate development.

Regulatory capital ratio based on asset color

A more advanced and comprehensive approach to assess climate risk is an asset rating scheme based on a color scale ranging from dark green to dark brown. The weighting would vary between 4.5% for dark green assets and 12% for dark brown ones. 4.5% represents the minimum Core Tier 1 ratio, while 12% is approximately the cumulated amount of Pillar 1, Pillar 2, countercyclical cushions, and management buffer. To determine the exact color classification, however, a common taxonomy such as the one being developed by the Technical Expert Group (TEG) in the EU would be required. This capital ratio could also be complemented by the dynamic risk progression factor for example.[26]

[24] ibid.

[25] ibid.

[26] ibid.

All the above elements include an assessment of the impact of climate risk on assets and would to some extent provide a better risk management perspective on climate risk. Yet, they come with several drawbacks.

First, there is the threat of double counting climate risk when its being treated as a separate risk type. If for example climate risk actually affects input factors of more than one existing risk type (credit risk, market risk etc.) through a direct or indirect impact of PDs and adverse changes in market prices, then climate risk would be captured by the new climate risk type, credit risk and market risk. This would in turn overestimate the actual risk arising from climate change and cause additional complexity to correct the overestimation down to the approximate real risk that climate risk poses for an asset.

Second, a new risk type would require an entirely new risk management cycle with increasing complexity in financial institutions with additional resources, transaction cost and management attention. Instead, changing the computation of existing risk types rather than the composition of the risk types could potentially foster a faster implementation in regulation and financial institutions. In light of the magnitude of climate-related financial risk shown in various studies and in the own empirical analysis (see chapter 3) and of the long-lasting discussion about the integration of climate risk into the CRR, this could turn out to be a major advantage along the road.

Third, the communication and messaging of the change in regulation could focus more on "changing the existing rules" rather than "inventing something new". Again, given the long-lasting process of communication and publications by regulatory agents about potentially new climate risk regulation in the EU since about 2018, a less drastic innovation of regulatory framework could again foster practical implementation considerably[27].

For these three reasons, this project favors the integration of climate risk into existing risk types. Out of the existing types, the projects favors the integration into credit risk (or PD) for two reasons: First, climate risk is expected to affect a company's operational performance and thus its direct creditworthiness. Second, the transmission channels of climate risk into credit risk are more transparent and known than for any other risk type (including market risk as most relevant type of risk in asset management)[28].

[27] ibid.

[28] See for example the various publications by the TCFD and NGFS to what topic since 2018.

2.3 Integration of climate risk into credit risk

Besides treating climate risk as new type of risk in the Basel III framework, another way is adding climate risk as an additive driver into existing types of risk, for example into credit risk. In the following several approaches are listed that have in most of the cases three things in common: First, they require a common taxonomy defining the environmental impact of assets ("green" vs. "brown"). Second, they suggest a climate risk-based adjustment of the risk-weighted assets to account for the new associated credit risk including the additive climate risk. Third, they all aim to foster to some extent green lending towards low-carbon economy as societal and environmental preference[29].

Green Supporting Factor (GSF)

Similar to the support factor for small- and medium-sized enterprises (SME) and infrastructure in the Basel III framework, the EU proposed a Green Supporting Factor (GSF) to incentivize lending to green investments as a first step in amending capital requirements. The factor would decrease capital requirements for banks’ lending to climate-friendly projects and potentially free up for other financing decisions. Since green lending would become relatively more attractive to banks due to its higher profitability, green projects could be awarded with more attractive financing. In the capital adequacy ratio (CAR) calculation, the implementation would look like as follows:

$$\text{Bank's CAR (GSF)} = \frac{\textit{Bank's total capital}}{\alpha \text{ x } \textit{Brown Loans} + (\alpha - \textit{GSF}) \text{ x } \textit{Green Loans}} \geq \text{Capital Requirement}$$

with α representing the initial risk weight of the asset. Brown loans’ capital requirements are unaffected by the GSF, while loans to green projects benefit from a capital reduction of (– GSF). However, the downside of this concept is a lower capital requirement for financial institutions with “green” assets from the perspective of financial stability if those “green” assets turn out to be (more) risky as initially estimated. This holds true particularly in light of limited empirical evidence of the riskiness of “green” assets.

[29] cf. note 18.

Brown Penalizing Factor (BPF)

Opposed to the GSF, the BPF would increase capital requirements for brown assets and is more in line with the risk-based approach. The applied factor can be represented by the following equation:

$$\text{Bank's CAR (BPF)} = \frac{\textit{Bank's total capital}}{(\alpha + BPF) \times \textit{Brown Loans} + \alpha \times \textit{Green Loans}} \geq \textit{Capital Requirement}$$

The BPF would increase with increasing environmental impact of the asset. Since brown assets are relatively more exposed to climate risks than what is currently implied by their risk weight, they should have a higher capital requirement as additional buffer against potential losses due to a carbon bubble or stranded assets, while at the same time reducing attractiveness of brown assets.

Combination of GSF and BPF

However, since the BPF is not really forward-looking and is also not fostering green investment but is setting higher capital requirements upon "brown" lending, a combination of GSF and BPF would bring the advantages of both factors together[30]. Yet, the potential downside for capital neutrality and financial stability particularly due to the GSF remains as can be seen from the arising equation:

$$\text{Bank's CAR} = \frac{\textit{Bank's total capital}}{(\alpha + BPF) \times \textit{Brown Loans} + (\alpha - GSF) \times \textit{Green Loans}} \geq \textit{Capital Requirement}$$

Environment Risk-Weighted Asset (ERWA)

Another way of adding a climate risk-based adjustment factor to the current RWA calculation proposal would be an Environment Risk-Weighted Asset (ERWA) that corrects the current risk-weights by a sector-specific pollution coefficient e_i[31]:

$$e_i = c_i r_i a_i$$

For every sector *i*, a specified weighing factor ranging from 0.5 and 1.5 must be determined with a value <1 for a green activity and a value >1 for a brown activity. The absolute minimum weight should then be given to sectors with almost zero CO2 emissions and/or positive environmental

[30] ibid.

[31] Lorenzo Esposito, Giuseppe Mastromatteo and Andrea Molocchi (2019). Environment – risk-weighted assets: allowing banking supervision and green economy to meet for good. *Journal of Sustainable Finance & Investment* 9 (1): 68–86. 10.1080/20430795.2018.1540171.

externalities. r_i stands for the weight calculated through the current framework, a_i for the book value of the asset and e_i for the resulting financial and environmental weight of the asset. Table 1 illustrated c_i values for a few industries together including a classification into “green” or “brown” from Italy in 2013.

Industry	ERWA c	‘Nature’
Agriculture, forestry, fishing	1.13	Brown
Electricity, gas, steam, and air conditioning supply	1.06	Brown
Manufacturing (overall)	1.00	Brown
Wholesale and retail trade	0.98	Green
Information and communication	0.98	Green
Construction	0.73	Green

Table 1: ERWAs, Italy 2013.[32]

There are 3 ways to come up with the sector-specific pollution coefficient: The simplest approach is the focus on CO2 emissions only because CO2 reporting is already pronounced with increasing availability and quality of ESG-reports. However, it does not consider other climate risks that are not directly related to the CO2 emissions.

The second approach is an external cost assessment of economic activities that translates raw environmental impact data into monetary effects into dimensions such as human health or economic value added. Yet, since this approach relies on CO2 emission data only, the approach suffers from the same issues as the first approach not to consider other climate risks. In addition, the approach also faces the issue of how to quantify the value of human health in monetary terms.

The third and last approach is based on an input-output computation of economic activities. The concept includes direct and indirect emissions over the entire life cycle of products and can be thus regarded as useful extension of the first two approaches. Since product-level specific results would often need to be aggregated industry-level though, this approaches requires higher granularity of data and higher calculation effort. A good starting point for such a database could be the quite extensive EXIOBASE database that captures input-output relationships between countries, regions and industries for example.[33]

[32] ibid., p. 71.

[33] ibid., p. 71.

Green Weighting Factor (GWF)

The GWF was developed by the French banking institute Natixis and is the only actively employed measure of this kind until June 2020. The factor was launched in 2019 in order to foster green lending and to enhance the bank's resilience to climate risks. In its nature, the factor is comparable to the combination of the GSF and BPF approach: It discounts the RWA of green assets and penalizes the RWA of brown assets along a 7-color scale based on environmental impact from dark brown to dark green. The concept considers direct and indirect environmental externalities and can be used on borrower-, asset-, or project-level. The seven color schemes are finally converted into a numeric factor that adjusts the RWA in the range of 0.5-1.24 from dark green to dark brown assets.[34]

Sustainable Finance Supporting Factor (SFSF)

As response to the GSF, the EBF has developed The Sustainable Finance Supporting Factor (SFSF) to eliminate the potential downside of the GSF to discount green assets without proper risk assessment on financial stability. The factors relies on the EU taxonomy and only applies under 2 conditions: Assets must be classified as sustainable – Sustainable Sectors/Activities/Projects (SSAP) – and proven to be associated with less financial risk due true sustainable character. The factor could be clustered by asset class (mortgages, economic project etc.) and reduces the RWA for the respective asset[35].

Sustainable Improvement Loans (SIL)

In another response to the shortcomings of the GSF's, the SIL not only discounts RWA by a green factor but also aims to induce lenders to meet a set of sustainability criteria[36]. The SIL itself is a loan with a variable interest rate that can be adjusted based on lender's performance along these sustainability criteria, for example captured in ESG-ratings. A positive performance leads to a discount and vice versa. Some companies have already used this mechanism such as Danone, Royal Philips with the sustainability criteria being their respective ESG-rating from Sustainalytics or VigeoEiris. To offset the potential reduction in interest rate due in case of a good sustainability

[34] Natixis (2019). *Natixis rolls out its Green Weighting Factor and becomes the first bank to actively manage its balance sheet's climate impact*. https://pressroom-en.natixis.com/news/natixis-rolls-out-its-green-weighting-factor-and-becomes-the-first-bank-to-actively-manage-its-balance-sheets-climate-impact-2dce-8e037.html. Accessed 26 April 2021.

[35] See the European Banking Federation publication on the supporting factor from March 2021.

[36] Jakob Thomä and Kyra Gibhardt (2019). Quantifying the potential impact of a green supporting factor or brown penalty on European banks and lending. *JFRC* 27 (3): 380–394. 10.1108/JFRC-03-2018-0038.

performance the higher cost in due diligence cost for the lender, also a so-called Sustainable Improvement Factor can decrease the RWA of the SILs.

All the concepts above are designed to adjust to some extent risk weight of the assets in the CRR subject to the classification of assets into a scale between "green" vs. "brown". Other mechanisms that do not address risk-weights of assets but aim to integrate climate risk through other channels that are mostly regulated in the Basel III framework are listed in the Appendix.

2.4 Review and assessment

Since the project team favors the integration of climate risk into credit risk, only those 7 options that integrate climate risk as part of credit risk into the CRR are assessed along the following 5 core criteria that are mainly derived from the two opposing paradigms (risk-based approach and economic policy approach):

- Capital neutrality and financial stability: Does the bank's capital base remain at least neutral and is thus the financial stability granted?
- Necessity of a common taxonomy of what is "green" or "brown": Is a common taxonomy or definition required to determine the classification "green" or "brown"?
- Impact on banks' profitability: Do for example tighter capital requirements reduce lending activities? To what extent could the profitability of banks be affected?
- Promotion of green investments: Does the conceptual option foster investment into green asset lending? This criteria is in part in contrast to the last criteria:
- Risk-based character: Does this concept follow the risk-based approach in the Basel III framework, in other words does the inherent financial risk (the additional climate risk as further driver of financial risk) exclusively determine the capital requirement of an asset, rather than any of the other considerations above?

