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# A text mining analysis of European banks' and insurers' disclosures on climate-related risks

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## Abstract

This paper empirically analyzes sustainability-related disclosures of listed European banks and insurance companies by focusing on transition risks, physical risks as well as stranded assets as a possible consequence of transition and physical risks. We employ a text mining analysis and apply a comprehensive keyword catalog to 142 firms. The dataset used for the analysis comprises 852 annual and 551 sustainability reports, covering a sample period from 2017 to 2022. Our results show that disclosure on climate-related risks considerably increases over the examined period, but that reporting on stranded assets is still in early stages. Moreover, European insurers report more on climate-related risks relative to the number of analyzed tokens than banks. Finally, statistical evidence suggests that larger banks and insurers with above-median market capitalization exhibit significantly more word hits on climate-related risks as compared to smaller firms.

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# 1 | INTRODUCTION

Climate-related risks are gaining increasing importance in the European financial services industry. With the introduction of the European Green Deal (see European Commission, 2019c) as well as the Action Plan on Financing Sustainable Growth (see European Commission, 2019b), the EU has witnessed heightened emphasis on tackling climate change and on facilitating the transformation into a resource-efficient economy by re-orienting capital flows to more sustainable investments, managing financial risks stemming from climate change as well as enhancing transparency. As a result, the financial services industry faces growing pressure from regulatory and public affairs to act against climate change (see, e.g., Alessi & Battiston, 2022; Gatzert & Reichel, 2022), not at least due to the emergence of increasing sustainability reporting requirements within the EU, such as the Sustainable Finance Disclosure Regulation (SFDR) (Directive (EU) 2019/2088)<sup>1</sup> or the EU Taxonomy (Directive (EU) 2020/852).<sup>2</sup> With the publication of the Delegated Regulation 2021/1256 amending the Solvency II regulation, European insurers are required to integrate sustainability risks into their Own Risk and Solvency Assessment (ORSA) as of August 2022, comprising climate change materiality assessments as well as scenario analyses by including transition and physical risks<sup>3</sup> (see European Commission, 2021). Regarding European banks, supervisory authorities require the integration of sustainability risks into existing risk management frameworks, for example, by conducting stress tests in the context of climate risk management (see European Banking Authority, 2022; European Central Bank, 2020; European Central Bank, 2022). Thus, despite their substantially differing business models, addressing the relevance of climate-related risks is crucial for both banks and insurers to mitigate risks, maintain long-term profitability, and align with evolving market and regulatory expectations related to environmental sustainability.

The transition to a low-carbon economy further evokes the risk of stranded assets, i.e., assets that have been impaired by unforeseen or premature write-downs or devaluations due to changes in market demand, technological advancements, or a dynamic regulatory environment (see Caldecott [2017] for further definitions). Consequently, banks and insurers as large institutional investors may face decreases in revenues of investments that do not meet sustainability criteria, which may in turn impede their ability to fulfill customer obligations. Simultaneously, physical and transition risks become increasingly important, which can be regarded as sources of stranded asset risks and may entail material financial impacts with strong interdependencies (see BaFin, 2020; Caldecott et al., 2021). However, toward this end, it

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<sup>1</sup>Directive (EU) 2019/2088 aims to reorient capital flows towards sustainable investments by means of integrating sustainability into risk management and promoting transparency as well as long-termism. It requires the classification of financial products into different categories according to their sustainability aspirations (see European Parliament and European Council, 2019).

<sup>2</sup>Directive (EU) 2020/852 as a common classification system for sustainable activities follows specific environmental objectives (i.e., climate change mitigation, climate change adaption, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, protection and restoration of biodiversity and ecosystems) and will continuously be amended through delegated acts (see European Parliament and European Council, 2020).

