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No Need to Worry? Estimating the Exposure of the German Banking Sector to Climate-Related Transition Risks

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Paola D'Orazio, Tobias Hertel, and Fynn Kasbrink[1]

No Need to Worry? Estimating the Exposure of the German Banking Sector to Climate-Related Transition Risks

Abstract

Climate change poses several risks to the value of financial assets and financial stability. The study conducted in this paper focuses on the German banking sector and estimates its exposure to climate risks arising from a transition to a carbon-neutral economy. Our analysis identifies the energy, transportation, and manufacturing sectors as the most sensitive to transition risks and shows that the German banking sector's direct exposure to climate transition risks is non-negligible. Moreover, it points out that an amplified exposure to transition risks characterizes large private banks. These findings are comparable to other countries' exposures and relevant to financial supervision and regulation, calling for increased engagement to assess, measure, and manage climate-related financial risks.

JEL-Codes: E58, G21, Q53, Q54

Keywords: Climate-related financial risks; transition risks; banking sector; climate policy; climate neutrality; climate-related prudential regulation

March 2022

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1. Introduction

The risks derived from an increase in greenhouse gas (GHG) emissions and global temperatures are widely studied (IPCC 2014, 2018, 2021), and the international community agrees on the relevance to addressing climate risks because they can lead to economic damages and financial losses (see Reaños 2021; Eckstein et al. 2019; Batten et al. 2020, among others). However, countries have yet to embark on deep decarbonization pathways in the wake of the Paris Agreement (Tagliapietra et al. 2019; Roelfsema et al. 2020; van Soest et al. 2021).

Germany is usually considered - together with the UK and Denmark - a climate "leader", although climate mitigation ambitions do not always correspond to substantial instruments and actions that lead to long-term emissions reductions (Michaelowa 2013; Vogt-Schilb and Hallegatte 2017; Lamb and Minx 2020). With France, Italy, and the UK, Germany has significantly reduced its GHG emissions from 1990 and is following the European Union (EU) climate change mitigations policies (Zheng et al. 2019). Across the EU Member States, the emissions were the highest in Germany in 2014-2016 (21% of the EU-28 total or 936 mil. tonnes of CO2eq.), followed by the United Kingdom and France (Zheng et al. 2019). For 2050, the EU set the target to reduce economy-wide GHG emissions by 80-95% (with 1990 as the reference year); more recently, as part of the European Green Deal, the Commission revised this goal and proposed on 4 March 2020 the first European Climate Law to enshrine a 2050 climate-neutrality target into law (EP 2021). In this revised framework, EU Member States are required to develop long-term national strategies on how they plan to achieve the GHG emissions reductions needed to meet their commitments under the Paris Agreement and EU objectives. A recent version of the German "Klimaschutzgesetz", or Climate Change Act, adopted in June 2021, requires reducing CO2-emissions by 65% by 2030 (with 1990 as the reference year) and achieving climate neutrality by 2045 (Bundesregierung 2021). The revised Climate Change Act also sets an annual path of aggregate emissions through 2040 and revised annual sectoral targets through 2030. However, the emissions' targets are far from being met and are still insufficient to limit global warming below the 1.5° threshold (D'Orazio and Löwenstein 2020; Keles and Yilmaz 2020).

Implementing the low-carbon transition will require targeted climate policies (such as carbon taxes), changes in regulations, environmental innovation, and changes in consumers' preferences (Semieniuk et al. 2021). Different tools are available to policymakers to implement their mitigation strategies (see Krogstrup and Oman 2019; Polzin and Sanders 2020, for a review) and governments are at the forefront of this endeavour (Boyle et al. 2021). Moreover, due to the interrelations between climate change, economic processes, and the financial sector, central banks, financial supervisors, and regulators have started to consider climate-related risks in their policymaking (NGFS 2020b; OMFIF 2020). Although their action cannot substitute for an adequate climate policy (Lane 2019; Weidmann 2020), it is now widely acknowledged that they cannot stand on the sidelines because of the effects climate change will have on their ability to achieve their monetary policy (Batten et al. 2016; Campiglio 2016; Campiglio et al. 2018; Coeuré 2018; Battiston et al. 2019; Kemfert et al. 2020) and financial stability mandates (Elderson 2018; D'Orazio and Popoyan 2019, 2020; Bressan et al. 2021).

In particular, it is now widely agreed that financial regulators and supervisors should consider both climate-related physical and transition risks (Carney 2015), although special attention should be devoted to risks deriving from a transition to a low-carbon economy which might play a larger role in the short-term. Since they represent a material risk to the banking system and may even be a source of systemic risk, it is crucial to understand the degree of concentration in climate risk exposures (D'Orazio and Popoyan 2019).

While there exist few experiences of assessing the exposure of the financial sector to climate risks at the country or EU level (see, e.g., Vermeulen et al. 2019; Battiston et al. 2020; Faiella and Lavecchia 2020; Roncoroni et al. 2021), the German case has been hardly studied yet. This paper aims at filling this gap by evaluating the carbon intensity of financial assets of the country's banking sector, thus quantifying transitions risks and estimating the banking sector's vulnerability to the transition to a low-carbon economy. Our empirical analysis relies on sectoral and aggregate bank data and GHG emissions data and shows that the exposure of the German banking sector to climate transition risks (as of 2018, because of data availability) is non-negligible. Depending on the estimation method used, the exposure is quantified as 19.4% (Carbon Critical Sectors), 32.56% (Loan Carbon Intensity), and 25.17% (Climate Policy Relevant Sectors) of the total loan volume. Moreover, the study indicates that especially the largest banks face an amplified risk.

The results of the proposed analysis could, on the one hand, help policymakers identify the allocation of climate-related risks in the banking sector, thus preparing an adequate prudential response. On the other hand, they could serve as a basis to evaluate how different sources of transition risks such as stricter climate policies, changes in investors and consumer preferences, and structural change might affect the financial sector.

The remainder of the paper is organized as follows. Section 2 offers a review of the literature focusing on the methods developed in the past decades to study the financial sector's exposure to climate risks. The methodology and data used in the proposed analysis are described in section 3. Section 4 shows and discusses the results of our study. The implications of the direct exposures of German banks to transition risks are then examined in detail in section 5 by considering the peculiarities of the financial sector and the current national political debate on its resilience to climate change. Finally, section 6 offers concluding remarks.

2. Climate-related financial risks and the stability of the financial system

The seminal contribution by Carney (2015) highlighted that banks and the banking system are exposed to climate change through transmission channels that depend on different risk drivers. On the one hand, the increasing frequency and severity of extreme weather events can lead to the materialization of physical risks, which imply economic costs and financial losses deriving from stranded assets or losses to human capital (Botzen et al. 2019; Battiston et al. 2021; Caldecott et al. 2021). On the other hand, changes in government fiscal and climate policies, technological developments, or investor and consumer sentiment and preferences can lead to the materialization of transition risks, implying increasing costs and losses for financial institutions.

It is now widely acknowledged that climate-related financial risks can be understood through traditional risk categories, namely credit, liquidity, market, operational, reputational risk (NGFS 2019a; Bolton et al. 2020; BCBS 2021b). The existing literature focuses on the impacts of climate risk drivers on credit risk, and credit risk quantification efforts are mainly aimed at addressing risks to corporate lending and real estate exposures (see, e.g., Delis et al. 2018; Westcott et al. 2019; Battiston et al. 2020). This strand of literature has been growing in the past years, thanks to the development of methodologies to explicitly study the channels of transmission (see BCBS 2021a, for a review). In particular, academic research has been primarily devoted to advancing instruments to include climate risks in conventional risk management tools adequately. This requires the set-up of granular and forward-looking measurement methodologies, knowledge of physical or transition risk drivers, risk management decisions, depending on the availability of relevant data and computational complexity (Krogstrup and Oman 2019; Monasterolo 2020; Breitenstein et al. 2021; Chenet et al. 2021). Nevertheless, studies on the diffusion and adoption of climate-related financial policies show that existing prudential frameworks in Europe and at the international level have not yet implemented adequate risk identification and risk management procedures (D'Orazio 2022). Thus, the assessment of climate-related financial risks is still in its infancy, with no consensus yet on preferred modeling and empirical approaches (Svartzman et al. 2021).