The two most relevant criteria are the two last mentioned ones because they address the central question which role the financial sector has in the transition towards a carbon-free economy: Shall the financial sector actively foster this transition through direct channeling of capital into "green" investments or shall the sector remain its currently neutral role in this transition process and solely manage the inherent financial risk arising from climate risk? This question needs to be finally answered by the regulatory agents in order to decide on the final implementation of the mechanism.

The 7 options are analyzed qualitatively without providing a detailed sub-category ranking with sub-weights and sub-ratings in each of the sub-categories for two reasons: First, all those options are at least at the moment far from being practically implemented and only exist as a conceptual idea. Way more details would be required particularly regarding the concrete risk weight adjustment factors, the scope of assets for which the options are applicable as well as the classification of "green" vs. "brown" assets:

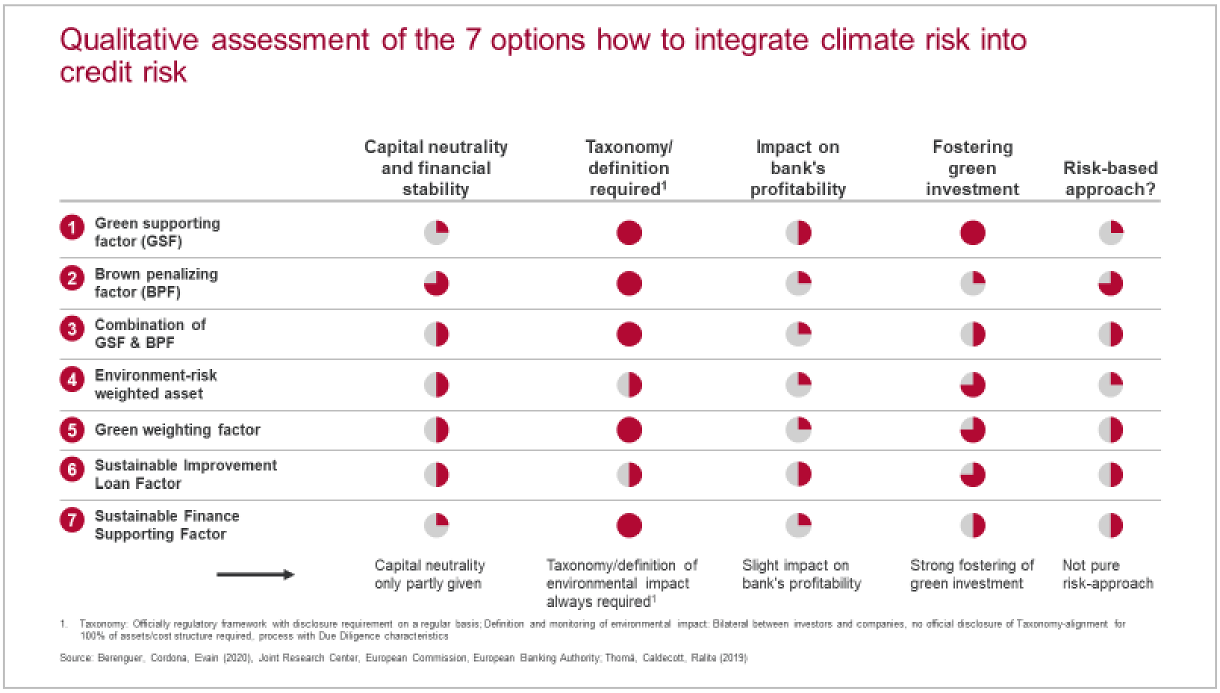

Figure 2: *Assessment of the 7 potential metrics.*

The key messages from this assessment are the following:

i. Most of the options will presumably affect the capital neutrality of institutions and thus rather negatively influence financial stability as of today. This holds true for all options that prescribe lower capital requirements with increasing share of "green" asset exposure. Again, the factor most complying with capital neutrality is the BPF as argued above.

ii. Almost all options require a very detailed classification scheme defining which assets are "green" and "brown" on a specific scale along a specific set of criteria. This is an absolute prerequisite for almost all options because no matter which option would be implemented, it must be clear whether this particular asset is classified as "green" or "brown". The most developed classification from all the options is the classification of the GWF along a 7-color traffic light scale by Natixis. Despite the ongoing efforts for the EU-wide taxonomy by the TEG, such a classification still would be a major step towards the integration of environmental risk in the current regulation.

iii. Most of the options affect the profitability of financial institutions but in different directions: Whereas all options easing capital requirements could slightly boost capital-return ratios (ROE etc.) of institutions, the SLIF and the BPF are going to reduce it. For the SLIF due to lower prescribed interest margins and potentially also due to increasing administration effort along to determine the classification of the assets, for the BPF due to higher capital requirements for “brown” assets.

iv. Since most of the options are intended to ease capital requirements for increasing capital flows into sustainable investing, those options will at least to some extent direct comparably more capital flows into sustainable investment channels and thus comply with criterion four ("Promotion of green investing") instead of criterion five ("Risk-based character"). The only concept that complies to a large extent with the risk-based approach is the BPF as it assigns a larger risk weight to "brown" classified assets, increasing the capital requirement ceteris paribus.

Besides those 7 options that directly affect the RWA of a financial institution and suggest to integrate climate risk into credit risk, there are further ideas discussed in the literature how to anchor climate risk in the Basel III framework independent of credit risk. These are outlined in the Appendix.

Summary

In sum, most of the proposals often have economic policy character to steer additional capital into green “lending” while only partly reflecting the inherent risk of these assets adequately in this intention. For this reason, the recommendation of this project is to stick as of time of writing with the current regulation. If there is a recommendation to make between the three options

1. Climate risk a new risk type,
2. Climate risk as a driver of credit risk or
3. Climate risk integrated in any other regulatory mechanisms,

the recommendation would be to proceed with the goal to integrate climate risk into issuer-related credit risk as every debtor has to a large extent company-specific exposure. Another argument is the threat of double counting climate risk in a new risk type and existing risk types (for example credit risk and market risk) and thus overstating the actual financial risk resulting from climate risk. Instead, integrating climate risk into PDs and thus credit risk would provide a direct transmission channel into issuer-specific credit risk as a starting point for further analysis. This approach would also be to some extent in line with the various publications of NGFS or TCFD. How climate risk can be measured on firm-level and how it can be captured in credit risk is shown in the following chapter.

3 Integration of climate risk into stress tests

This chapter deals with the question how to integrate climate risk in stress tests as demanded by the ECB by 2022 for financial institutions. Similar efforts have been made by the Bank of France in May 2021 by conducting a climate-related stress test of the French financial sector. It is also in line with the announcement of the Bank of England in June 2021 to launch a climate stress test for banks and insurers. The chapter starts with a literature review on climate risk-related stress tests, presents a standardized 6-step approach how to execute climate stress tests and ends with the results of two empirical stress test applications for investment portfolios and capital requirements of financial institutions.

3.1 Literature review

While "Top-down" or macro-approach studies analyze the impact of climate risk on either sectors, countries, regions or even continental spheres without any insight into company-specific differences, “Bottom-up” studies compute the impact of climate risk on a microeconomic firm-level with higher complexity and more granular data availability on corporate level.

Top-down studies

An early study that analyzed the impact of climate risk is from 2014. It estimated the exposure of the European financial institutions towards fossil fuel-intensive sectors equal to be €1 trillion and the potential losses due to a quick transition towards a low-carbon economy based on high-level shock to be 3% of total assets for pension funds, 2% for insurance companies and 0.4% for large banks[37].

A study from 2015[38] analyzed the impact of the transition towards a carbon-free economy from the macroeconomic perspective based on the IPCC scenarios. The results indicate lower economic growth for the transition phase but comparably higher growth in the long-run compared to the "No Mitigation" scenario. A fictional portfolio with 40% equity weight would lose between 15-20% of its value in 2015-2020 according to another analysis in the study.

A study from 2016[39] compiled a ‘Climate value at risk’ of global financial assets equal to 1.8% or USD 2.5 trillion based on a representative global financial asset portfolio. Similar to the other

[37] cf. note 13.

[38] CISL (2015). *Unhedgeable Risk: How climate change sentiment impacts investment*. University of Cambridge.

[39] Simon Dietz, Alex Bowen, Charlie Dixon and Philip Gradwell (2016). ‘Climate value at risk’ of global financial assets. *Nature Clim Change* 6 (7): 676–679. 10.1038/nclimate2972.

studies[40], the authors find that a combat against climate change early on is going to reduce the long-term cost of climate change.[41]

A very relevant paper for the 6-step approach and the empirical analysis is from the Dutch Central Bank (DNB)[42]. The authors assessed the impact of sudden transition to a low-carbon economy for more than 80 Dutch financial institutions (incl. also pensions funds and insurers) with a total value of €2.3 trillion assets along 56 NACE industry sectors. The analysis includes four major steps: First, they design 4 transition scenarios called "narratives" along two central anchors: climate policy intervention and energy technology development. Second, they predict the macroeconomic environment along key figures (Interest rate, trade, GDP etc.) in a multi-country macro-econometric model from NiGEM and transform the 4 derived scenarios into detailed input figures for these econometric models (e.g., CO2 prices into commodity prices). Third, they design so called "transition vulnerability factors" by the carbon intensity relative to the economic output in order to derive the vulnerability of sectors against environmental risk. Lastly, they conduct stress tests by applying the Basel framework for credit and market risk and derive financial losses. As a result, banks would face 1-3% asset value loss compared to 9-11% for insurers and 5-10% for pension funds. These results are largely driven by higher risk-free interest rates projected in the macroeconomic forecasting. Besides, CET1 of Dutch banks could fall by about 4% compared down to 12% from a 16% baseline in 2018/2019.

Another relevant paper[43] uses a Distance-to-Default (DtD)-approach and develops similar scenarios as the paper described above. A €100-200 carbon tax is used to analyze the impact of climate risk along 4 different transition scenarios (2x timing of the tax and 2x pass-through rates onto consumers) for the stability of Dutch banks. Based on these 4 scenarios and the corresponding CO2 emissions per sector, they calculate a NPV of future carbon tax payments and use Merton' model to derive new post-shock valuations and PDs. The most hit sectors are utilities and manufacturer of commodities with devaluations shocks of 31-89%. Then, they use financial exposure data of the 3 largest Dutch banks as proxy and extrapolate these losses for the entire Dutch banking sector. These results could lead to a decline in CET1 capital of 4-63% and in total assets of 3.2% for the entire Dutch banking sector, largely driven by losses in corporate debt and -loans in the most affected sectors.

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[40] cf. note 34.

[41] They find that limiting global warming to 2° reduces the expected losses by 0.6-1.2% and preserves about 800 bn. USD of assets of that global financial asset portfolio.

[42] cf. note 13.

[43] Henk Jan Reinders, Dirk Schoenmaker and Mathijs A. van Dijk (2020). A Finance Approach to Climate Stress Testing. *SSRN Journal*. 10.2139/ssrn.3573107.

Further studies from the private sector[44] also estimate the effect in different metrics (e.g., EBITDA at risk or portfolio losses of MSCI indices) and generally confirm the notation that climate risk indeed drives financial risk[45].

Bottom-up studies

One of the first studies[46] applied a network-based stress test methodology and divided the potential climate risk into first- and second-round effects. Based on a classical Value at Risk (VaR) analysis of exposures of large European banks, the authors conclude that action early on might be more beneficial than belated policy action that might ultimately lead to “adverse systemic consequences". In the most pessimistic scenario, the authors find a VaR < 1% in a “brown” scenario for the largest 50 banks in the Euro area.