<sup>3</sup>Physical risks arise from extreme weather events and its consequences, e.g., floods or storms, but also emerge from long-term changes of climatic and ecological conditions, such as a rise in sea level or changes in air circulation (see Bundesanstalt für Finanzdienstleistungsaufsicht BaFin, 2020). Transition risks result from the transition to a low-carbon economy, comprising political risks (e.g., shortage of energy, increasing investment costs), regulatory risks (e.g., environmental taxes), or technological innovations (see Bundesanstalt für Finanzdienstleistungsaufsicht BaFin, 2020).

is not yet determined to what extent European banks and insurers report on climate-related risks, and how their public awareness has evolved over time, even though climate-related disclosures are crucial to effectively evaluate such risks, inform decision-makers, and build resilience (see Battiston et al., 2017).

Considering recent empirical studies on sustainability risks in the financial services industry, Gatzert and Reichel (2022) analyze the determinants and value of European and US insurers being aware of climate risks and opportunities. In contrast to the present study, the authors do not compare European insurers and banks and do not classify climate-related risks by separately examining stranded asset risks, transition risks, and physical risks with a text mining approach, but rather revert to a binary indicator from LSEG Workspace. They find that the proportion of insurance undertakings being aware of climate-related risks and opportunities increases from 2009 to 2018, with larger European insurers exhibiting the highest awareness. Stewart (2024) further refers to “climate adaption engineering” and identifies strategies aimed to reduce the vulnerability to extreme weather events as promising tools to mitigate losses resulting from climate change. Moreover, Alessi and Battiston (2022) ascertain that investment allocations in sustainable activities might increase the exposure to transition risks, whereby they find that insurers face a significantly higher exposure than banks. To investigate climate risk perceptions, Krueger et al. (2020) conduct a survey among global institutional investors and observe that long-term, larger, and ESG-oriented investors display a heightened level of concern about environmental risks. Regarding existing text mining analyses on sustainability reporting, Gatzert and Reichel (2024) investigate US and European insurers’ reporting practices on sustainable investment approaches from 2013 to 2018. They conclude that reporting on sustainable investments has considerably increased over time, with the stronger regulated European insurance industry exhibiting more word hits than US insurers. Another study focusing on US insurers has been conducted by Lin et al. (2023) in the context of the mandatory Climate Risk Disclosure Survey, who identify textual analyses on the responses to this survey as a promising tool for further investigations. Further text mining analyses have been conducted by Baier et al. (2020) on the relevance of socially responsible investments, Moreno and Caminero (2020) by examining compliance with the Task Force on Climate Related Financial Disclosures (TCFD) in the Spanish banking sector as well as Fiandrino and Tonelli (2021) on the accountability of information being disclosed under the Non-Financial Reporting Directive (NFRD).

The findings stated above motivate further research about which climate-related risks are actually addressed in corporate reports and whether there exist differences in corporate reporting regarding the type of firm, type of report or firm size. Since there does not yet exist an empirical study on disclosures about climate-related risks in the European financial services industry that simultaneously takes into account stranded assets as a special type of climate-related risks next to transition and physical risks, the present study aims to fill this gap. Moreover, we contribute to existing empirical literature on sustainability-related disclosures in the European financial services industry in being the first to compare the reporting intensiveness about climate-related risks of European banks and insurers. We especially compare banks’ and insurers’ reporting practices since both types of financial services providers are increasingly required to disclose climate-related risks due to the ongoing emergence of prudentially defined sustainability reporting frameworks within the European financial services industry. Additionally, the importance of financial institutions to reliably report on climate-related risks is highlighted by the potential consequences of misperceptions, since incomprehensible disclosures of environmental risks can result in delayed efforts on climate

change mitigation, the persistence of carbon lock-ins, as well as amplified reputational risks (see European Securities and Markets Authority ESMA, 2023).

Regarding the applied methodology, the present text mining analysis comprises 107 listed European banks and 35 listed European insurance undertakings with a market capitalization of at least EUR 1 billion at the end of 2022 and publicly available reports over the sample period from 2017 to 2022. Following Gatzert and Reichel (2024), we develop a keyword catalog with synonyms to analyze how often these terms are mentioned in annual reports (ARs) and sustainability reports (SRs) as commonly used formats for sustainability reporting. The underlying methodology offers distinct advantages for investigating disclosed climate-related risks as it allows for a standardized analysis of a large amount of unstructured data with enhanced precision compared to manual analyses, and it minimizes subjectivity in comparison to qualitative studies, such as interviews.