Because of (geolocational) data availability issues, empirical works devoted to capturing the financial sector's exposure to physical risks are less developed, and a common assessment methodology is currently lacking.

In the case of transition risk, methods usually entail mapping its drivers into specific counter-party and portfolio exposures to assess credit risk (Breitenstein et al. 2021). Depending on the aim of the investigation and data availability, exposures' analyses can be performed at the portfolio, sectoral or geographical level. The results can then be used by supervisors for microprudential supervision and inform macroprudential policies (D'Orazio and Popoyan 2019). Existing literature has focused on capturing the carbon intensity of portfolio specific and sectoral exposures, providing internal climate risk ratings or scores, or estimating the effects of more stringent climate regulation (see Krogstrup and Oman 2019; BCBS 2021a, for a review of methods), or considering how to improve conventional risk management tools (see for a discussion Svartzman et al. 2020; D'Orazio 2021). A seminal contribution to the assessment of transition risks has been provided by the development of a taxonomy of the Climate Policy Relevant Sectors (Battiston et al. 2017). Drawing on this approach, other methods such as scenario analysis (Schulten et al. 2021), stress testing (Batten et al. 2016; Monasterolo 2020), climate value-at-risk (Dietz et al. 2016), and sensitivity analysis (BCBS 2021a) have been proposed.

Despite the lack of credit data at a sufficiently granular level and the absence of a standard methodology, a growing literature studies the exposure of financial systems at the national level. An overview of existing studies is presented in Table 1 and a detailed discussion is provided in the following.

Study	Geographical scope	Financial actor	% exposure
Weyzig et al. (2014)	EU	Pension Funds	5%
		Banks (loans)	1.4%
		Insurance companies	4%
Battiston et al. (2017)	EU	Insurance & Pension Funds	8%
		Banks (loans)	14%
Vermeulen et al. (2019)	Netherlands	Pension Funds	8%
		Banks (loans)	13%
		Insurance companies	5%
Battiston et al. (2020)	Austria	Banks (loans)	26%
Faiella and Lavecchia (2020)	Italy	Banks (loans)	9.9/12.9/14.4 %*
Roncoroni et al. (2021)	Mexico	Investment Funds	3.5%
		Banks (loans)	1%

Table 1.: Overview of studies estimating the exposure of the financial system to climate-related transition risks. Source: Authors' elaboration
Notes: * these values depend on the methodology adopted, as explained in the main text.

Weyzig et al. (2014) provided a seminal contribution and studied the exposures to firms owning oil, gas, and coal assets of EU pension funds, banks, and insurance companies as of December 2012. They find that the total estimated exposures are roughly €260-330 billion for EU pension funds, €460-480 billion for banks, and €300-400 billion for insurance companies. According to the authors' calculations, the estimated exposures - expressed as an average proportion of total assets - are approximately 5% of total assets for pension funds, 4% for insurance companies, and 1.4% for banks.

Battiston et al. (2017) proposed a methodology to identify the so-called Climate Policy Relevant Sectors (CPRS). The CPRS derive from the re-mapping of the existing classification of economic activities (i.e., NACE Rev. 2) and take into account to what extent economic activities are affected by a disorderly transition to a low-carbon economy by identifying their (in)direct contribution to GHG emissions, their relevance for climate policy implementation and their role in the energy value chain[1]. The classification was developed to determine climate financial risk exposures by calculating climate scenarios or financial risk metrics like the Value-at-Risk. Based on this, the authors find that direct and indirect exposures to CPRS represent a large portion of investors' equity portfolios, especially for investment and pension funds. In particular, the top 50 listed European banks are characterized by large exposures to CPRS.

Schotten et al. (2016) and DNB (2017) have provided an early contribution to the study of the impact of transition risks in the Netherlands, finding that the exposures of financial institutions to energy transition risks could be sizable. More recently, by relying on a granular approach that assigns transition risks to 56 individual NACE industries, Vermeulen et al. (2019) compute vulnerability measures on the CO2-emissions used to generate value-added of a particular industry. They estimate that 13% of the financial assets held by banks at the end of 2017 were directly exposed to carbon-intensive activities. For insurance companies, 5% of assets were exposures to industries with carbon-intensive production processes, most of which were exposures to carbon-intensive activities other than mining and petrochemical. For pension funds, the exposure has been reported to be at 8%.

Faiella and Lavecchia (2020) focus on the Italian financial sector and develop a methodology to estimate its exposure to transition risks. By linking the information on GHG emissions with the distribution of loans, they compute the "loan carbon

[1]Relying on the classification table retrieved from the Center for Financial Networks and Sustainability website, economic activities are identified as negatively affected by transition risks if they are assigned to the CPRS 01-05 (FINEXUS 2021).

intensity" and find that approx. 10% of the banks' financial assets at the end of 2018 were directly exposed to carbon-intensive activities. They also adopt the CPRS method and find that the exposure would be 12.9% in that case. Further, they develop an alternative methodology to identify the so-called "carbon-critical sectors" aiming to sort the economic sectors with the highest share of loans and emissions. By adopting this approach, the total exposure of the financial sector amounts to 14.4%.

Roncoroni et al. (2021) study the Mexican banking sector by applying the CPRS methodology. Because of the peculiarities of the Mexican economy related to the presence of state-owned large energy firms and the role of informal economy, they find low asset values and distribution patterns across the CPRS.

Our study aims at contributing to this stream of literature by offering a quantification of the exposure of the German banking sector to transition risks. As explained in Section 3, we rely on the approaches developed in Battiston et al. (2017), and Faiella and Lavecchia (2020) because they allow us to clarify the direct exposure of German banks to climate vulnerable assets.

3. Methodology

3.1. *Data*

It is crucial to have reliable data on financial firms' exposure to nonfinancial companies to estimate climate-related transition risks adequately. To this aim, we retrieve loan data for the period 2008-2018 from the Deutsche Bundesbank's Quarterly Borrowers Statistic (QBS)[2]. The QBS provides information on the granular exposure of German banks to all domestic enterprises and households classified by borrowers, economic sectors (following the WZ 2008 classification, based on NACE Rev. 2), and maturities[3].

Transition risk exposures can be computed at the economic sector and aggregate levels by combining loan data with GHG emissions data retrieved from Eurostat. Regarding GHG emissions data, we consider the direct industry-specific GHG emissions (Scope 1 and Scope 2 emissions following the Greenhouse Gas Protocol) between 2008 and 2018 from the Air Emissions Accounts (AEAs) and industry affiliations based on the NACE Rev. 2 classification[4]. The advantage of the AEA's methodology is its applicability to other scales, such as linking the emission data with the National Accounts data on the sectoral level. We can thus use the National Account's gross value-added (GVA) and the GHG emissions data provided by Eurostat to compute industry-specific

[2]Financial institutes' data was obtained during multiple research visits at the Research Centre of the Deutsche Bundesbank (Project-Number: 2021/0016). For further information, see (Beier et al. 2018; Gomolka et al. 2021; Stahl 2021) and the data disclosure agreement. In line with previous studies (see Section 2), we focus on the analysis of loan exposure, as the total exposure of all German banks to corporate bonds (corporate equities) amounted to 60.301 mil. €(€63.361 mil.) at the end of 2018, each representing less than 5% of the analyzed loan exposure (Bundesbank 2021a).

[3]With a response rate of 100% and no minimum thresholds regarding the loan volume, the QBS provides full coverage of the loan activities in the German banking system Beier et al. (2018).

[4]There is an ongoing debate on how a countries' emissions should be computed. A first option relies on the so-called territorial principle according to which the emissions are attributed to the products manufactured within a country territory, even if intended for export (Tukker et al. 2020). Alternatively, they can be calculated according to the consumption principle by adding all the emissions accumulated by consuming goods within a country, including emissions from imports (Peters 2008). Considering Germany's comparatively high balance of payment surplus, we believe that the territorial principle is the appropriate approach for our analysis. For a more granular analysis of GHG emissions, considering the whole value chain of produced goods, one should consider the product-level embodied emissions originally developed by Vermeulen et al. (2019). However, the current level of data availability limits the application of this method on a larger scale.

carbon intensity[5]. Data sources and descriptions are provided in Table 2.