The DtD approach is also used in a study [47] that measures the impact of transitory risk on the eligibility of assets for purchase by the ECB’s corporate sector purchase program (CSSP). Their sample consists of 875 securities from 166 issuers equal to 73% of the CSSP portfolio. They break down the global CO2 emission reduction required to limit global warming to 2°C top-down onto country, industry and finally company specific-level. Then they add the necessary CO2 prices on national level to the CO2 reductions and calculate new firm valuations as well as PDs. The paper only shows 2 concrete results: An increase in PDs for a Utilities company of +0.29% and +3.34%

[44] Mercer LLC (2019). *Investing in a Time of Climate Change: The Sequel*. Global Wealth; Andrew Howard and Ovidiu Patrascu (2017). *Climate change: redefining the risks;* Joseba Eceiza, Holger Harreis, Daniel Haertl and Simona Viscardi (2020). *Banking Imperatives for Managing Climate Risk*.

[45] Howard and Patrascu (2017) show detailed carbon exposures and integrate a carbon tax into the P&L of companies that is partly offset by price increases and pass-through rates onto consumers. The remainder is modelled into cash-flows and EBITDA of key benchmark indices such 500 yielding EBITDA at risk of roughly -12% for the S&P 500 and MSCI up to -16.5% for MSCI Emerging Markets.

A study by Eceiza et al. (2020) from McKinsey & Company analyzed among others the Impact of flooding in Florida on a mortgage portfolio loss rate and compounded a loss rate rate of 0.5-7.25% subject to the specific scenario. These numbers become even more drastic when comparing these loss rates with those in the financial crisis of 2.95%.

[46] Stefano Battiston, Antoine Mandel, Irene Monasterolo, Franziska Schütze and Gabriele Visentin (2017). A climate stress-test of the financial system. *Nature Clim Change* 7 (4): 283–288. 10.1038/nclimate3255.

[47] Pierre Monnin (2018). *Integrating climate risks into credit risk analysis: Current Methodologies and the Case of Central Banks Corporate Bond Purchases,* 2018th edn.

for a Materials company, resulting in new PDs "after-shock" of 0.94% (Utilities) and 4.77% (Materials). The latter PD of 4.77% would fall below the typical investment-grade threshold of 3% and would the ECB no longer allow to purchase these assets in the CSSP.

A different approach is used by authors from the International Monetary Fund (IMF) . They analyze the effect of climate risk for the Norwegian economy and its consequences for financial sector in three different transmission channels[48]. First, they analyze the financial risk of an big increase in domestic carbon prices. Second, they model a drastic increase in global carbon prices on the Norwegian economy via Norwegian oil sector as directly affected key industry as intermediary transmission channel. Third, they model the impact of a tight reduction in oil output of Norwegian firms to meet CO2 scope-3 emissions reduction targets on shareholder portfolios. Roughly 4% of all corporates fall below an Interest Coverage Ratio (ICR) of 1 or 2 based on different domestic CO2 prices while loans lose about 0.9% of their value in case of a global CO2 price of USD 150. Ultimately, losses for households, banks and pensions in asset valuations would lie between 5-11%.

Overall, the number of studies analyzing the impact of climate risk on individual firm-level is very limited. The project aims to fill this gap by providing a general concept on climate risk assessment and applying this concept on firm-level to two investment funds and a pillar III disclosure of a large European bank example.

3.2 Model

The literature review led to the development a 6-step approach how to run a climate stress test that analyzes the impact of transitory-climate risk for firms, for credit risk for banks and also for asset management portfolios. The six steps summarize many different climate stress test approaches as generic umbrella, i.e. top-down/macro, bottom-up/micro or any hybrid format. The concept can serve as initial guidance for researchers and practitioners how to run stress test for transitory-climate risk, a field which is developing rapidly not at least due to the initiatives by supervisory and regulatory authorities.

[48] Pierpaolo Grippa and Samuel Mann (2020). Climate-Related Stress Testing: Transition Risks in Norway WP/20/232: 1–38.

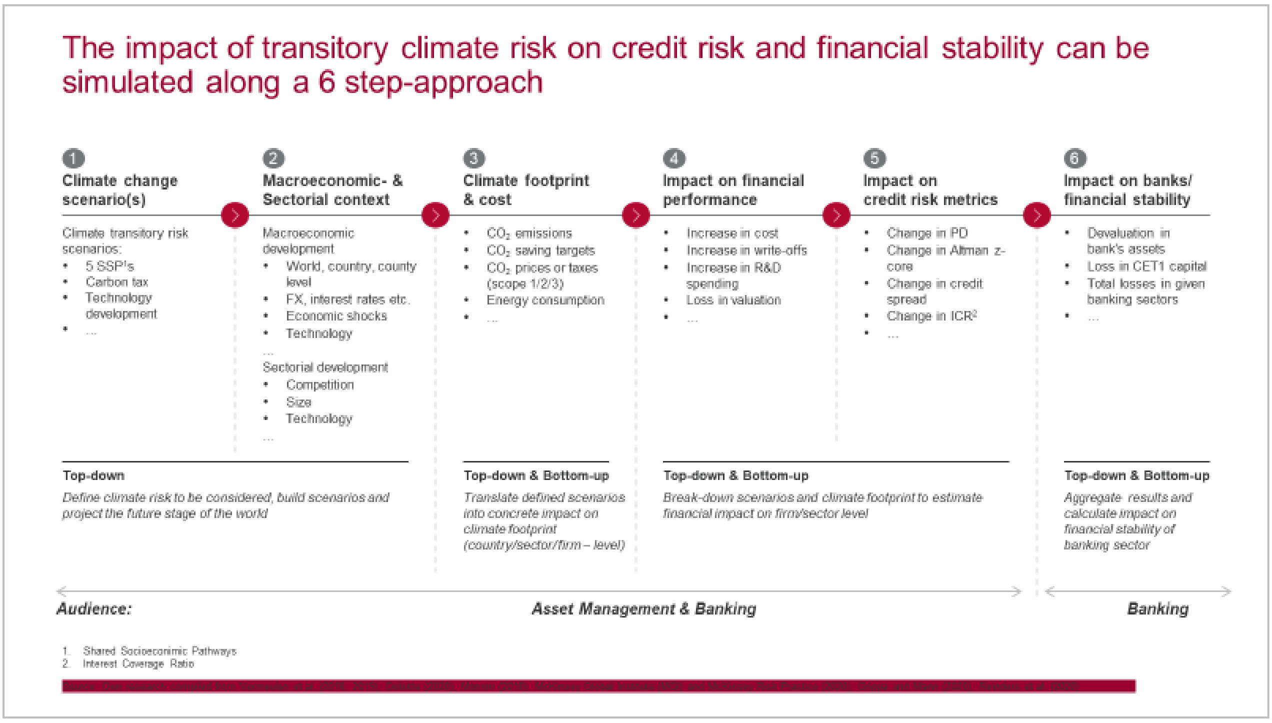

Figure 3: Generic 6-step approach to simulate transitory climate risk in stress tests.

The generic 6-step approach

Step 1 - Define transitory risk scenarios

The very first step is defining top-down the overarching scenarios in order to describe the "future (climate) states of the world". A good example for such scenarios are the five Shared Socioeconomic Pathways (SSPs) that forecast the future stage of the world with regards to climate, population, economics, technological progress etc. Transitory-climate risk scenarios are then integrated into these future stages of the world, for example through the assumption of a change in climate policy (e.g., CO2 tax) or changing consumer preferences towards sustainable, "green" business models.

Step 2 - Break-down scenarios onto macroeconomic/sectoral level

Once the future stages of the world are defined, they must be translated into macroeconomic development of nations, regions or sectors. On national/regional level, this can include for example GDP, investment or R&D development. On sector-level, the competitiveness, the technological progress or the size can be projected, subject to the pre-defined objective and scope of analysis. As a result, the economic development of countries or sectors are projected based on the defined scenarios in step 1. As for step 1, this step has rather top-down/macro character unless the sectorial analysis is also broken down onto firm-level and then aggregated again on sector level.

Step 3 - Develop climate footprint & cost

In the next step, the climate footprint together with its associated costs is computed based on the macroeconomic or sectoral forecast from step 2. This can include for example the CO2 emissions, the tax or price of CO2 emission before calculating the impact on financial performance in step 4. Alternatively to the bottom-up collection of CO2 emission data together with a CO2 tax or price, there is a way[49] to break down the globally aligned CO2 saving targets on country- and sector-level. Step 3 is then a hybrid form of top-down/macro and bottom-up/micro approach if the impact of transitory-climate risk is finally broken down on firm-level.

Step 4 - Calculate the impact on financial performance

Once the carbon footprint and its associated cost are computed, the impact on financial performance can be calculated. The results can then be translated into financial metrics (P&L, balance sheet items or financial statements) of firms or sectors. One example can be translating the cost of carbon footprint into operative P&L cost or write-offs (for example on stranded assets) and then integrating them into EBITDA[50]. Another example could be integrating the financial cost of carbon into DCF valuation items such as WACC or the risk-free interest rate (step 2). Since this can occur again on sector- and/or firm-level, the step is top-down and/or bottom-up.

Step 5 - Compute the impact on credit risk metrics

Once the impact of carbon footprint and its cost is integrated into the financial performance on firm- and/or sector-level, the impact on common supervisory (credit) risk figures can be derived. One example is to calculate new values of equity, debt and asset and compute new PDs (including transitory-climate risk) in a classical DtD-model approach. Other credit risk metrics (e.g., the Altman z-score or credit spread) can also be applied to assess the impact of climate risk on credit risk metrics[51], although they are the not the most commonly types of risks used by supervisory. Step 5 can be again compiled top-down and/or bottom-up.

Until this point, the calculation steps are regardless of the specific asset portfolio of financial institutions as the outcome of step 5 estimates the impact of transitory climate risk on firm- and/or

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[49] cf. note 45.

[50] Vincent Bouchet and Theo Le Guenedal (2020). Credit Risk Sensitivity to Carbon Price. *SSRN Journal*. 10.2139/ssrn.3574486. and cf. note 41.

[51] Suleiman A. Badayi, Bolaji T. Matemilola, Bany-Ariffin A. N and Lau Wei Theng (2020). Does corporate social responsibility influence firm probability of default? *Int J Fin Econ*. 10.1002/ijfe.1966; Mingzhi Liu and Wenxia Ge (2012). The Impact of Corporate Social Responsibility Disclosure and Performance on the Cost of Corporate Bonds. *Journal of Accounting and Public Policy* 34 (No. 6). 10.2139/ssrn.1985218.

sector-level. A typical climate "stress test" as mandated by the regulatory authorities is not yet conducted and therefore follows in the final step 6.

Step 6 - Calculate the impact on banks/financial sector - credit risk

Since step 5 yields the impact of transitory-climate risk on credit risk of firms or entire sectors, these numbers can be integrated into the common CRR stress test framework to compile the risk-weighted assets (RWA)[52] and change in capital ratios (CET 1, Tier 1 etc.) after transitory-climate risk. Subject to the previous entity and data exposure level data of financial institutions, this step can be performed on sector- or firm-level exposure for aggregated national financial sectors or single individual institutions [53].

The above step 6 takes primarily the banking/risk audience and suggest how to execute climate risk-related stress tests for the credit risk type. For the asset management audience to estimate potential portfolio losses due to climate risk, step 1-5 is largely the same. In step 6 though, the debt and equity devaluations from step 5 need to be integrated into relative share in the portfolio from to yield the new “post-shock” value of each position in the portfolio.

[52] This applies particularly for larger financial institutions with IRB-approach

[53] cf. note 39; cf. note 13.