One of our main findings implies that reporting about climate-related sustainability risks has steadily increased over the sample period, with *General physical risks*, *Carbon bubble*, and *Acute Physical Risks* as well as respective synonyms accounting for the majority of references. Moreover, insurers' SRs exhibit the highest amount of relative word hits, followed by banks' SRs and insurers' ARs. We further find statistical evidence for larger firms to report more on climate-related risks than smaller firms with below-median market capitalization. Our results are relevant for practitioners, academics, and regulators as they provide an overview about the extent to which European banks and insurers report on climate-related risks and which risk types are most frequently addressed. This could enable financial services providers to evaluate their preparedness against the background of increasing sustainability reporting requirements and the growing interest of different stakeholders regarding the financial services sector's response to climate change.

The remainder of this paper is structured as follows: Section 2 presents the underlying methodology and data for the analysis. Section 3 evaluates the empirical results and Section 4 provides further analyses as well as robustness checks. The last section concludes, addresses limitations, and gives an outlook for further research opportunities.

## 2 | DATA AND METHODOLOGY

### 2.1 | Data sample

We compare the two industry sectors, banks and insurers, contingent upon the extent to which they report on climate-related sustainability risks in ARs and SRs over the sample period from 2017 to 2022. This 6-year period represents the widest possible time horizon with regard to data availability but at the same time still covers recent regulatory advancements, with the globally applicable recommendations set forth by the TCFD in 2017<sup>4</sup> representing the starting point for subsequent sustainability reporting requirements. For the composition of the underlying sample, we retrieve all listed European (including the UK and Switzerland due to their intensive business relations with European firms) banking and insurance firms from LSEG Workspace<sup>5</sup> and apply screening criteria, as

<sup>4</sup>See <https://assets.bbhub.io/company/sites/60/2021/10/FINAL-2017-TCFD-Report.pdf> for the final report of the TCFD.

<sup>5</sup>For further information, see <https://www.lseg.com/en/data-analytics/financial-data/company-data>.

TABLE 1 Sample selection process.

Screening criteria	Percentage of market capitalization	Total number of firms	Number of banks	Number of insurers
Initial data sample (European firms with TRBC = “insurance”, “Banking & Investment Services”, status = listed)	100% (EUR 2,599,223,323,954)	957	875	82
After exclusion of small-cap firms (available market capitalization >1 bn EUR)	96.84% (EUR 2,517,212,655,049)	205	165	40
After exclusion of TRBC subsectors “Financial & Commodity Market Operators”, “Insurance Brokers” and firms with other business models <sup>a</sup>	86.34% (EUR 2,244,254,961,879)	182	145	37
After exclusion of firms with missing ARs for the sample period	79.68% (EUR 2,071,176,755,379)	142	107	35

Note: The data has been retrieved from LSEG Workspace in July 2023.

<sup>a</sup>Insurers and banks that have been excluded due to their business model are firms that deal with commercial leasing, stock exchanges, diversified investment services, factoring, private equity, and venture capital as provided by the company descriptions in LSEG Workspace. Moreover, we exclude the conglomerate Talanx Group since it comprises the separately examined reinsurer Hannover Rueck SE as well as Unipol Gruppo SpA due to the inclusion of the separately examined subsidiary UnipolSai Assicurazioni SpA.