Data	**Description**	**Source**
Loan value (LV)	Loan value data (loans, discount credits, mortgage loans) from domestic MFIs to domestic enterprises from 2008 – 2018.	Quarterly Borrower Statistic (QBS), Deutsche Bundesbank
Bank group	Affiliation for each institute to the following bank groups: BGRS 1) Private Banks BGRS 2) Sparkassen and Landesbanken BGRS 3) Credit Cooperatives	Selected Master Data for MFIs (MaMFI), Deutsche Bundesbank
Size group	Affiliation for each institute to the following size groups based on the yearly average of total asset: SZ 1) up to €250 mil. SZ 2) more than €250 mil., up to €500 mil. SZ 3) more than €500 mil., up to €1 bil. SZ 4) more than €1 bil., up to €5 bil. SZ 5) more than €5 bil., up to €10 bil. SZ 6) more than €10 bil.	Monthly Balance Sheet Statistics (BISTA), Deutsche Bundesbank
GHG data	Total greenhouse gas emissions (CO2 equivalents).	Eurostat
GVA data	Gross value added, chain linked, base year = 2010.	Eurostat

Table 2.: Data description and sources

Moreover, we implement separate subsample analyses considering the size group (based on the year-end value of the bank's total assets, see Table 2) and the bank group (see Table 4) of the reporting institutions by relying on Selected Master Data for MFIs (MaMFI)[6] to identify the bank group and the Monthly Balance Sheet Statistics (BISTA) to assess the size group of each institute[7]. An overview of the economic sectors and the bank and size groups included in the analysis are displayed in Tables 3 and 4.

To ensure that each subsample consists of at least five individual institutes, we scale the size groups following the classification applied in the "Bankenstatistik"[8] (Bundesbank 2021a). Accordingly, an analysis of transition risk exposure (and potential stability implications) at the level of individual institutes cannot be performed.

[5]Although GHG emission and GVA data are sporadically available up to 2020, there is no or only preliminary data for some sectors. Therefore, we only employ data until 2018 to provide consistency throughout our analyses.

[6]For further information see Stahl (2021) and the data disclosure agreement.

[7]For further information see Gomolka et al. (2021) and the data disclosure agreement.

[8]However, since only a few institutes exhibit loans' exposures towards some economic sectors, a more aggregated size group differentiation should be applied. In addition, due to the restrictions regarding the minimum number of reporting institutes, the loan exposure to specific size group and bank group combinations can only be assessed for some of our analyses.

QBS Code	QBS Description	NACE Rev. 2 sector	NACE Rev. 2 division
110	Agriculture, forestry, fishing and aquaculture	A	01-03
120	Electricity, gas and water supply; refuse disposal, mining and quarrying	B, D, E	05-09; 35; 36-39
130	Manufacturing	C, S	10-33; 95
140	Construction	F	41-43
150	Wholesale and retail trade, repair of motor vehicles and motorcycles	G	45-47
160	Transportation and storage; post and telecommunications	H, N	49-53; 79
184	Hotels and restaurants	I	55-56
185; 182	Information and communication, research and development, membership organisations, publishing activities, other business activities; Holding companies	J, M, N, S	58-63; 69-75; 78, 80-82; 94
170, 171	Financial intermediation (excluding MFIs)and insurance companies, Financial lease corporations	K	64-66
181, 183	Housing enterprises; other real estate activities	L	68
186	Health and social work (enterprises and self-employment)	Q	86-88

Table 3.: NACE Rev. 2 sectors and divisions linked to loan sectors of the QBS.
Notes: There is only aggregated emission data for the NACE Rev. 2 divisions $80-82$ on Eurostat. The emission of all division are assigned to QBS sector 185, although the NACE Rev. 2 division 81 is originally part of QBS sector 183. There is only aggregated emission data for the NACE Rev. 2 divisions $74-75$ on Eurostat. The emissions of both division are assigned to QBS sector 185, although NACE Rev. 2 division 75 is originally part of QBS sector 186. There is no corresponding NACE Rev. 2 division for the activity Own asset management from QBS sector 185.

SZ	BGRS 1	BGRS 2	BGRS 3	$\sum$
1	53	5	261	319
2	19	21	188	228
3	32	50	156	238
4	77	259	247	583
5	22	48	22	92
6	33	32	20	85
$\sum$	236	415	894	1545

Table 4.: Number of financial institutes by size (SZ) and bank group (BGRS) at the end of 2018. Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, datasets: BISTA, MaMFI, data period: 01.01.2008-31.12.2018, own elaborations.

3.2. *Empirical approach*

The analysis proposed in the paper relies on the Climate Policy Relevant Sectors approach developed by Battiston et al. (2017) and the "Loan carbon intensity" (LCI) and "Carbon-critical Sectors" (CCrS) proposed by Faiella and Lavecchia (2020).

The methodology developed by Battiston et al. (2017) takes into account to what extent economic activities are affected by a disorderly transition to a low-carbon economy based on their (in)direct contribution to GHG emissions, their relevance for climate policy implementation, and their role in the energy value chain. Considering the CPRS methodology, we classify economic activities (based on the NACE Rev.2 classification) to be substantially exposed towards transition risks if they are assigned to one of the following five climate policy relevant main sectors: fossil fuels, utilities, energy-intensive, buildings, and transportation.

Faiella and Lavecchia (2020) distinguish between the LCI and the CCrS approaches. The LCI is computed by mapping the GHG emissions of each economic sector s for each time t, defined as $GHG_{s,t}$, to the distribution of loans of each economic sector s for each time t, denoted as $LV_{s,t}$, so that

$$LCI_{s,t} = \frac{GHG_{s,t}}{LV_{s,t}} \tag{1}$$

However, the authors explain that the LCI approach described in equation 1 could yield biased results. Consider, for instance, the case in which a sector is characterized by high emissions and a high volume of loans; the result, in this case, will be a low LCI. Nevertheless, from a financial stability perspective, despite a low LCI score, a sector with these characteristics should be considered highly relevant for assessing transition risks because of both high emissions and high loan exposure. To overcome the possible bias deriving from the LCI measure, Faiella and Lavecchia (2020) propose the implementation of the CCrS approach that consists in a function $\mathcal{F}$ that takes two rank variables that provide information on sectors' share of total emissions, namely $\frac{GHG_{s,t}}{GHG_t}$) and loan concentration, namely $\frac{LV_{s,t}}{LV_t}$, thus obtaining a measure of the relevance of each sector in terms of emissions and exposure in each year t, as shown in equation 2. According to this approach, the carbon critical sectors are those whose simple average *mean* of both emissions and exposure ranks (Rank AVE) belongs to the first quantile q_1 of the distribution.

$$CCrS_s = \mathcal{F}\left[mean\left(rank_t\left(\frac{GHG_{s,t}}{GHG_t}\right), rank_t\left(\frac{LV_{s,t}}{LV_t}\right)\right) < q_1\right] \tag{2}$$

By using both total emissions and carbon intensity, this approach allows us to show the sectors with the highest overall transition risk (as proxied by total emissions) and the sectors with the highest discrepancy between current emission levels and their economic importance (as proxied by carbon intensity). In this way, we identify the sectors that will potentially pose the highest threats to financial stability in a low-carbon transition.

4. Analysis

4.1. *Sectoral and aggregate GHG emissions in Germany*

Germany is responsible for around 20% of all GHG emissions in the EU and around 2% of the world's CO2 emissions with a total of around 700 million tonnes of carbon dioxide equivalents[9] (CO2e). As shown in Figure 1, GHG emissions decreased between 2008 and 2018 in both Germany and the EU-28 at a similar rate. However, in contrast to Germany's proclaimed ambition to position itself as a leading force in climate change mitigation, the decrease in GHG emissions does not significantly exceed the EU average (Bundesfinanzministerium 2021).

To provide a broader understanding of the evolution of GHG emissions by considering the sectoral composition of the German economy, we compute the carbon intensity, i.e., the ratio of GHG emissions by GVA, as it is a useful indicator for a country or sector's additional amount of CO2e emitted per unit of GVA, expressed in grams of CO2e per €(gCO2e/€). As reported in Figure 1, while carbon intensity for Germany (the EU-28) drops by about 25% (24%) until 2018, GHG emissions are only decreasing by about 14% (18%) until 2018. Accordingly, the German (EU-28) economy seems to become more emission-efficient, while the overall GHG emissions are not decreasing at the same pace due to steady economic growth. Moreover, to explain the economic sector's contribution to GHG emissions, we calculate the industries-specific share of

[9]CO2 equivalent is a metric measure used to compare the global warming potential of various greenhouse gases such as methane (CH4) or nitrous oxide (N2O) based on their global warming potential. The amounts of other greenhouse gases are converted into the equivalent amount of carbon dioxide that would have the same effect on global warming (over one hundred years).