Merton Model

The impact of transitory-climate risk (CO_2 tax) on valuations and PDs for the Eurostoxx 600 companies is estimated through Merton's structural option pricing model. The Merton Model assumes a simple capital structure where the firm's debt consists of one large outstanding bond with maturity as the weighted average of the firm's short-term liabilities (with maturity of one year) and long-term liabilities (with maturity of 13 years). The models assumes a firm's default when the value of the firm's assets fall below the book value of its total liabilities. This default point assumption is way more strict and severe than, for example, the approach taken by external rating agencies and also leads to an overestimation of the financial impact of climate risk.

Asset valuation shocks are then determined by dividing the NPV of the carbon tax payment by the company's total asset value. The amount of each year's cash outflow is determined by multiplying the company's yearly CO_2 emissions in tons $\gamma_{t,}$ by the tax fee τ_t for each year t. The discount rate used for finding this value is each company's specific weighted average cost of capital[54]. Furthermore, companies are expected to respond to such policies by passing a portion of the tax payments onto consumers by higher prices. This pass-through rate is represented by φ_i. Then, the NPV of future carbon tax payments for a given company can written as follows:

$$NPV_{tax} = \sum_{t=1}^{T} \frac{-\gamma_t(1-\phi)\tau_t}{(1+WACC)^t}$$

Lastly, the calculation for asset shocks is carried out by dividing the NPV of the carbon tax payments by the company's original total asset value V before the carbon tax payments:

$$\omega = \frac{NPV_{tax}}{V}$$

[54] For simplicity, cost of capital is assumed to be constant. However, increasing awareness of sustainability may affect cost of capital, leading to a rather conservative asset devaluation assessment for carbon-intensive firms du their higher risk exposure.

3.3 Scenarios

The asset valuation shocks stemming from transitory-climate risk policy are embedded into a set of scenarios around the following four dimensions:

- The specific tax rate per ton of CO2
- The adaptation capabilities of companies to reduce their carbon footprint in light of the upcoming increase in carbon price due to the introduction of/rise in the carbon tax
- The pass-through rate of this tax rate onto consumers
- The time horizon over which the tax is being implemented

Tax rate per ton of CO2

This analysis assumes an effective carbon tax rate of €50 or €100 per tCO2. According to a World Bank study by Stiglitz and other researchers from 2017, a carbon price of €50 and €100 per tCO2 is required to reach the Paris Climate Agreement goals[55]. Another study estimated a global carbon price of €100 to be sufficient with a ~ 95% probability to limit global warming to 3°C, with ~ 85% probability to keep it below 2.5°C, and with ~70% probability to keep it even below 2°C[56]. Another study from 2019 states that a price of €200[57] might be required to meet the climate targets. Other sources state that this could rise up to several hundreds of € per tCO2 under several pathways of emerging technology to replace CO2-intensive energy sources[58]. Despite the heterogenous landscape of CO2 price/tax rate levels in Europe (Germany for example with €25 per tCO2 fuel and heating while in Scandinavia, prices for several sectors are considerably higher), tax rates per tCO2 in the analysis are assumed to be uniformly valid across sectors and countries. The tax rates are also assumed to be imposed on top of the ETS on European level as are all national CO2 tax rates. Depending on the current level and scope of the taxes, this is equal to either an introduction of-/a rise in tax rate, respectively. Moreover, the analysis assumes that market participants already priced a rise in CO2 price/tax rates in the future. Then, the sudden introduction of-/a rise in CO2 price/tax rates of €50 and €100 per tCO2 is truly an exogenous shock

[55] High-Level Commission on Carbon Prices. 2017. Report of the High-Level Commission on Carbon Prices. Washington, DC: World Bank.

[56] Rogelj et al. (2013). *Probabilistic cost estimates for climate change mitigation*

[57] cf. note 39; Stefan et al. Bach (2019). *Für eine sozialverträgliche CO2-Bepreisung: Politikberatung kompakt,* 138th edn.

[58] Steven Poelhekke (2017). *How expensive should CO2 be? Fuel for the debate on optimal climate policy,* 579th edn.

that market participants need to account for in their valuation of firms and management of their asset portfolios.

Adaptation capabilities of companies

An introduction and/or rise in CO2 taxes may alter the optimal choice of energy mix by firms. Therefore, the analysis assumes in the most favorable scenario a decrease in CO2 emissions of 25% compared to latest ESG-report disclosures of firms. This number is based on selected case examples over recent years from carbon-intensive and carbon-efficient companies across industries, e.g., from utilities, basic resources or grocery/consumer goods. Alternatively, this factor can interpreted as sudden availability of green technology that makes renewable energy sources relatively more efficient. As a consequence, firms can easier substitute fossil fuel energy with renewable sources to lower their carbon emissions already in the short-run time horizon of stress tests of 1-3 years. In the most adverse scenario 4, the analysis assumes no CO2 emission reduction by firms though.

Pass-through rates onto consumers

Increasing “cost”, in this case through new/rising CO2 tax payments, can be passed by firms onto consumers through higher prices in order to limit the financial impact. The capability to do is highly based on the competitiveness and/or price sensitivities of the specific sector. Since a carbon tax has similar character as a consumption tax (a product or service that produces emissions is consumed), the analysis relies on empirically estimated pass-through-rates from the VAT literature. Across the four defined scenarios, the range of the pass-through rate is assumed to be 50-80%.

Time horizon of the actual introduction of the tax

Since the analysis aims to reproduce a common stress test in an adverse scenario as required by the supervisory authorities with typical stress-test time-horizon of the next 1-3 years, the analysis uses the abrupt introduction up to €50€ or €100, respectively. The results then truly reveal the resiliency of firms and financial institutions against a sudden increase in CO2 tax[59].

[59] A phase-in implementation of the tax over 3 years does not produce substantial differences in the analysis for two reasons. First, the time horizon of 3 years is rather small to spread the burden of a higher/rising tax over several years and at least in the last modelled year, the tax had to equal the final tax amount anyway; Second, as typical with NPV calculation schemes, the terminal value is the major driver in the overall impact on valuations.

The following tables summarizes the four scenarios in the analysis:

Scenario	Tax Rate (€ per tCO2)	CO2 Reduction (% of y0)	Pass-through rate (%)
1	€50	-25%	80%
2	€50	0%	80%
3	€100	-25%	50%
4	€100	0%	50%

Table 2:: Definition of 4 main scenarios.

Due to the complexity of the analysis (firm-level analysis of 600 companies for each of the four scenarios), results are mostly displayed only for the lowest and highest impact scenarios 1 and 4 or as a range between those two scenarios. Scenarios 2 and 3 illustrate, however, the change in magnitude of results when changing any of the 3 variable scenario dimensions: the tax rate, emission reduction capabilities and the pass-through rate onto consumers. In most cases, scenarios 1 and 2 on the one hand and scenarios 3 and 4 on the other hand are comparably close to each other.

3.4 Data and exposure

The dataset consists of the companies listed in the Euro STOXX 600 excluding 69 financial corporations due to their higher leverage compared to non-financial corporations and 127 companies due to missing scope 1 GHG emission data in their ESG reports. This results in 404 European publicly listed companies in the final sample. While market prices of the stocks for calculations are extracted from January 1st, 2015 until June 1st, 2021, accounting data is taken from the most recent published statements as per time of writing.

The following chart shows individual scope-1 CO2 emissions of firms sorted by- and also aggregated by ICB supersector classification. In other words, the tables provides a first glimpse on the vulnerability of firms and sectors towards rising “cost” of CO2 in form of future carbon tax payments.

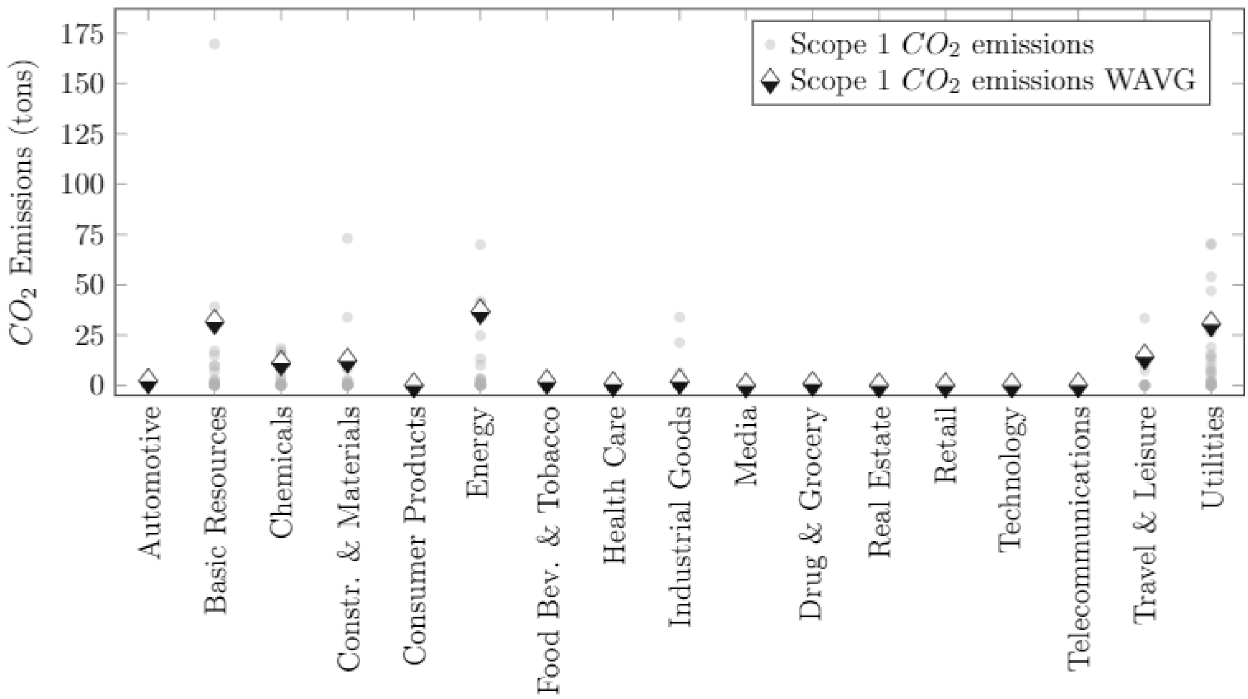

Figure 4: Scope 1 CO2 emissions by ICB supersector.

In figure 4 and other charts in this report, WAVG stands for the weighted average of firms within a sector by total liabilities. The plot reveals two central messages: First, there are sectors such as basic resources, energy or utilities with relatively high CO2 emissions on aggregated level compared to relatively low or almost zero emissions in consumer products, health care or real estate. Second, there is a substantial variance in emissions among firms particularly in the high CO2 emission sectors compared to low CO2 emission sectors in which the very large majority of companies emits very few or almost CO2 emissions.

3.5 Results

The plot below shows the asset shocks compiled by ICB supersector for scenarios 1 and 4 as defined in table 2.