summarized in Table 1. We thereby include the Thomson Reuters Business Classification (TRBC) sectors “Insurance” and “Banking & Investment Services”. Since large public companies might be more likely to disclose information on climate-related risks, we exclusively focus on listed firms with a market capitalization of at least EUR 1 billion, as done, for example, in Gatzert and Reichel (2024). Moreover, the business descriptions of each firm are manually reviewed to check whether its business model or specific subsectors can be related to banks or insurance undertakings, which led to an additional exclusion of 23 companies. Since ARs are characterized by a higher degree of standardization and SRs in some cases are incorporated in ARs in terms of integrated reporting, we follow the screening criteria of Gatzert and Reichel (2024) and presume at least one available AR per year to remain in the sample. Conversely, SRs are not required to be available for each sample year. This led to an exclusion of 39 companies without publicly available ARs in English over the sample period. Table A1 shows which type of report has been assigned to the respective category. All firms included in the analysis had to be in operation throughout the entire period. After having applied the screening criteria, the final sample covers 142 European banks and insurers,<sup>6</sup> which represent a market share of 79.68% relative to the total industry market capitalization (see Table 1).

## 2.2 | Methodological design

The following text mining approach analyzes the number of word occurrences with regard to specific keywords and assigned synonyms on climate-related risks (see Table 2), which will be compared throughout the assessed reports of the sample banks and insurers. For the textual analysis, the programming language Python is used, which can be applied to text mining with the help of specific packages and allows for standardized evaluations of numerous reports without being reliant on external data providers. After having selected the data for the analysis, the documents have been preprocessed, where all texts have been tokenized, that is, split into single words (see Vel, 2021), transformed into lowercase, and stemmed to obtain root words (see Baier et al., 2020).

For the keyword analysis, we iteratively developed a dictionary (see Table 2) with climate-related risk indicators and respective synonyms, which consists of three broader categories: stranded asset risks, transition risks, and physical risks. We investigate a large variety of climate-related terms and consider risks in a broader sense in terms of upside and downside risks by additionally capturing chances and opportunities, such as *Divestment*, or *Decarbonization*.<sup>7</sup> Moreover, we control for double counts that would lead to biased positive results. As an example, *Physical risks* encompass both *Acute physical risks* and *Chronic physical risks*, so that the respective word hit is only assigned to the more specific latter two keywords if the full term consisting of 3-grams appears in the text.

<sup>6</sup>The list of banks and insurance companies included in the analysis are provided in the online appendix.

<sup>7</sup>Even though the terms *Divestment* and *Decarbonization* offer significant opportunities for the transition to a low-carbon economy, such as improved energy efficiency (see, e.g., Ayling & Gunningham, 2015), they nevertheless entail considerable financial risks as soon as the value of fossil assets declines. In addition, divestment campaigns and decarbonization efforts can amplify reputational risks due to failures to adapt to evolving regulatory frameworks or public pressure (see Ansar et al., 2013), which underlines the interdependencies between the considered risk types.

TABLE 2 Keyword catalog on terms referring to climate-related risks and exemplary synonyms.

Keyword	Exemplary synonyms <sup>a</sup>	Definition/Explanation	Sources
<b>1. Keywords and synonyms related to stranded asset risks</b>			
<b>Stranded assets</b>	*Carbon-risk investments *Climate-exposed capital *Climate-impacted assets *Fossil fuel assets *Impaired assets *Premature write-downs *Sunk asset	“(…) assets that lose economic value ahead of their anticipated useful life, whether that is a result of changes in legislation, market forces, disruptive innovation, societal norms, or environmental shocks.”	Bos & Gupta, 2019, p. 1
<b>Divestment</b>	*Capital withdrawal *Carbon divestment *Climate-conscious portfolio *Fossil fuel divestment *Phase-out fossil fuels *Replacement of assets *Shift of carbon assets *Shift of fossil fuel investments	“(…) the divestment movement uses a large range of strategies to shame, pressure, facilitate, and encourage investors in general, and large institutional investors in particular, to divest their holdings of fossil fuel stocks in favor of other climate-friendly, or at least climate-neutral, alternatives.”	Bos & Gupta, 2019, p. 2
<b>Carbon bubble</b>	*Carbon footprint *Carbon pricing *Coal phase-out *Decarbonization *Emission certificate *Unburnable carbon	“A hypothesized overvaluation of fossil fuel reserves and related assets due to neglecting the possibility of those assets becoming unusable or “unburnable”.”	Carbon Tracker Initiative (2011)
<b>2. Keywords and synonyms related to transition risks</b>			
<b>General transition risks</b>	*Adaptation risk *Adjustment risk *Biodiversity transition *Clean energy transition *Green transition *Restructuring risk	“Arise in connection with the transition to a low-carbon economy: political measures can lead to an increase in the price and/or shortage of fossil fuels or emission certificates (examples: coal phase-out,	Bundesanstalt für Finanzdienstleistungsaufsicht BaFin, 2020, p. 14