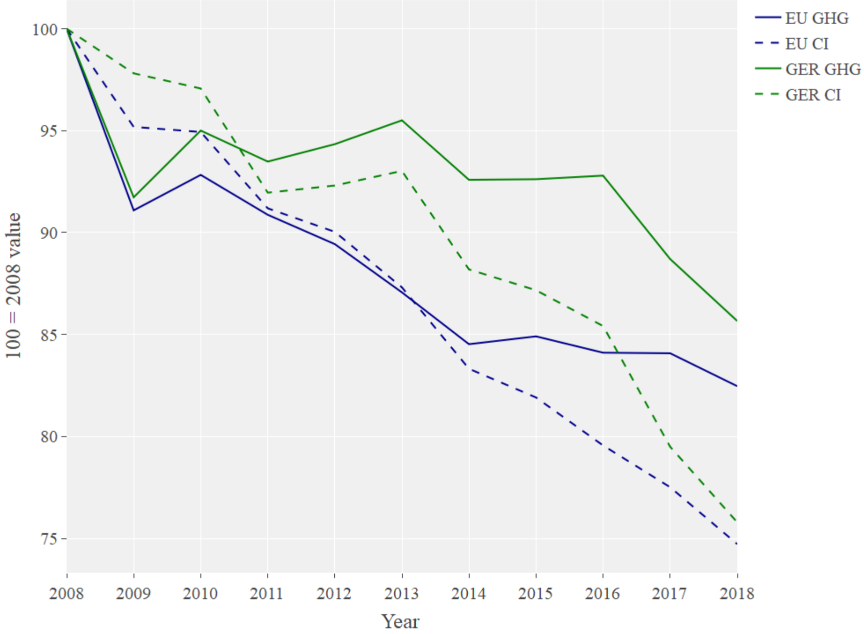

Figure 1.: GHG emissions and carbon intensities for Germany and EU-28, 2008 level = 100)

GHG emissions, their carbon intensity, and their rate of change in the period from 2008 to 2018 for the ten highest emitting sectors; the results are shown in Table 5.

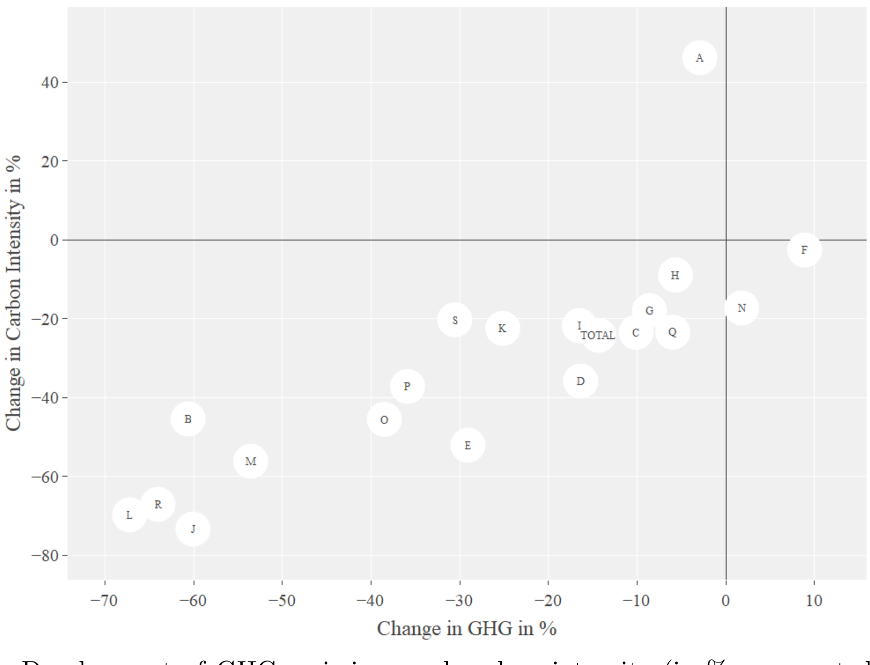

Figure 2.: Development of GHG emissions and carbon intensity (in %, aggregated sectors). Source: Authors elaboration based on Eurostat (2021a) and Eurostat (2021b). Sectors based on the NACE Rev. 2 classification.

GHG emissions in Germany are heavily dominated by the electricity (D) sector, as it accounts for about 40% of total emissions, in line with other European countries

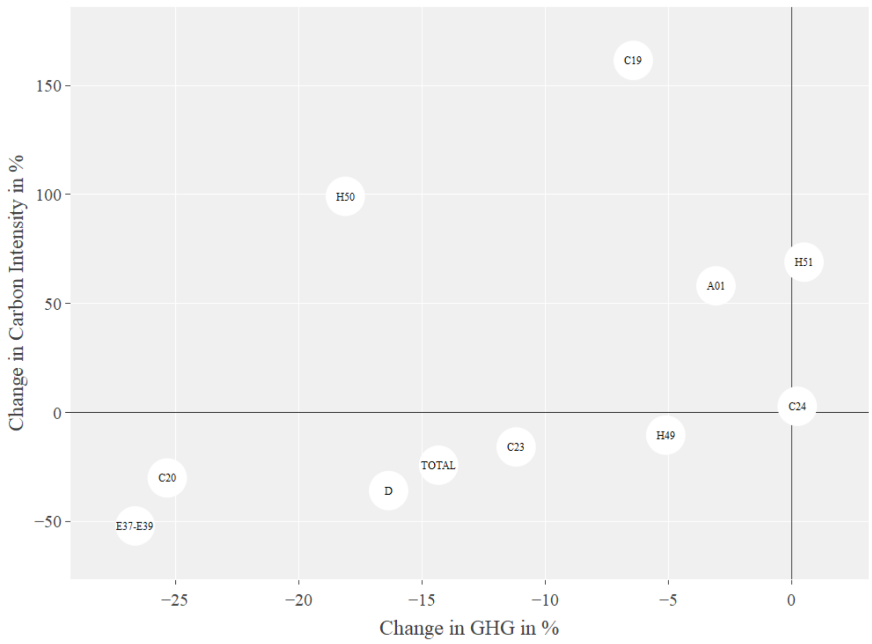

Figure 3.: Development of GHG emissions and carbon intensity (in %, Top 10). Source: Authors elaboration based on Eurostat (2021a) and Eurostat (2021b). Sectors based on the NACE Rev. 2 classification.

NACE Rev. 2 classification	GHG emissions in 2018 (%)	Cumulative change in GHG emissions (%) (2008-2018)	Carbon intensity in gCO2e/2018	Cumulative change in carbon intensity (%) (2008-2018)
D	42	-16.36	4892.3	-35.84
A01	9.69	-3.09	5411.58	58.08
C24	6.63	0.21	2314.45	2.82
C23	5	-11.19	2186.93	-15.83
H51	4.27	0.48	8954.88	68.95
C20	3.88	-25.34	656.24	-30.05
H50	3.56	-18.12	7138.42	99.14
C19	3.12	-6.44	10291.95	161.49
E37-E39	2.54	-26.64	585.8	-52.04
H49	2.37	-5.12	387.06	-10.41
TOTAL	100	-14.34	270.86	-24.21

*As there is no carbon intensity data for (E37-E39), the sector average is displayed.

Table 5.: Emission trends of the 10 highest emitting sectors in Germany in 2018. Source: Authors elaboration based on Eurostat (2021a) and Eurostat (2021b). Divisions based on the NACE Rev. 2 classification. See Table 3 for the list of sectors, divisions and codes.

(see, e.g., Faiella and Lavecchia 2020). The manufacturing (C), transportation (H), and agricultural (A) sectors are also important contributors. Overall, the five most emitting sectors contributed to nearly 68% of total emissions. Besides the manufacture of basic metal (C24) and air transport (H51), each of the highest emitting sectors exhibits decreasing GHG emissions between 2008 and 2018 (see Table 5). The decrease in GHG emissions is steeper for half of the sectors than the German economy's average decrease. While the highest emitting sectors have the greatest potential (or need) to decrease emissions, it could also be interpreted as a sign of ambitious decarbonization efforts from these sectors (Zheng et al. 2019).