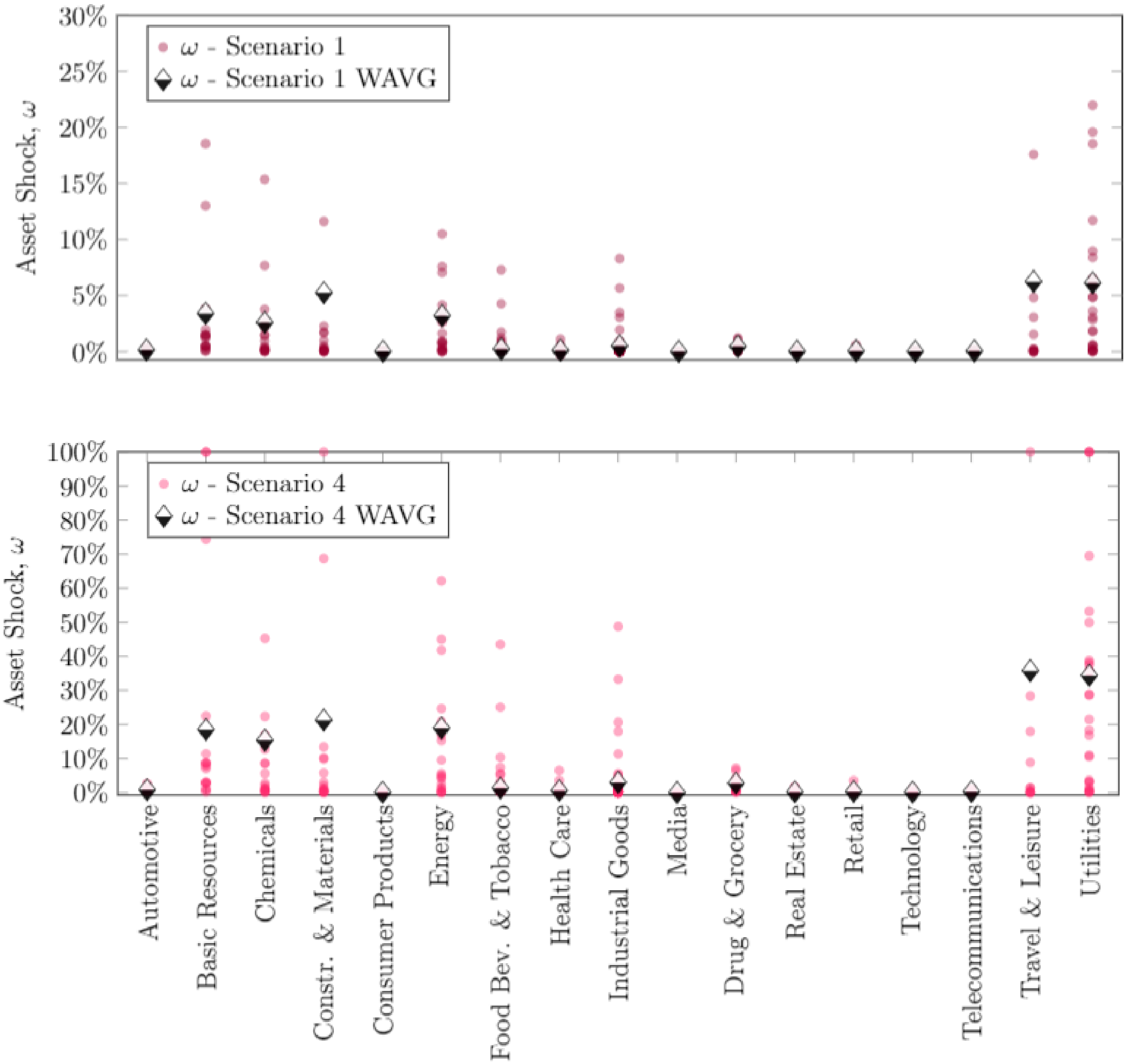

Figure 5: Asset Shocks for individual firms ordered per ICB supersector – Scenarios 1 and 4.

In figure 5, the dots represent individual asset devaluations of single firms while the black and white markers again reflect the average asset valuation shocks per sector weighted by total liabilities of that sector.

The following table shows the numbers the asset shock valuation for all four defined scenarios on aggregated level from figure 5:

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Automotive	0.14%	0.17%	0.71%	0.84%
Basic Resources	3.40%	3.95%	16.38%	18.53%
Chemicals	2.61%	3.08%	13.03%	15.39%
Constr. & Materials	5.25%	6.21%	19.45%	21.31%
Consumer Products	0.02%	0.02%	0.10%	0.12%
Energy	3.20%	3.79%	16.02%	18.94%
Food, Bev., & Tobacco	0.23%	0.27%	1.13%	1.33%
Health Care.	0.10%	0.12%	0.52%	0.61%
Industrial Goods	0.51%	0.60%	2.56%	3.01%
Media	0.00%	0.01%	0.02%	0.02%
Drug & Grocery Stores	0.46%	0.55%	2.32%	2.76%
Real Estate	0.03%	0.04%	0.17%	0.20%
Retail	0.05%	0.06%	0.27%	0.31%
Technology	0.02%	0.03%	0.11%	0.13%
Telecommunications	0.05%	0.06%	0.27%	0.32%
Travel & Leisure	6.25%	7.40%	31.26%	35.82%
Utilities	6.13%	7.28%	30.24%	34.43%

Table 3: Asset Shocks by ICB supersector, scenarios 1,2,3 and 4.

43 or about 10% of the sample firms would exhibit asset devaluations >15% and 25 firms asset devaluations with >30% in the adverse scenario 4. These numbers per se illustrate that climate risk in the form of a new/rising CO2 tax under the defined scenario assumptions poses substantial financial risk for those firms.

On sector-level, the analysis reveals three groups of sectors by impact of climate risk: First, the two heavily affected industries with the highest asset devaluations between ~6% in scenario 1 to ~35% in scenario 4 are travel & leisure as well as utilities. Within the travel & leisure sector, the main driver of asset devaluation on sector-level are the two airlines Lufthansa AG and International Consolidated Airlines Group SA with asset devaluations between ~17.6-100% and ~3.1-18.0%, respectively[60]. Another big contribution in the sector comes from the sea transportation company Carnival PLC with asset devaluations of ~1.5-8.9%. These three companies together constitute about two third of the entire total liabilities of the sector in the sample. In the utilities sector the impact across firms is more equally distributed with 10 out of 27 companies in the sector experiencing asset devaluation shocks larger >30% in the most adverse scenario 4. Besides the French company EDF, the share of the 27 constituents in the sector is also more equally distributed across the firms. In other words, the sector is on average higher affected than the travel & leisure sector across its firms.

The second group of industries also suffering substantial asset devaluations is basic resources, chemicals, construction & materials and energy with an range of asset shocks between 2.6% in scenario 1 to 21.3% in scenario 4. In sum, also these sectors would be heavily affected under the assumed scenarios although the variance in asset devaluations is not as high as for travel & leisure.

The third and remaining group of sectors would be barely affected in the analysis, such as consumer products, health care, media, industrial goods or drug & grocery stores, although the two latter industries would be slightly more affected then the other sectors with asset devaluations up to 2.7% and 3.0%, respectively.

The above results can be interpreted economically in two different ways. In scenario 1 and 3 with emission reduction capabilities of 25%, the rise/introduction in CO2 taxes incentivizes companies successfully to deploy a higher share of green energy mix as the relative cost of fossil fuel energy sources increase with higher CO2 cost. In this case, the above asset devaluation could stem from firms writing off their "brown" assets, resulting in the CO2 carbon tax payments[61]. In contrast, the rise in CO2 cost in scenario 2 and 4 could be insufficient to move firms towards a greener energy mix, for example because the timing is too abrupt and/or the marginal cost of replacing "brown" energy are deemed to be too high. In that case, firms are exposed to the full extent of asset devaluation due to CO2 tax payments on a remaining amount of "brown" assets in the balance sheets[62].

[60] The impact of airlines on the travel & leisure sector may very well be stronger in reality. However, most of them do not report scope 1 emissions, that's why they are not part of the sample.

[61] cf. note 13.

[62] See Vermeulen et al. (2019) for the full argumentation.

The above asset valuation shocks are then taken one step further to calculate the company's new PD after the transitory-climate risk has been integrated into the valuation.

At this stage it is important to note that already pre-shock PDs are considerably high due to the specifics of the applied Merton Model, most notably the strict default point of firms when the value of assets drops below the value of debt. Other models used by practitioners (i.e. banks or rating agencies) might therefore lead to somewhat lower pre-shock and post-shock PDs across all four scenarios.

The following charts depict the new PDs after transitory-climate risk:

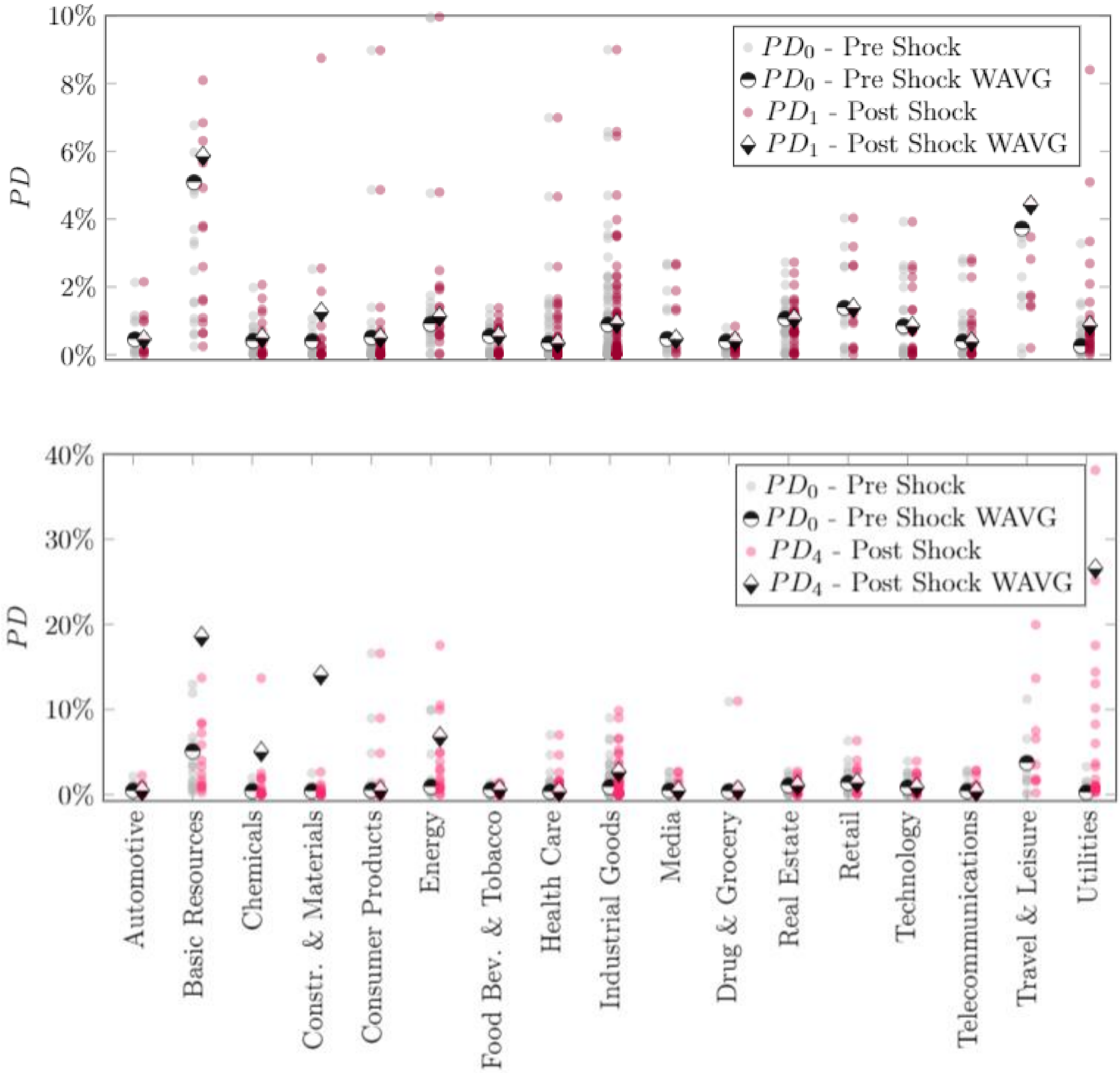

Figure 6: Pre-shock and post-shock PDs by ICB supersector, Scenarios 1 and 4.

The lighter left-side dots in each ICB supersector column represent individual companies' 1-year PDs before the exogenous policy shock is applied. The darker right-side dots represent post-shock PDs.