(Continues)



TABLE 2 (Continued)

Keyword	Exemplary synonyms <sup>a</sup>	Definition/Explanation	Sources
<b>Policy risks</b>	*Transformation risk	CO2 tax) or to high investment costs due to the necessary renovation of buildings and plants. New technologies can displace familiar ones (...) and changing preferences of contractual partners and societal expectations can endanger companies that have not adapted.”	European Commission EC, 2019a, p. 6
	*Transition of infrastructure		
	*Disclosure requirements		
	*Energy policies		
	*Energy efficiency standard		
	*Energy efficiency requirements		
	*Environmental tax		
<b>Market risks</b>	*Government risk	“(...) a result of energy efficiency requirements, carbon-pricing mechanisms which increase the price of fossil fuels, or policies to encourage sustainable land use.”	Bundesanstalt für Finanzdienstleistungsaufsicht BaFin, 2020, p. 18
	*Regulatory risk		
	*Changing commodity prices		
	*Changing sustainability preferences		
	*Commodity price risk		
	*Pricing climate change		
	*Shift in sustainable consumption		
<b>Technology risks</b>	*Carbon capture and storage technology	“(...) risks are poorly understood and are regularly mispriced, which has resulted in a significant over-exposure to environmentally unsustainable assets throughout our financial and economic systems. Some of these risk factors	Ansar et al., 2013, p. 2
	*Clean technology risk		
	*Energy disruption		
	*Technological disruption		
	*Technology costs		

TABLE 2 (Continued)

Keyword	Exemplary synonyms <sup>a</sup>	Definition/Explanation	Sources
Legal risks	*Technology resilience	include (...) falling clean technology costs (e.g. solar PV, onshore wind).”	European Securities and Markets Authority ESMA, <a href="#">2023</a> , p. 15
	*Carbon liability	“Legal risks describe the potential litigation issues a firm may face in relation to greenwashing accusations.”	
	*Climate liability		
	*Climate lawsuits		
Reputational risks	*Environmental lawsuits	“(…) the difficulty of attracting and retaining customers, employees, business partners and investors if a company has reputation for damaging the climate.”	European Commission EC, <a href="#">2019a</a> , p. 6
	*Carbon image		
	*Climate perception risk		
	*Climate reputation		
	*Damaged image		
	*Green reputation		
	*Image risks		

### 3. Keywords and synonyms related to physical risks

<b>General physical risks</b>	*Breakdown of supply chains	"Arise both from individual extreme weather events and their consequences (...) and from long-term changes in climatic and ecological conditions (...). Physical risks can also have indirect consequences (examples: collapse of supply chains; abandonment of water-intensive business activities to climate-induced migration and armed conflict)."	Bundesanstalt für Finanzdienstleistungsaufsicht BaFin, 2020, p. 14
	*Changes in climate		
	*Changing climatic conditions		
	*Changing ecological conditions		
	*Collapse of supply chains		
	*Environmental risks		
	*Extreme weather events		
	*Physical threat		
	*Physical risk		
<b>Acute physical risks</b>	*Drought	"(...) arise from particular events, especially weather-related events such as storms, floods, fires or heatwaves, that may damage production facilities and disrupt value chains."	European Commission EC, 2019a, p. 6
	*Flood		
	*Heat period		
	*Heatwave		
	*Natural disaster		
	*Storm		
<b>Chronic physical risks</b>	*Wildfires	"(...) arise from longer-term changes in the climate, such as temperature changes,	European Commission EC, 2019a, p. 6
	*Changes in land productivity		

(Continues)

TABLE 2 (Continued)

Keyword	Exemplary synonyms <sup>a</sup>	Definition/Explanation	Sources
	*Changes in soil productivity	rising sea levels, reduced water availability,	
	*Changing precipitation patterns	biodiversity loss and changes in land and soil productivity.”	
	*Loss of biodiversity		
	*Reduced water availability		
	*Rise in sea level		
	*Temperature changes		
	*Temperature increase		

<sup>a</sup>The full list of the applied synonyms can be provided upon request.