At the aggregate level (NACE Rev. 2 sectors), only the agricultural sector (A) exhibits an increase in carbon intensity, as shown in Figure 2. With nearly constant GHG emissions, this effect can only be explained by declining economic value-added (i.e., a decrease in GVA), which adds to the assumed decreasing importance of the agricultural sector in modern economies. Both construction (F) and administrative and support service activities (N) show increased GHG emissions between 2008 and 2018 (see Figure 2). However, their carbon intensity is stagnant or marginally decreasing, which implies that the increase of their GHG emission does not significantly exceed the increase of their economic importance (as proxied by the GVA).

Regarding the carbon intensity at the sub-sector level (NACE Rev. 2 divisions), half of the highest emitting sectors increase between 2008 and 2018. In addition, the rate of increase significantly exceeds the one observed for the aggregate sectors. For instance, the carbon intensity of the Manufacture of coke and refined petroleum product (C19) has more than doubled between 2008 and 2018, while the highest increase in the carbon intensity of the aggregate sectors is 46% (see Figure 3). In contrast, the GHG emissions of the ten highest emitting sectors stagnated or decreased between 2008 and 2018. Thus, the increase of carbon intensity for the sectors A01, C19, C24, H50, and H51 can be linked to the decreasing economic importance (i.e., the decreasing GVA).

4.2. *Banks' exposure to climate-related transition risk*

In this section, we present the results of the implementation of the empirical approaches described in Section 3 to analyze the direct exposure of the German banking sector to transition risks. We start by reporting the carbon intensity of loans and the carbon-critical sectors[10]. Results shown in Table 6 provide a summary of the LCI for the QBS sectors as of 2018; we also display other core variables such as the loan value (LV), gross value added (GVA), GHG emissions, and their rank for comparison purposes.

When considering the LV, the housing sector displays the highest value with €396.65 bn., i.e., 29.36% of the total LV, followed by the financial sector with 11.39% and the manufacturing sector with 10.61%. As shown in Figure 4, the LV of the housing sector (181, 183), financial intermediation (170), and the manufacturing sector (130) amount together to more than half of the total LV. Concerning their GHG emissions, these sectors are responsible for around 25%, while the manufacturing sector is responsible for 24.8% alone. The largest emitting sectors like Energy, water, waste (120), Manufacturing (130), and Transportation (160) account for 83.56% of the country's emissions, but only for 23.33% of loans.

As shown in Table 6 (column 6), the highest LCI is recorded for the Energy, water,

[10]We note that in the analysis in this section, different industry aggregations are applied compared to those used in Section 4.1 because the QBS sectors often consist of or are assigned to multiple NACE Rev. 2 divisions. For a comparison see Table 3.

waste sector (120), followed by Transportation (160) and Agriculture (110). These values are aligned with sectors' (high) carbon intensity values. Following the ratio logic of (loan) carbon intensity, the rationale is their high emissions (see, e.g., the difference between the Rank GHG and Rank LV in Table 6) in comparison to their economic and loan value weight. In addition to analyzing current LCI, observing changes in LCI over time is equally important, as they reveal the dynamics of emissions reduction efforts and the financial sector's exposure to a specific economic sector over time. The energy sector (120) provides a primary example of these dynamics. As shown in Figure 5, it displays a negative change in LCI between 2008 and 2018 because the GHG emissions decreased by 20% while the LV doubled in the same period, in line with the increasing economic importance measured by the increasing GVA.

(1) QBS_Code & Description	(2) Loan Value LV	(3) GHG emissions GHG	(4) Gross Value Added GVA	(6) Carbon Intensity CI	(7) Loan Carbon Intensity LCI	(8) Rank GHG	(9) Rank CI	(10) Rank LV	(11) Rank AVE
110 - Agriculture	52.76	70476.63	15.96	4415.77	1335.83	4	1	10	7
120 - Energy, water, waste	118.82	327576.94	99.76	3283.75	2756.82	1	2	5	3
130 - Manufacturing	143.41	175884.59	618.72	284.27	1226.41	2	4	3	2.5
140 - Construction	72.41	10097.69	107.22	94.18	139.45	6	5	8	7
150 - Wholesale	140.26	16834.64	277.32	60.7	120.02	5	7	4	4.5
160 - Transportation	52.93	89609	120.45	743.96	1693.08	3	3	9	6
170 - Financials	153.84	1557.43	111.86	13.92	10.12	10	10	2	6
181, 183 - Housing enterprises	396.65	379.31	281.31	1.35	0.96	11	11	1	6
184 - Hospitality	25.14	3188.02	39.56	80.59	126.79	9	6	11	10
185 - Info & Comm.	112.79	7801.63	425.44	18.34	69.17	7	9	6	6.5
186 - Health & Social	82.08	6562.87	187.07	35.08	79.96	8	8	7	7.5

Table 6.: Loan Carbon Intensity and other core variables computed for the QBS sectors (as of 2018). Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, dataset: QBS, data period: 01.01.2008-31.12.2018, own elaborations.
Note: Loan values and GVA are displayed in billion €. GHG emissions are displayed in Tsd. Tonnes.

Regarding the agricultural sector (110), the high LCI results from its relatively low loan value compared to its (medium to high) GHG emissions. Still, the overall LCI change over time is negative due to an increased LV and decreased GHG emissions as reported in Figure 5. In contrast to the increase in LV, which is in line with an overall increase of aggregate LV, the sector's GVA decreased by around 34%. As mentioned, the declining relevance for GVA is due to the less economic importance of the agricultural sector for industrial countries. Despite the negative LCI change over time, transitions risks for the agricultural sector can arise through different transmission channels than the pricing of CO2 emissions, i.e., agricultural policy reforms or consumption changes, and the need to adapt to climate change makes it vulnerable to physical and transition risks NGFS (2019a). Due to its dependency on nature-based ecosystems, the sector can be exposed to severe physical and, therefore, financial risks because of, e.g., land-use change through soil sealing and landscape fragmentation, widespread pollution of terrestrial and aquatic ecosystems, as well as overexploitation of natural resources (Ufz-Umweltforschungszentrum 2006; Batten et al. 2016; Allen et al. 2020; NGFS 2021). In addition, the loss of biodiversity can represent a major risk for financial stability (Kedward et al. 2020; Crona et al. 2021; Dasgupta 2021).

Despite the negative LCI variation over time, transitions risks for the agricultural sector can manifest over different transmission channels. The NGFS (2019a) emphasizes the interdependence of physical and transition risks, which makes the agricultural sector especially vulnerable to political or consumption changes. Due to its dependency on nature-based ecosystems, the sector can be exposed to severe physical risks, e.g., because of land-use change through soil sealing and landscape fragmentation, widespread pollution of terrestrial and aquatic ecosystems, as well as overexploitation of natural resources (Ufz-Umweltforschungszentrum 2006; Battiston et al. 2021). Related to this, the loss of biodiversity can represent a major risk for financial stability (Kedward et al. 2020; Crona et al. 2021; Dasgupta 2021). Since the agricultural sector (110) is mainly dependent on natural capital and its possibility to generate flows of ecosystem services, further losses can pose severe financial risks (Batten et al. 2016; Allen et al. 2020; NGFS 2021).

Transportation (160) and Manufacturing (130) exhibit positive LCI changes over time because their decrease in LV exceeds the decrease in GHG emissions.

The gap between decreasing LV and increasing GVA for the manufacturing sector (130) can be explained by more diversified funding sources. The equity ratio for the German manufacturing sector has steadily increased since 2008 (Bundesbank 2018), and the debt financing changed due to the increasing importance of bond emissions (Statista 2021). Both tendencies contribute to a lower LV. However, we expect the sector's loan demand to increase since it will face deep transformation processes during the next decade, such as digitalization, use of artificial intelligence, automatization, predictive maintenance, and carbon neutrality (Nacchia et al. 2021). Moreover, additional massive investments from the private sector are needed to increase its energy efficiency (Energiewende 2021). Due to its economic importance, future challenges, and industrial diversity, the evaluation of the positive LCI, in this case, is more difficult.