	Scenario 1 PD	Scenario 2 PD	Scenario 3 PD	Scenario 4 PD
Automotive	0.46[+0.01]	0.46[+0.01]	0.49[+0.03]	0.49[+0.04]
Basic Resources	5.86[+0.78]	6.02[+0.94]	15.87[+10.79]	18.57[+13.49]
Chemicals	0.51[+0.10]	0.53[+0.13]	3.76[+3.36]	5.05[+4.65]
Constr. & Materials	1.27[+0.87]	1.78[+1.38]	12.09[+11.69]	14.05[+13.65]
Consumer Products	0.51[+0.00]	0.51[+0.00]	0.51[+0.00]	0.51[+0.00]
Energy	1.13[+0.22]	1.18[+0.28]	4.64[+3.74]	6.81[+5.90]
Food, Bev., & Tobacco	0.56[+0.01]	0.56[+0.01]	0.59[+0.04]	0.59[+0.04]
Health Care	0.34[+0.00]	0.34[+0.00]	0.36[+0.02]	0.36[+0.02]
Industrial Goods	0.92[+0.04]	0.93[+0.07]	1.96[+1.07]	2.66[+1.77]
Media	0.47[+0.00]	0.47[+0.00]	0.47[+0.00]	0.47[+0.00]
Drug & Grocery Stores	0.41[+0.04]	0.42[+0.05]	0.52[+0.22]	0.55[+0.27]
Real Estate	1.06[+0.02]	1.06[+0.02]	1.07[+0.13]	1.08[+0.16]
Retail	1.39[+0.01]	1.39[+0.01]	1.41[+0.03]	1.41[+0.03]
Technology	0.85[+0.00]	0.85[+0.00]	0.85[+0.01]	0.85[+0.01]
Telecommunications	0.39[+0.00]	0.39[+0.00]	0.39[+0.01]	0.39[+0.01]
Travel & Leisure	4.42[+0.70]	4.85[+1.13]	33.39[+29.67]	34.21[+30.49]
Utilities	0.86[+0.61]	1.20[+0.95]	21.72[+21.47]	26.58[+26.33]

Table 4: ICB supersector PDs for each scenario and PD spreads from pre-shock state; All numbers in%.

The table illustrates new PDs after transitory-climate risk as well as the incremental increase in PDs, i.e. the PD spread, to the base case (pre transitory-climate risk) in square brackets per scenario.

The table generally confirms the notation from the asset devaluation results, however the three groups of sectors from the asset devaluation impact are slightly dissolving in the PD analysis.

First, there are again heavily affected sectors such as travel & leisure, utilities, basic resources, or construction & materials. Then, there are sectors such as chemicals, energy or industrial goods with substantial impact in the range of about 3-7% PD after transitory-climate risk. Last but not least, there are sectors that are again only slightly affected such as automotive, consumer products or media. Interestingly, the PDs from chemicals and energy sector are not among the highest ones across sectors, explanations are for example a lower leverage or different maturity of debt among these two sectors compared to other sectors.

When it comes to specific sectors, travel & leisure shows again a large variance in PDs within the sector with the large majority of the rise in PD driven by airline companies.

Utilities is again one of the most affected sectors as new PDs range from 0.6-26.3%, with the PD spread in similar range. The main driver in the sector are again companies producing and distributing of electricity companies.

The increase in PDs the basic resources sector with new PDs between 5.7-18.6% and new PD spreads between 0.78%-13.49%, respectively is mainly due to companies operating in very CO2 intensive sectors such as mining or casting of metals. Manufactures of paper, household and sanitary products are on the other hand only affected to a very limited extent.

Lastly, the construction & materials sectors shows again considerable impact with new PDs and PD spreads up to 13-14% with the heaviest impact on the cement industry within the sector.

Although the CO2 tax is to some extent comparable to a consumption tax such as the valued added tax and could therefore have similar effect across sectors, the analysis shows that the main driver behind the deviation of impact among firms and sectors is the CO2 emission intensity. This holds particularly true when looking at the difference in PDs between the two most extreme scenarios 1 and 4 for the CO2 intensive sectors (for example: about 13 percentage points for Basic Resources and Construction & Materials, about 30 percentage points for Travel & Leisure and 25 percentage points for Utilities, respectively) compared to a relatively limited difference in PDs for all the other CO2 efficient sectors. The two most notable exceptions are chemicals and energy with considerably lower PDs despite facing asset valuations up to 15-19% in the most adverse scenario.

Two main conclusions can be drawn from the results. First, there are heavily affected sectors with severe and dangerous asset shocks and increases in PDs due to transitory-climate risk while the impact on the other sectors remains very limited. Second, the results show the severe risk for financial institutions in asset management and credit lending arising from the asset shocks and drop in PDs.

The results are, presumably, on the more aggressive side of the scale primarily for two reasons: First, because the Merton Model assumes default when the value of assets is below the value of liabilities in contrast to for example rating agencies and second, because market participants may have already priced in a certain rise in CO_2 prices or taxes in their investment decisions. Hence not the entire tax of €50-100 per ton entails a shock but only part of it.

However, not all assumptions and inputs point towards an aggressive scenario as the analysis includes for scenarios 1 and 3 adaptation capabilities of companies up to 25% to reduce their carbon footprint and pass through rates onto customers of 80% and 50% respectively across all 4 scenarios, respectively. These two factors smoothen the effect of the rising CO_2 tax payments and thus the impact on asset devaluations and PDs of the companies. Nevertheless, the financial risk arising from transitory-climate risk can pose a considerable threat for the stability of the financial sector as the results show particularly in scenarios 3 and 4.

This risk is further illustrated by applying the results from this analysis to two investment portfolios and by running a stress test on credit to measure the impact of the decrease in PDs on Basel III capital ratios in the following.

3.5.1. Impact on investment portfolios

Besides devaluations of asset values, the Merton Model also yields devaluations in market values of equity and debt. Both values for the 404 firms are then taken in order to illustrate the impact of transitory climate risk in form of a CO_2 tax on the asset management side. The analysis includes two funds, one fund with 96% pure equity share consisting mainly of Eurostoxx companies and one mixed fund consisting of 63% equity share and 27% bond share. The % devaluations in market values of debt and equity from the previous analysis are applied by the relative share of the 404 companies in the two investment funds. For example if a company experiences a 10% equity devaluation from the Merton Model and has a 2% share within the entire fund, then the loss for the entire fund equals 0.2%. For simplicity, the same approach has been taken for all corporate debt positions, regardless of their specific coupon or maturity. A more granular approach will be required in the future to adequately derive the financial impact from climate risk particularly on debt positions. The aggregate losses of the two investment funds range between 2.3-9.1% for the equity fund and 1.2-3.5% for the mixed fund while only addressing about 79.5% of the equity fund and about 45.3% of the mixed fund. If the two funds were perfectly replicating the sample of 404 companies of the asset devaluation and PD analysis, the losses for the two were equal to 11.4% and 7.8%, respectively. The magnitude of the results indicate again the relevance of climate risk from asset management perspective and requires asset managers to manage their inherent climate risk in their portfolios very carefully.

	Equity fund	Mixed fund
Actual addressable share within portfolio fund	79.5%	45.3%
Scenario 1	2.27%	1.19%
Scenario 2	2.69%	1.39%
Scenario 3	8.05%	3.20%
Scenario 4	9.10%	3.53%

Table 5: Impact of transitory climate risk applied to two investment funds.

3.5.2. Impact on Basel III capital ratios

For the practical application from the banking perspective, the analysis relies on a pillar III disclosure from 2019 of a large European bank. The new PDs ("post shock") from the previous section are used to recompute the risk-weighted assets (RWA) of corporate loan exposures equal to 36% of the bank's total RWA. The change in RWA due to the transitory climate risk and higher ("post shock") PDs is then used to recalculate capital ratios.

The macroeconomic environment is again assumed to remain constant throughout the scenarios to isolate the financial impact of transitory-climate risk. If the macroeconomic environment worsens, the effects on capital ratios would be substantially higher. The calculations are on industry-level due to missing loan exposure data on issuer-level in the pillar III disclosure.

The following figure shows the results for the three main capital ratios that banks are required to comply with under Basel III regulation.

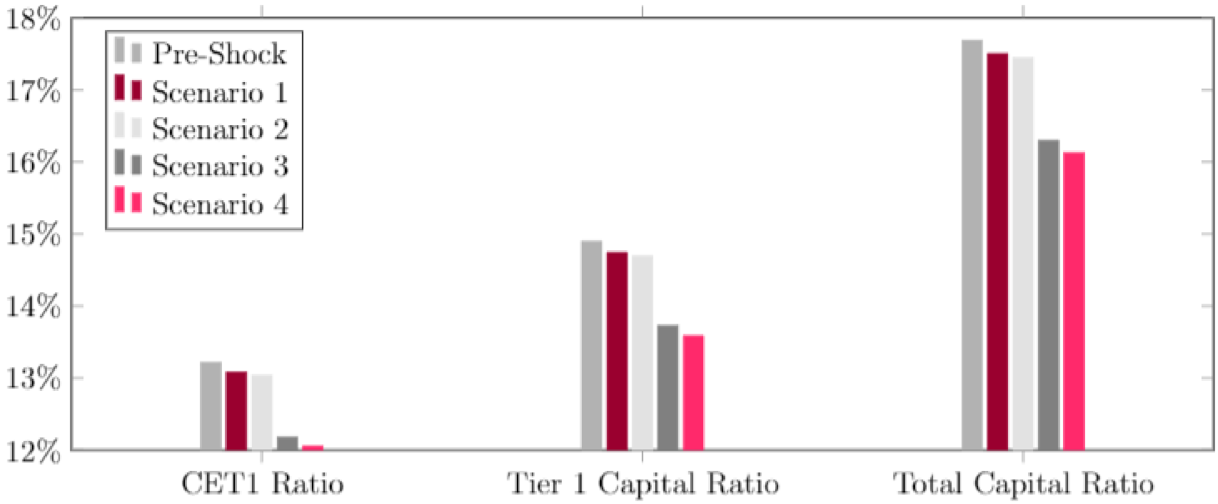

Figure 7: Basel III Capital Ratios by scenario

The table below reports exact values from figure 7.

	CET1 Ratio	Tier1 Capital Ratio	Total Capital Ratio
Pre-Shock	13.22%	14.90%	17.69%
Scenario 1	13.08%	14.74%	17.50%
Scenario 2	13.04%	14.69%	17.45%
Scenario 3	12.18%	13.73%	16.30%
Scenario 4	12.05%	13.59%	16.13%

Table 6: Basel III Capital Ratios by scenario – values.

The analysis yields a decline in CET1 ratio from 0.14 to 1.17 percentage points, a decline in Tier 1 ratio from 0.15 to 1.31 percentage points and finally a decline in Total Capital ratio within the range of 0.18 and 1.56 percentage points. Again, the analysis addresses only about one third (36%) of the bank's total RWA and, therefore also the results reflect only a part of the actual risk this bank would be confronted with the underlying assumptions of the analysis.

Conclusion

Climate change with its various types of risk can materialize in severe financial risk for firms, entire sectors and the financial sector as lender of these sectors. Through direct and indirect transmission channels, this financial risk can harm the stability of the financial stability, which can in turn feed back into the real economy and the financial sector in so-called 2nd round effects[63]. In order to adequately integrate climate risk in the regulation and decision making in the financial sector, this report addresses two questions:

First, how to anchor climate risk in the regulation of financial institutions, most notably into the CRR. The literature reveals three options: Introducing a completely new risk type “climate risk”, integrating climate risk into credit risk (climate risk as a driver of credit risk) or using other mechanisms in the regulation (e.g., minimum reserve requirements) to integrate climate risk. For the reasons outlined in chapter 2, the project suggests to stick with the status of the current regulation because most of the options above often have economic policy character and intend to steer additional capital into “green” lending.