To ensure that the identified terms exhibit a direct relation to environmental sustainability, keywords in context (KWIC) have been used analogously to Gries and Newman (2013) for risks related to stranded assets as well as transition risks.<sup>8</sup> Therefore, we create a separate list with sustainability-related terms (see Table A2 for illustrative tokens) and apply it to 20 preceding and 20 following words as soon as a word hit has been achieved. This allows for an automatic verification of whether the context of a word hit can directly be related to sustainability. In case the context does not contain at least one term of the predefined list of sustainability-related keywords, the respective reference has been subtracted. Even though this approach has some limitations,<sup>9</sup> it is still beneficial compared to manual word counts which are more prone to error and not feasible in case of large amounts of unstructured data (see Heideringer & Gatzert, 2018).

### 3 | TEXT MINING RESULTS

For the evaluation of the results, we first display descriptive statistics, followed by an evaluation of the development of reporting on climate-related risks over the considered time horizon as well as report types, subsectors, and firm size.

<sup>8</sup>Since the keywords *General physical risks*, *Acute physical risks* as well as *Chronic physical risks* and respective synonyms exhibit a direct link to sustainability, KWIC have not been applied to the category of physical risks.

<sup>9</sup>As the applied word list for reviewing the sustainability context is not exhaustive, a word count may be subtracted in case the context does not match with a predefined word list of sustainability-related tokens, although it refers to sustainability topics other than those included in the word list.

### 3.1 | Descriptive statistics

In total, 852 ARs and 551 SRs have been analyzed,<sup>10</sup> with further exclusions being applied to reports published by asset managers, one-pager documents, factsheets, reports that exclusively contain figures and tables, active ownership reports (due to its missing focus on climate-related risks), principles for responsible banking reports, or questionnaires on the carbon disclosure project (see Gatzert & Reichel, 2024). In 228 cases, SRs are directly included in a firms' AR as part of integrated reporting. We further assigned six SRs to two years where it was clearly attributable that the respective report partly covers both years. Table 3 summarizes the descriptive statistics from the keyword analysis of the 1403 firm-year observations.

### 3.2 | Differences between banks and insurers

To get a first indication of how differences in reporting on climate-related risks between banks and insurers have evolved over the sample period, Figure 1 displays the developments of median absolute and median relative word hits<sup>11</sup> from 2017 to 2022. In line with the expected development, which can be derived from the initially mentioned regulatory developments on the integration of sustainability risks (see Section 1), Figure 1 displays that all four median absolute variables have steadily increased over the sample period, indicating that reporting on climate-related sustainability risks has gained considerable importance for European banks and insurers. European insurers show a similar development in absolute values of ARs and SRs, whereas for banks, ARs exhibit a significantly higher number of absolute word hits compared to SRs. A possible explanation for the significant increase of banks' absolute word hits from 2020 onwards might stem from supervisory expectations relating to the risk management and the disclosure of climate-related risks in November 2020 (see European Central Bank, 2020), resulting in a higher reporting intensiveness for the considered risk categories in subsequent reporting periods. Regarding relative values, insurers' SRs exhibit the highest word hits, followed by banks' SRs and insurers' ARs, indicating that the high number of absolute references in banks' ARs primarily stems from the high number of analyzed tokens. Overall, reporting on climate-related risks has increased in relative terms as well, whereby the marginal decrease of banks' SRs in 2022 can be attributed to the significantly larger number of analyzed tokens compared to the previous years. When comparing the results with mean values, we find similar effects, but median word hits exhibit a lower number of references, so that single outliers with a disproportionately high number of word hits account for the overall higher mean values.