According to the method discussed in Section 3 and the ranks reported in Table 6, the carbon-critical sectors (CCrS) can be identified, showing that Energy, water, waste (120), and Manufacturing (130) are the most exposed to transition risks (see Rank AVE in Table 6). Both sectors are responsible for a considerable amount of GHG emissions (see Rank GHG in Table 6) and are thus significantly affected by future climate policy actions. In addition, the banking sector shows substantial loan exposure to these sectors (see Rank LV in Table 6). Thus, the negative implications of an abrupt change in climate policy on the economic situation and, consequently, companies' creditworthiness from these sectors imply the materialization of credit risks, thus presenting the most relevant transition risk for financial stability. The robustness of these results was further assessed by computing the CCrS by considering the carbon intensity (Rank CI) instead of the total GHG emission, as the respective sector's economic activity might inflate total GHG emission. Our findings do not change, implying that the transition risk potential for Energy, water, waste (120), and Manufacturing (130) can both be deemed substantial when considering their overall GHG emissions and the carbon intensity.

4.3. *Transition risks for different banking and size groups*

Germany is considered the prototype of a country with a bank-based financial system (Behr and Schmidt 2015; Memmel and Schertler 2012; Dietrich and Vollmer 2012) that consists of three different types of banks, usually also defined as the three banking pillars (see Figure 6). Pillar 1 comprises private profit-oriented credit institutions defined exclusively by a private ownership structure. Pillar 2 includes saving banks divided into local and regional banks, i.e., the Landesbanken. Pillar 3 comprises cooperative banks (and their regional institutions) and has the largest number of independent institutions of any bank group (see Table 4).

Considering the financial system's structure, we analyzed the exposures of the different size (SZ) and bank groups (BGRS) to each QBS sector, as reported in Table 4.

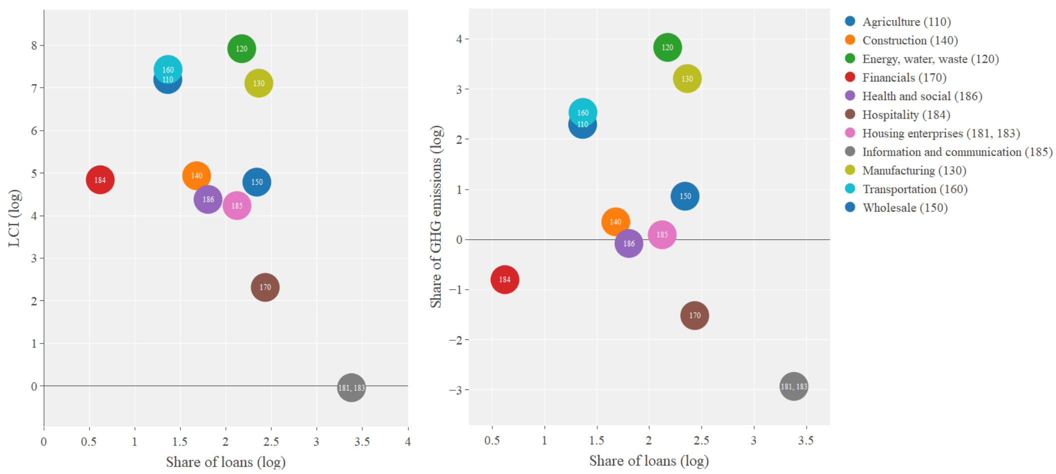

Figure 4.: Share of loans and LCI (left panel) and Share of loans and GHG emissions (right panel) Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, dataset: QBS, data period: 01.01.2008-31.12.2018, own elaborations.

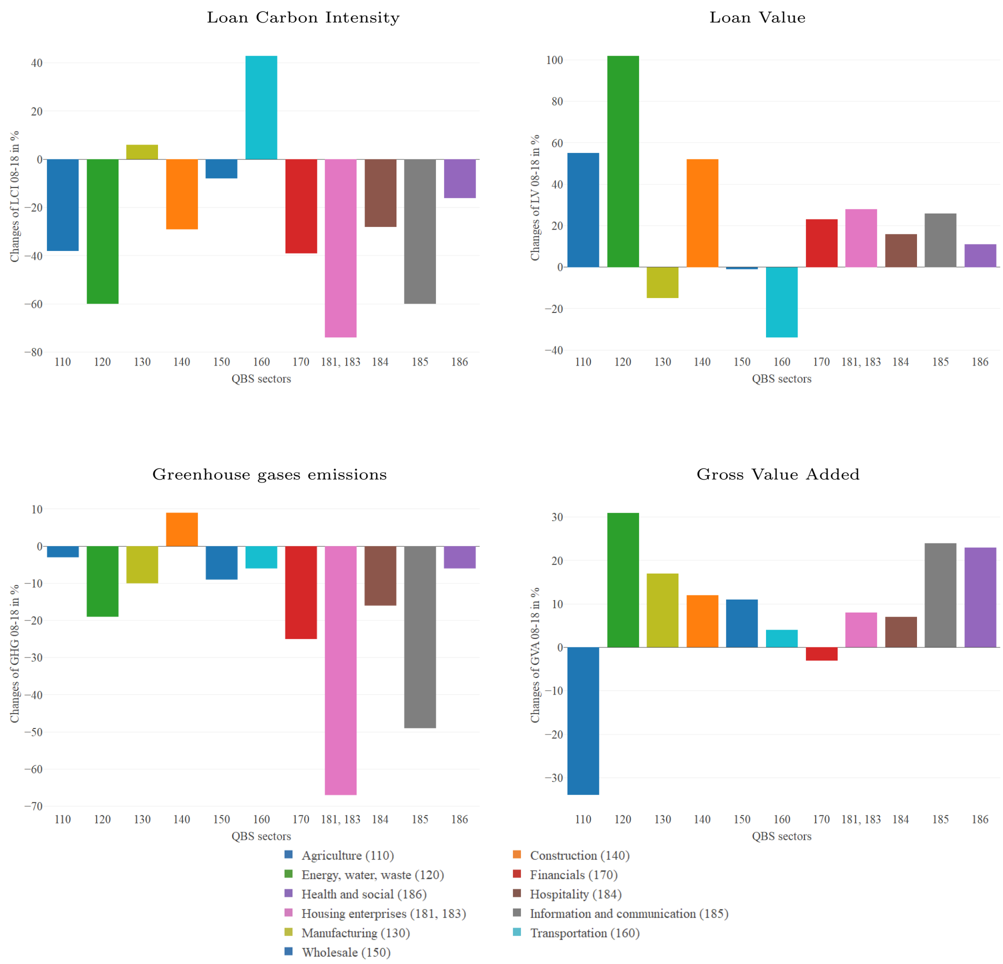

Figure 5.: Changes (in %) of the main variables under scrutiny over the period 2008-2018. Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, dataset: QBS, data period: 01.01.2008-31.12.2018, own elaborations.

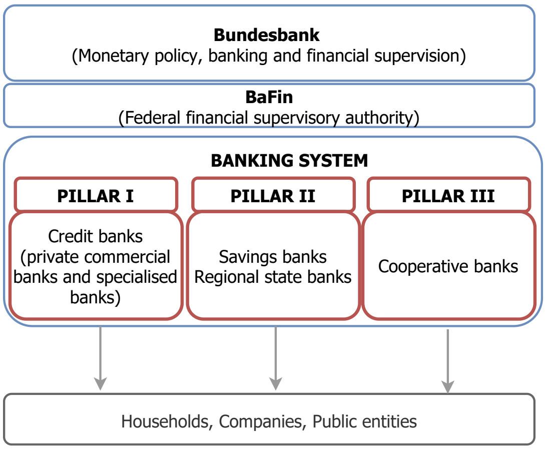

Figure 6.: The German financial system. Source: Authors' elaboration

Regarding the size groups, we note that the biggest banks (SZ 6) have a higher share of their loan exposure assigned to sectors: Energy, water, waste (120), Transportation (160), and Financials (170) than any other size group, as shown in Figure 7. Further, larger banks (SZ 4-6) have a higher share of their loans exposed to the Housing sector (181, 183) than smaller banks (size group 1-3). Since the Energy, water, waste (120) is identified as a CCrS sector, the biggest banks (SZ 6) are characterized by an over-proportional transition risk exposure compared to other size groups. In addition, the share of loans to this sector has increased from 6.43% (2008) to 10.40% (2018) for this size group. Further, the largest banks (SZ 6) also possess the highest share of loan exposure towards the Financial sector (15.25%), making them more vulnerable to potentially destabilizing feedback loops and second-order effects. In contrast, the share of loan exposure to the agricultural sector (110) is consistently higher for smaller banks, resulting in higher financial risks after the materialization of physical risks, which are in particular floods in the case of Germany (Pagliari 2021). Concerning the other CCrS sectors, the exposure of the different size groups is equally distributed.