Second, how can climate risk be integrated into stress tests in light of increasing relevance of climate risk as driver of financial risk and increasing regulatory efforts to integrate this risk in the regulation. Based on a literature review with the very limited availability of studies, a standardized 6-step approach has been developed how to run climate risk-related stress tests. This 6-step approach is then applied for two investment funds and a pillar III framework to illustrate the practical application and relevance of climate risk per se. A carbon tax of €50-100 per tCO2 equivalent that targets the constituent companies of the Euro Stoxx 600 price index along 4 precise scenarios yields for 43 or about 10% of the firm sample asset devaluations >15% and for 25 firms asset shocks with >30% in the adverse scenario. Aggregated on sector by weighted liabilities within a sector, asset devaluations range between 15.4% and 35.8% for the 6 most affected sectors according to the ICB sector classification while the other 11 sectors are only affected to some extent.

Once these asset devaluations are used to compute new (post-shock) PDs, the results yield for 66 out of 404 firms in the final sample new PD levels >3% in the adverse scenario. The 6 most affected sectors face PDs between 5.1% and 34.2%.

Once the market devaluation of asset values is split in debt and equity devaluation, the impact on two exemplary investment funds yields portfolio losses for those two funds between 1.2-9.1% while only addressing about 45.3-79.5% share of those two funds.

[63] NFGS(2020)

The new (post-shock) PDs yield a decrease in the capital ratios of one large European bank example up from -1.2% to -1.6% if the Eurostoxx 600 members were representative for the exact corporate credit exposure of this bank.

The report underlines the importance of ESG risks for the financial industry based on the effects of transitory climate risks on asset valuation PDs and reveals three concrete fields of action.

First, financial institutions should continue the intensive examination of the topic initially focusing on – analogous to the paper – assessing interdependencies and transmission channels and establishing market standards while monitoring the entire ESG topics as such.

Second, the risk analysis relies on extensive data availability of debtors that must be significantly increased both in breadth (e.g. SMEs) and in depth (e.g., not only the current CO2 emissions but also target values of companies) . The project team recommends establishing uniform regulatory standards for the disclosure of ESG data also in other industries beyond the financial sector. The data collection from debtors should not be the task of financial institutions alone to prevent institutions with ambitious ESG goals from losing market share. The issue of data availability remains particularly relevant for SMEs due to their comparably lower publication requirements. Rather, the transformation to a carbon-free world economic system is a cross-sectoral and cross-border task that must be facilitated through adequate political frameworks and actions in a competition-neutral manner.

Third, the quantitative part of the study shows how climate risk drives credit risk. The project team recommends to integrate the management of ESG risks into the established risk management cycles of credit risks and other types of risk, while showing transparently how ESG risks drive these established risk types. A risk management only for ESG risks might induce high overlaps with other risk types in the context rating processes or non-differentiable fair value effects. Therefore, the team proposes to stick with the current Basel III/CRR in Pillar 1 regulation and not to add any new ESG-specific risk types.

Appendix

Further ideas of how to anchor climate risk in the Basel III regulation

Countercyclical capital buffer (CCyB) and negative capital buffer

The purpose of the CCyB since its introduction in 2010 is to force financial institutions to build up a financial buffer for systematic vulnerabilities as buffer in contractionary phases[64]. According to the review of the CCyb[65] and other authors[66], the actual effectiveness of the CCyB is at least questioned. That's why other authors[67] suggest to reinforce the CCyB to mitigate the effects of transition risk lending. The CCyB can be established in a phase of high carbon-intensive credit growth and used a buffer against losses, e.g. due to stranded assets. Figure 8 shows the CCyB mechanism for "brown" credits over one credit cycle.

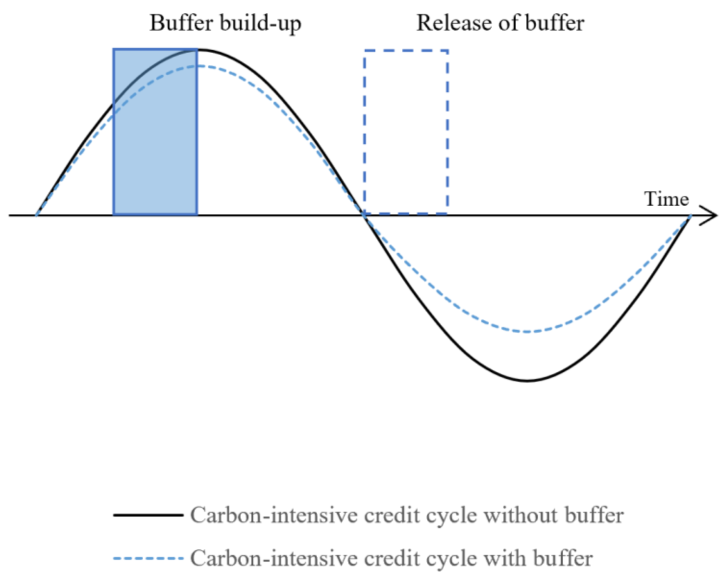

Figure 8: CCyB mechanism over the carbon-intensive credit cycle[68].

[64] BCBS (2020). *Climate-related financial risks: a survey on current initiatives*.

[65] Paola D'Orazio and Lilit Popoyan (2018). Fostering Green Investments and Tackling Climate-Related Financial Risks: Which Role for Macroprudential Policies? *SSRN Journal*. 10.2139/ssrn.3106350.

[66] cf. note 62.; Eugenio Cerutti, Stijn Claessens and Luc Laeven (2017). The use and effectiveness of macroprudential policies: New evidence. *Journal of Financial Stability* 28: 203–224. 10.1016/j.jfs.2015.10.004; BCBS (2017). *Basel III: Finalising post-crisis reforms*

[67] cf. note 63.

[68] D'Orazio and Popoyan (2018, 16).

Similar to the CCyB and the GSF nature, one could argue for a negative capital buffer that eases capital requirements with increasing share of green assets in the portfolio[69].

Sectoral leverage ratio (SLR)

A maximum sectoral leverage ratio could set a tight limit to lending towards carbon-intensive sectors that could formally look as such:

$$LR_t^{Sector} = \frac{Tier\ 1\ capital}{Exposures\ to\ carbon - intensive\ sector} \geq \gamma$$

In order set an adequate ratio limit, a detailed exposure of financial institutions by a uniform sector classification as well as detailed carbon-intensities per sector of borrowers or loans would be required. The SLR sets an incentive for financial institutions to reduce their exposure to carbon-intensive sectors to avoid tighter capital requirements for carbon-intensive while it also enhances their resilience to unexpected losses.[70]

Liquidity regulation

The Basel III framework requires financial institutions to meet two central liquidity requirements in order to smooth the maturity mismatch between rather short-term obligations such as deposits and typically rather long-term assets (loans, mortgages etc.): Whereas the Liquidity Coverage Ratio (LCR) requires institutions to hold a minimum of short-term liquidity, the Net Stable Funding Ratio (NSFR) prescribes to fund long-term assets with sources of at least one-year maturity[71]. However, the long-term nature of "green" lending and the combination of these two ratios could prevent banks from holding excessive long-term assets (e.g., green lending assets), due to the comparably higher cost of long-term liabilities versus short-term liabilities,[72] but also other authors[73] for reluctance of holding excessive long-term assets. As a response, the EBF proposes to introduce a "lower required stable funding factor (RSF)" for green asset exposure in the following manner:

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[69] ibid.

[70] ibid.

[71] ibid., p. 17.

[72] ibid.

[73] Michael Liebreich (2013). *Financial Regulation – Biased against Clean Energy and Green Infrastructure?: Discussion paper prepared by the Global Agenda Council on New Energy Architecture*. Cologny/Geneva: World Economic Forum.; Thomas Spencer and Jamie Stevenson (2013). EU Low-Carbon Investment and New Financial Sector Regulation: What Impacts and What Policy Response? *Working Papers* n°04 (13)

Large exposure limit

The rationale behind this option to reduce the potential losses to a certain extent that does not endanger the bank's solvency. The concept could set maximum exposure limits for specific counterpart(s) from carbon-intensive sectors as they are associated with considerable climate risk raising credit risk of those assets as such. By protecting institutions from potential heavy losses that could jeopardize the bank's solvency, this approach would also act as a safeguard against systemic (climate-related) risk[74].

Differentiated reserve requirements

Another instrument could be the use of differentiated reserve requirements as incentive for banks to foster the transition to a carbon-free economy. Originally, they are used as counterpart to customer deposits and notes and regulated by the national central banks. Similar to the logic of other options mentioned, the reserve requirements could be eased for banks with increasing share of "green" lending- and tightened for a large share of "brown" lending in the overall portfolio:

$$R_t = \sigma * D_t,$$

where D_t is the amount of customer deposits held by a bank at time t and σ the fraction of deposits kept as a reserve. σ would distinguish between banks with a green or "brown" loan portfolio, i.e.,

$$\sigma \in \{\sigma_{brown}, \sigma_{green}\} \text{ and } 0 < \sigma_{green} < \sigma_{brown}.$$

Again, the design of the factor "omega" is the crucial aspect in this instrument as this sets the incentive for banks to channel capital into "green" assets or reduce exposure towards "brown" assets, respectively. This instrument is or has been applied in some countries, for example in China or Lebanon[75].

Minimum credit floors and maximum credit ceilings

Besides the above options referring to a large extent to the Basel III framework, there is also one quite drastic approach to integrate climate risk into the current regulation: Minimum floors and maximum ceilings of credit exposures regardless of the actual creditworthiness and credit risk of borrowers solely based on pre-defined exposure rations to "green" (Minimum) and "brown" (Maximum) exposures by the regulator. Yet, according to several studies[76], they gained some

[74] cf. note 63, pp. 18–19.

[75] ibid.

[76] C. Lim, F. Columba, A. Costa, P. Kongsamut, A. Otani, M. Saiyid, T. Wezel and X. Wu (2011). Macroprudential Policy: What Instruments and How to Use Them? Lessons from Country Experiences. *IMF*

momentum immediately after the financial crisis to limit further potential write-offs due to insolvencies of several institutions[77]. However, given the drastic intervention into the credit lending processes, this option remains highly unlikely and is only mentioned here for completeness reasons.

Further approach to integrate climate risk into stress tests – Macroeconomic regression approach

Besides computing credit risk through an estimation of asset valuation shocks and translating those into PDs, another approach is to link PDs with scenario-based forecasts of macroeconomic variables from 2020 to 2050. The 3 stressed scenarios include a base scenario, an orderly scenario in which climate impacts are considered right from the start and a disorderly scenario in which measures are implemented with a delay of ten years. The framework builds on a distributed lag regression model which predicts sector-specific default rates by taking several macroeconomic indicators as predictors. The historical data is based on publicly available time series. The sector-specific breakdown builds on the commonly used NACE Rev. 2 classification on the granularity of NACE divisions and sections. Sector-specific vulnerabilities to climate risks are considered by transition vulnerability factors which are applied to sector-specific deviations in default rates. The results show severe impacts in terms of absolute values of default rates and deviation in default rates to the base scenario for the stressed scenarios, in general with an even more severe impact for the disorderly scenario. The most vulnerable sectors turn out to be D35 - Electricity, gas, steam and air conditioning supply, C19 - Manufacture of coke and refined petroleum products, 24C - Manufacture of basic metals, C17 - Manufacture of paper and paper products and C23 - Manufacture of other non-metallic mineral products. The outcomes suggest that financial institutions and authorities should closely monitor default risks and implement measures to address potentially increasing future default rates for vulnerable sectors.