More precise analyses further reveal that not only the number of word hits has increased over time, but also the number of risk types reported per individual company. Thus, these findings indicate a growing relevance of climate-related risks in the financial services industry

<sup>10</sup>The reduced number of analyzed SRs can be explained by the fact that in some cases, SRs are part of a firms' ARs in terms of integrated reporting and one publicly available AR for each considered year is required to remain in the sample, which is not the case for SRs.

<sup>11</sup>For the relative values, we compute the share of references relative to the total number of analyzed tokens in the respective report.

TABLE 3 Summary statistics of the keyword approach.

	ARs	SRs	ARs and SRs
Number of analyzed documents	852	551	1403
Number of analyzed tokens	147,925,657	20,111,971	168,037,628
Number of total word hits	21,659	18,094	39,753
Proportion of word hits relative to total amount of tokens	21,659/ 147,925,657 = 0.0146%	18,094/ 20,111,971 = 0.0900%	39,753/ 168,037,628 = 0.0024%

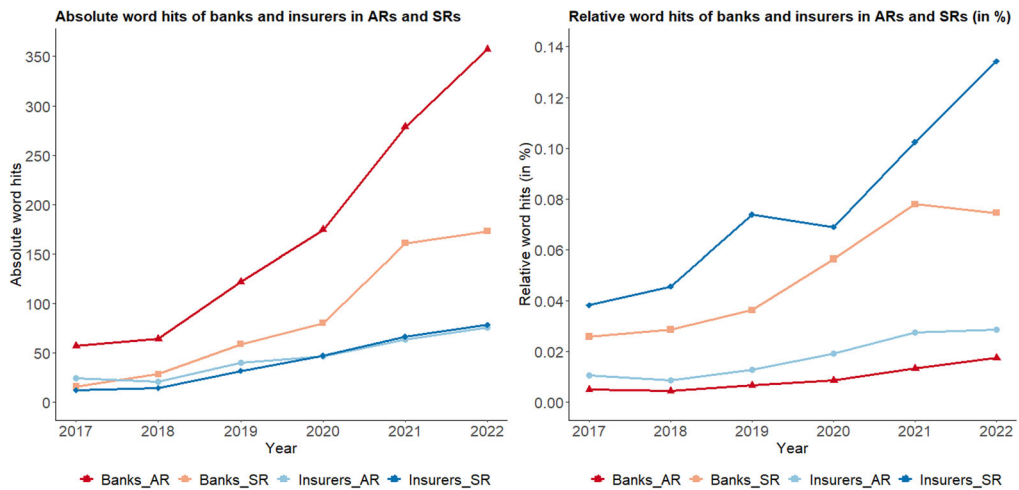


FIGURE 1 Median absolute and relative word hits of banks and insurers over time.

especially from 2020 onwards, which could be attributed to the initially mentioned regulatory developments. To study the impact of such regulations in more detail, we use a paired t-test to examine whether there is a significantly higher number of absolute and relative word hits for the year 2021 compared to 2020 as well as for the year 2022 compared to 2021. The results show that on average, absolute word hits in ARs<sup>12</sup> are significantly higher in 2021 as compared to 2020 after the introduction of the SFDR, which applies to both banks and insurers (resulting in a mean difference of 18.1429 for insurers ( $\bar{x}_{\text{Insurers\_ARs\_2021}} = 52.6286 - \bar{x}_{\text{Insurers\_ARs\_2020}} = 34.4857$ ) with a p-value of 0.0885 as well as mean difference of 12.0935 for banks of 17.0965 ( $\bar{x}_{\text{Banks\_ARs\_2021}} = 30.9159 - \bar{x}_{\text{Banks\_ARs\_2020}} = 18.8224$ ) with a p-value of 0.0015). Regarding regulatory developments coming into effect in 2022 that exclusively apply to insurers, the Delegated Regulation 2021/1256 did not lead to a significant increase in reporting