Considering different bank groups as shown in Figure 8, Housing enterprises (181, 183) account for the highest share of LV across all bank groups, followed by Manufacturing (130) and Wholesale (150). Regarding Manufacturing (130), the share of loans to this sector is considerably higher for private banks (BGRS 1) than for the other two bank groups. No substantial differences between the different bank groups are observed when considering Energy, water, waste (120). However, the share of loans to this sector nearly doubles for all bank groups between 2008 and 2018. From a transition risk perspective, our analysis demonstrates that the saving banks group (BGRS 2) and credit cooperatives (BGRS 3) are slightly less exposed to this kind of risk. Moreover, credit cooperatives show the highest exposure to the agricultural sector, indicating higher exposure to physical risk for this bank group.

Finally, we analyze the exposures of the different size and bank groups to the CPRS sectors on an aggregate level (i.e., without looking at exposures to a single CPRS) in Table 7. The rationale for performing an aggregate analysis is related to matching issues between the definition of sectors according to the CPRS approach and the QBS data aggregation; this implies that our analysis on German data cannot distinguish between the loan exposure towards different CPRS. Nevertheless, we can observe differences in the overall level of transition risk exposure. While the exposure towards CPRS is comparable across all size and bank groups at around 25%, private banks

(BGRS 1) are slightly more exposed than other bank groups, which is in line with the previous analyses considering the CCrS. Further, banks from SZ 6 have a higher share of their loan exposure assigned to CPRS than any other size group, which is again in line with the results of our previous analyses. In addition, there are some outliers regarding specific size and bank group combinations. For instance, the exposure of small Sparkassen and Landesbanken (SZ 1 and BGRS 2) to the CPRS substantially exceeds the exposure of any other size and bank group combination[11]. In contrast, the second biggest group of Pillar 3 banks have only 13% of their loans exposed to CPRS.

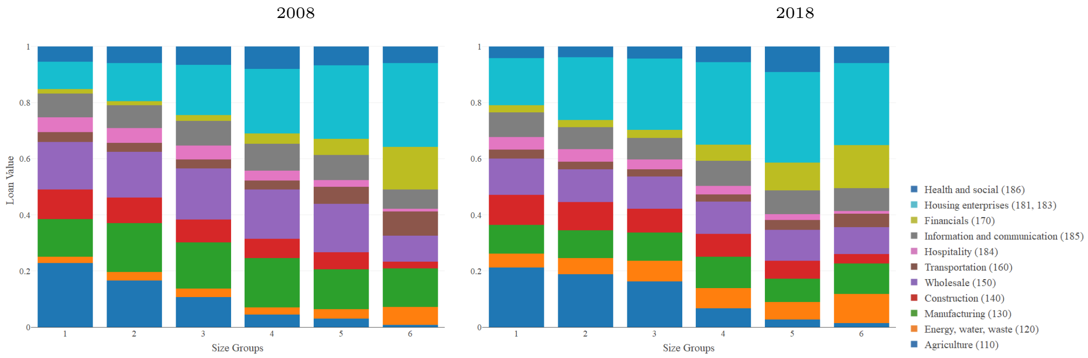

Figure 7.: Distribution of loans to QBS sectors per size group as of 2008 and 2018. Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, datasets: BISTA, QBS, data period: 01.01.2008-31.12.2018, own elaborations.

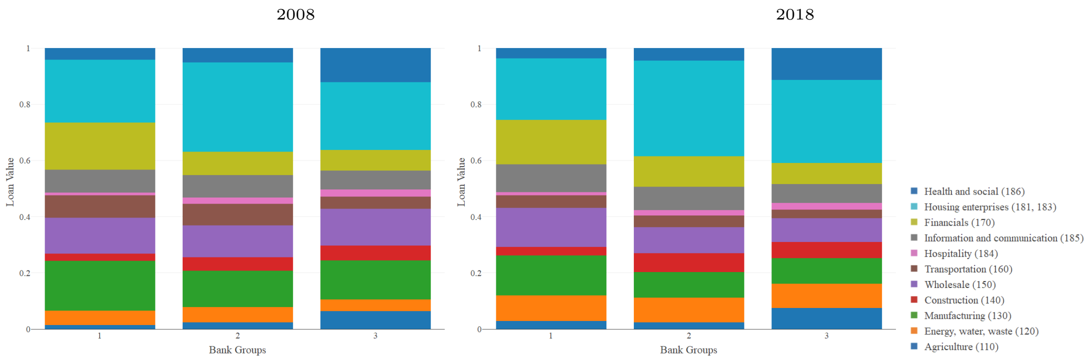

Figure 8.: Distribution of loans to QBS sectors per bank group as of 2008 and 2018. Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, datasets: MaMFI, QBS, data period: 01.01.2008-31.12.2018, own elaborations.

5. Discussion

The proposed empirical analysis indicates that the exposure of the German banking system to climate transition risks is non-negligible. Depending on the estimation method used, we find that the exposure is 19.41% (CCrS), 32.56% (LCI), and 25.17% (CRPS) of the total loan volume, as summarized in Table 8, and that certain banks face an amplified risk from a possible transformation in climate policies, technological change, or preference shocks, because of concentration of risks in certain sectors.

[11]We note that for this size and bank group combination only five reporting institutes were considered (see Table 4).

SZ	BGRS 1	BGRS 2	BGRS 3	Mean by size
1	22.22	40.23	24.89	24.95
2	19.60	25.95	24.63	24.54
3	28.12	26.84	23.76	24.89
4	25.81	25.94	23.88	25.16
5	26.13	22.85	13.78	21.31
6	27.22	24.96	26.03	26.09
Mean by group	26.98	24.93	23.58	25.17

*Averages are value-weighted.

Table 7.: Distribution of loan exposure to CPRS sectors for different size and bank groups in % as of 2018.
Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, datasets: BISTA, MaMFI, QBS, data period: 01.01.2008-31.12.2018, own elaborations.
Notes: BGRS indicates the category of bank (list abriged by the Bundesbank RDSC). BGRS 1 = Big banks, regional and other commercial banks, private bankers, branches of foreign banks; BGRS 2 = Landesbanken, Sparkassen, and Building and loan associations; BGRS 3 = Credit cooperatives, and Regional institutions of credit cooperatives, banks with special,development and other central support tasks

Method	**Sector**	**Outstanding Loan Volume in bn.â¬**	**Share of Loan Volume in bn.â¬**	**Affected Size Group**	**Affected Bank Group**
CCrS	Total	262.23	19.41%		
	Energy, water, waste	118.82	8.79%	Large Banks (Group 6)	All
	Manufacturing	143.41	10.61%	All	Private Banks (Group 1)
LCI (above median)	Total	440.33	32.59%		
	Transportation	52.93	3.92%	Large Banks (Group 6)	Private Banks (Group 1)
	Energy, water, waste	118.82	8.79%	Large Banks (Group 6)	All
	Agriculture	52.76	3.90%	Small Banks (Group 1 & 2)	Credit Cooperatives (Group 3)
	Manufacturing	143.41	10.61%	All	Privat Banks (Group 1)
	Construction	72.41	5.36%	Small & Mid-size Banks (Group 1-4)	Sparkassen & Landesbanken (Group 2)
CPRS	Total	340.07	25.17%	Large Banks (Group 6)	Private Banks (Group 1)

Table 8.: Quantification of transition risks of the German banking system according to alternative methods. Source: Research Data and Service Centre (RDSC) Deutsche Bundesbank, datasets: BISTA, MaMFI, QBS, data period: 01.01.2008-31.12.2018, own elaborations.