The following result tables show the new final PDs over time for selected sectors with the described method and the percent deviation from the orderly and disorderly scenario relative to the base case scenario as defined by the NGFS.

Working Papers 11 (238): 1–85. 10.5089/9781463922603.001. Jan Willem van den End (2016). A macroprudential approach to address liquidity risk with the loan-to-deposit ratio. *The European Journal of Finance* 22 (3): 237–253. 10.1080/1351847X.2014.983137

[77] cf. note 63.

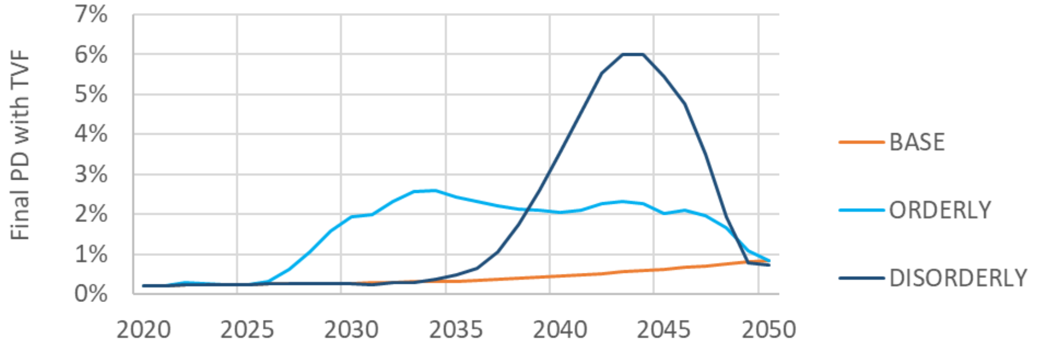

Figure 9: PDs of sector D35 (Electricity, Gas, Steam and Air Conditioning Supply) for the base, the orderly and the disorderly scenario.

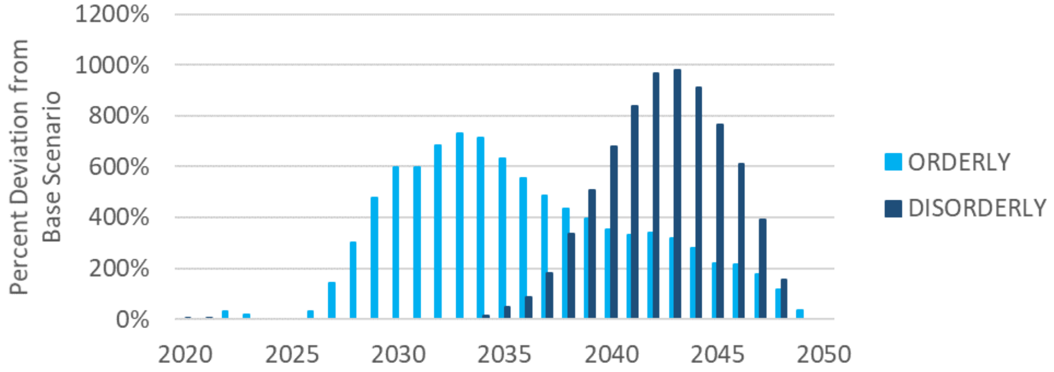

Figure 10: Deviations from the base scenario of sector D35 (Electricity, Gas, Steam and Air Conditioning Supply) for the orderly and the disorderly scenario.

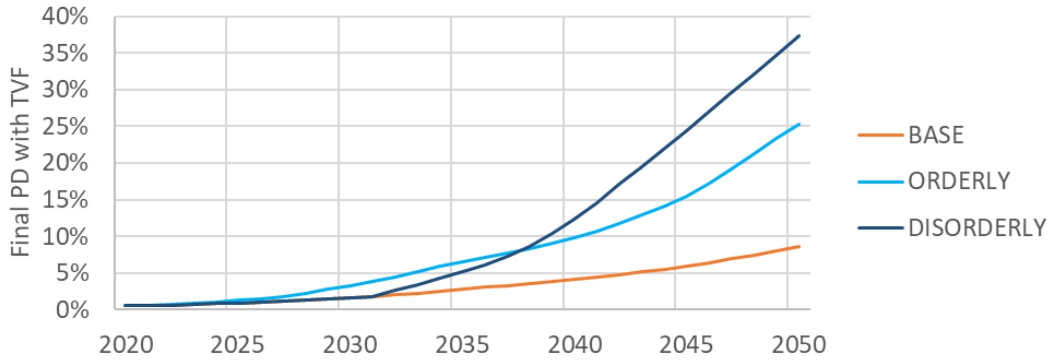

Figure 11: PDs of aggregated sectors C19, C22, C23, C24, C25, C33: Medium-low-technology Manufacturing Industries for the base, the orderly and the disorderly scenario.

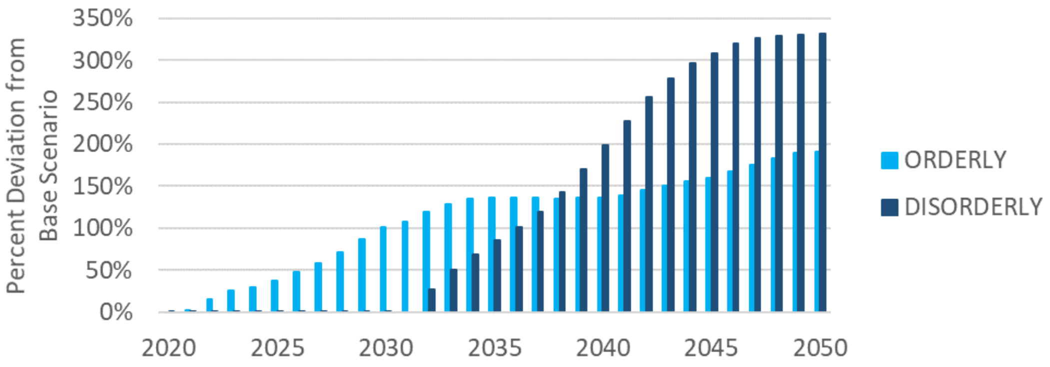

Figure 12: Deviations from the base scenario of aggregated sectors C19, C22, C23, C24, C25, C33: Medium-low-technology Manufacturing Industries for the orderly and the disorderly scenario.

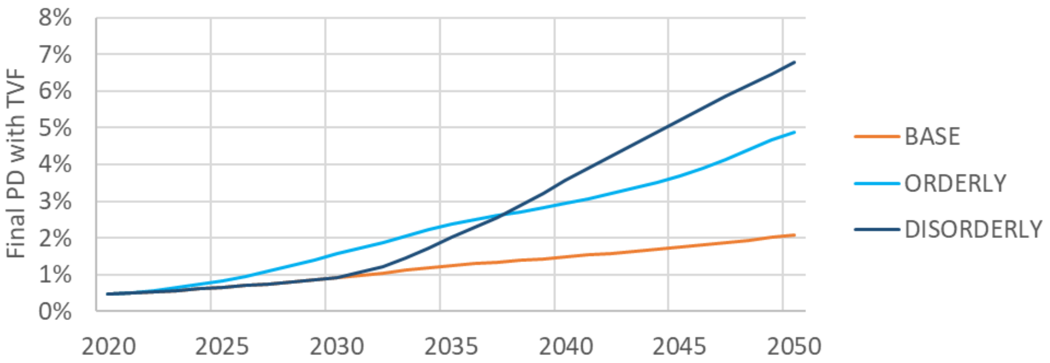

Figure 13: Resulting default rates of sector C20 (Manufacture of Chemicals and Chemical Products) for the base, the orderly and the disorderly scenario.

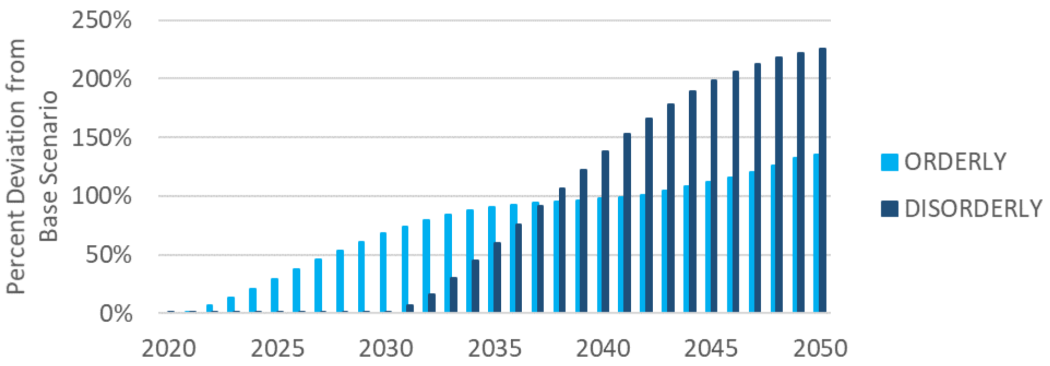

Figure 14: Deviations from the base scenario of sector C20 (Manufacture of Chemicals and Chemical Products) for the orderly and the disorderly scenario.

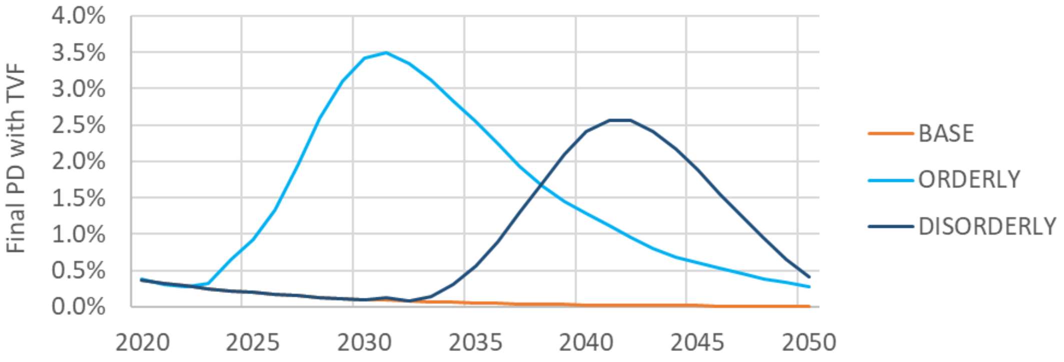

Figure 15: Resulting default rates of sector C24 (Manufacture of basic metals) for the base, the orderly and the disorderly scenario.

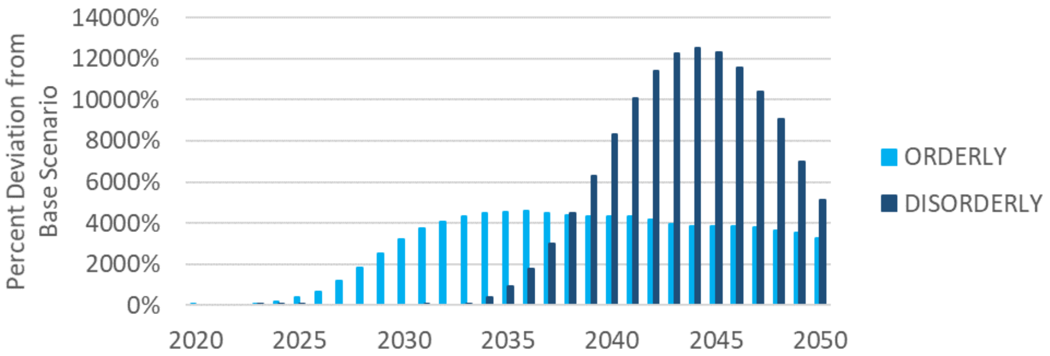

Figure 16: Deviations from the base scenario of sector C24 (Manufacture of basic metals) for the orderly and the disorderly scenario.

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