When comparing the exposure estimates across the different approaches used in our analysis, methods and data requirements should be carefully considered [12]. To estimate the LCI, we aggregate the loan volume of the QBS sectors above the median LCI, implying an overall higher exposure level for the LCI than for the CCrS assessment. The analysis indicates that a higher share of big private banks' portfolios tends to be exposed to CCrS. In particular, when relying on the CCrS method, we find that 8.79% of exposures refer to the Energy, water, waste (120); while all bank groups are affected, the most exposed are large banks. The manufacturing sector accounts for 10.61% of exposures, with private banks presenting the most exposed bank group. Resorting to the LCI method, we find that the sector that accounts for the highest exposure is the Energy, water, waste (120), followed by Transportation (160). Regarding the bank and size groups, we find evidence for the highest exposures to affect large banks and private banks in this case.

When applying the CPRS method, we find an overall exposure of 25.17% involving large banks, private banks, and small saving banks. Overall, the analysis highlight that the energy, transportation, and manufacturing sectors are particularly exposed towards transition risks. This finding implies that renewable energy policies, coal and gas exit strategies, and other economic and transportation policies could potentially negatively affect financial stability in Germany if they are introduced too late or without coordination across countries (thus leading to carbon leakage), or if financial investors cannot fully anticipate their impact (Sen and von Schickfus 2020; van der Ploeg and Rezai 2020; Caldecott et al. 2021). Indeed, because the country's emissions targets are far from being met and still are not aligned with the 1.5° target, further policy efforts might be needed for Germany to undertake a low-carbon transition and achieve net-zero emissions (Gils et al. 2021; Höhne et al. 2021; Black et al. 2021). Climate change and the transformation to a carbon-neutral economy currently dominate German political debate and agenda (Giegold 2021) and several actions are already in progress. Consider, among others, the recent German federal constitutional court decision that former Climate Protection Laws are insufficient and need to be more precise about emission mitigation beyond 2030[13] and emissions' targets in specific sectors. Similarly, other institutions such as the World Economic Forum on a global scale or Germany's Federal Environment Agency on a national level emphasize the danger of ecological risks like climate action failure and consequently extreme weather events (WEF 2021; Umweltbundesamt 2021).

Considering transformations related to the climate policy framework is particularly relevant because a disorderly transition to a low-carbon economy could affect the German banking sector via the exposures highlighted by our investigation, implying the materialization of credit risks and threats to systemic stability. On the one hand, the transition must be "timely and orderly" (NGFS 2020a), implying that early and ambitious action to a net-zero CO2-emissions economy is needed. Against this background, it is thus crucial that banks monitor and assess their climate risks adequately and that

[12]Because of matching issues between the QBS data aggregation and Eurostat's emission data, we can only differentiate between 11 economic sectors. Hence, when implementing the CCrS methodology, it identifies only two sectors as carbon critical. Besides the inherent differences between the Italian and German financial systems, this difference related to economic sectors' classification might explain why the exposure estimations for German banks are considerably lower than those found for Italian banks, as described in Faiella and Lavecchia (2020).

[13]German lawmakers adopted a crucial reform of the Climate Action Law in summer 2021, introducing more ambitious greenhouse gas reduction targets and details on post-2030 goals. This became necessary after a landmark ruling by the Constitutional Court on 29 April 2021, according to which the law was insufficient as it lacked details on emissions reduction beyond 2030 (Bundesregierung 2021).

financial supervisors assess, measure, and manage climate-related financial risks from a systemic perspective (EBA 2020b; ECB 2021). Different methodological approaches already exist and have been implemented to perform scenario analyses and climate-related stress tests at the country level (NGFS 2019a; Giuzio et al. 2019; Cleary et al. 2019). Current efforts are, however, not sufficient and Germany, together with several other European countries, has not yet implemented appropriate risk identification and risk management procedures (see D'Orazio 2021, 2022, for a recent review).

For example, the stress test conducted by the Bundesbank and BaFin for small and medium-sized banks (i.e., less significant institutions, LSIs) in 2019 showed that only one-third of the German credit institutions had incorporated climate-related risks into their risk management at least to some degree and two-thirds did not take them into account at all[14] (BaFin 2019). Our analysis showed that LSI might suffer less than larger banks from climate transition risks; nevertheless, a precautionary approach towards climate-related prudential regulation could prove beneficial when it comes to addressing the challenges posed by climate change to all financial intermediaries (NGFS 2019b; Chenet et al. 2021).

6. Conclusions

Recognizing the potential impact of climate risks on the German banking sector stability, we aimed to study its exposure to climate-related transition risks and identify its vulnerabilities in the case of a low-carbon transition as this analysis is currently lacking in the existing literature. Our study represents the first contribution to assess the exposure of the banking sector to transition risks considering the German case and provides a quantification of both the aggregate and sectoral exposures. Regarding the former, although the use of different evaluation methods does not allow for an accurate comparative analysis, our findings are in line with other countries' experiences, pointing to moderate but non-negligible exposure. Regarding the latter, the highest exposures are recorded for the manufacturing, electricity, and transportation sectors. Moreover, the study highlights that certain banks - especially the largest ones - will face a heightened risk in the case of a disorderly low-carbon transition.

Our findings could be integrated into broader macro stress test exercises to understand the effects of changes in climate and/or green fiscal policies, changes in economic agents' preferences, and technological change on the financial system's resilience. The results of this exercise could then be used to decide to activate specific supervisory instruments and adequately calibrate them (D'Orazio and Popoyan 2019). Schober et al. (2021) have recently provided a first contribution in this direction, considering the NGFS (2020a) scenarios and focusing on the implementation of a climate policy (i.e., increase of the carbon tax) as a source of transition risk. The results of this exercise are reported in the latest Financial Stability Review, which highlights a moderate effect of transition risks on financial institutions' portfolios (Bundesbank 2021b). This result is in line with the findings of our study, although the two analyses rely on different sources of data.

[14]The report points out that most German LSI (44%) are not taking ecological and climate-related risks into their risk management. The institutes were asked to answer the question, "To what extent do you currently consider ecological and climate-related risks in your risk management?" (see BaFin 2019). Only 1% of the institutes answered that climate risks are taken fairly comprehensively into account, 33% to some extent and 22% not at all, but planning to take risks into account. Overall, 73% perceive the climate risk to their institution as low, 14% as moderate, and 0.6% as high.

In our view, besides the long-term work of revising the existing regulatory framework, complementary short and medium-term measures, such as supervisory and disclosure measures and developing a macroprudential approach to addressing climate risk, can be implemented (see D'Orazio 2021, for a recent contribution on policy options for G20 countries). Among others, a Green Asset Ratio proposed by EBA (2020a) is relatively easy to implement as a risk management measure and implies the assessment of the exposure of banks' portfolios to carbon-intensive assets. Additionally, as discussed in D'Orazio (2021), the implementation of mandatory climate-related disclosure requirements can help quantify the materiality of climate and environmental risks, enhance understanding of carbon-related assets concentration, and inform investment, credit, and insurance decisions.

Based on the findings of our analysis, we believe that adopting timely and effective climate-related financial policies at the macro level is especially relevant considering the disruptions and instabilities related to the materialization of transition risks (D'Orazio 2021). This "prudent" approach is crucial considering that the magnitude, timing, and form of the effects of climate change on financial stability are uncertain and thus difficult to quantify with standard econometric and integrated assessment models (Beck and Krueger 2016; Diaz and Moore 2017; Duan et al. 2019). In our view, early action from both governments and financial supervisors can generate considerable benefits in reducing the nature and severity of disruptions and risks to the economy and financial markets from climate change. Moreover, this approach will be aligned to the ECB guidelines (ECB 2020) and recommendations of the Network for Greening the Financial System, which highlighted the risks of inaction regarding climate-related financial measures (NGFS 2019b).

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Data disclosure statement

The financial institutes data were obtained during multiple research visits at the Bundesbank (Project-Number: 2021/0016) and are based on the following datasets:

Monthly Balance Sheet Statistics (BISTA), published 2021-04-29, Version 1, **DOI**: `https://doi.org/10.12757/BBk.BISTA.99Q1-20Q4.01.01`.

Quarterly Borrowers Statistics (QBS), **URL**: `https://www.bundesbank.de/de/bundesbank/forschung/fdsz/forschungsdaten/vierteljaehrliche-kreditnehmerstatistik-vjkre--604532`.

Selected Master Data for MFIs (MaMFI), published 2021-09-30, Version 1, **DOI**: `https://doi.org/10.12757/Bbk.MaMFI.199901-202106.01.01`.

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