<sup>12</sup>We restrict our analysis for statistical tests on the impact of regulation to ARs for a better comparison between firms, as each sample firm shows one available AR per examined year, which is not the case for (voluntary) disclosures in SRs.

on climate-related risks in ARs, since absolute word hits in 2022 as compared to 2021 result in a mean difference of 8.3714 ( $\bar{x}_{\text{Insurers\_ARs\_2022}} = 61 - \bar{x}_{\text{Insurers\_ARs\_2021}} = 52.6286$ ) with a rather high p-value of 0.482. However, we find statistically significant mean differences between absolute word hits in 2022 as compared to 2021 for banks ( $\bar{x}_{\text{Banks\_ARs\_2022}} = 48.8224 - \bar{x}_{\text{Banks\_ARs\_2021}} = 30.9159$ ). When investigating the impact of regulation on relative instead of absolute word hits in ARs, results remain robust for the banking industry but are no longer significant for insurers' difference in relative word hits from 2021 to 2020 (p-value of 0.2273), indicating an overall weaker effect of prudentially defined reporting requirements on the subsample of 35 insurers. All results remain robust when additionally conducting Wilcoxon rank sum tests on differences in medians.

Additional statistics on differences between banks and insurers in relative values are summarized in Table 4, which shows that insurers report more on keywords and synonyms related to the aggregated categories *Stranded asset risks* (comprising the keywords *Stranded Assets*, *Divestment*, and *Carbon bubble*) and *Physical risks* (consisting of *General*, *Acute*, and *Chronic physical risks*), while median relative word hits with regard to the category *Transition risks* (including the terms *General transition risks*, *Policy risks*, *Market risks*, *Technology risks*, *Legal risks*, and *Reputational risks* with its respective synonyms) are higher for banks than insurers. These differences can be explained by the diverging business models of banks and insurers: While insurers are especially exposed to increasing extreme weather events on the liability side (and thus also stranded asset risks and physical risks), banks might be more affected by market risks (including, e.g., credit risks), leading to a higher number of word hits for transition risks. Another possible explanation for banks to report more on transition risks than insurers might be that banks face stricter regulatory requirements (see European Central Bank ECB, 2020, 2022). However, even though banks report more on these risks than insurers, this does not necessarily indicate that their exposure to transition risks is higher, since weaker regulated markets might be more susceptible to transition risks (see Semieniuk et al., 2022). Alessi and Battiston (2022) additionally confirm that insurers are more exposed to transition risks than banks. Thus, the findings on the exposure towards climate-related risks cannot be translated to risk disclosures in corporate reports, since median relative word hits for the category of transition risks are higher for banks than for insurers in the present study. Overall, we find no statistical support for *Transition risks* to exhibit significantly higher relative word hits for banks than for insurers.<sup>13</sup> The least mentioned tokens in relative terms comprise *Technology risks* and *Stranded assets* for banks, while insurers exhibit the lowest references for *Technology risks* and *Legal risks*. The low number of references for *Technology risks* and *Legal risks* can be explained by the missing direct relation to sustainability when applying KWIC, as explained in Sections 2.2 and 4.3.

When controlling for subsectors,<sup>14</sup> Table A3a in the Appendix shows that the TRBC subdivisions “Banks”, “Corporate banks”, and “Investment management & fund operators”

<sup>13</sup>We apply a Wilcoxon rank sum test on the difference in relative word hits for transition risks of European banks and insurers, which results in a p-value of 0.4731.

<sup>14</sup>TRBC subsectors included in this study comprise 11 subsectors for banks (Banks, Consumer lending, Corporate banks, Corporate financial services, Investment banking, Investment banking & brokerage services, Investment management, Investment management & fund operators, Private banks, Retail & mortgage banks, Wealth management) and 7 subsectors for insurance undertakings (Insurance – automobile, Life & health insurance, Life insurance, Multiline insurance & brokers, Property & casualty insurance, Property & casualty reinsurance, Reinsurance).

TABLE 4 Relative word hits (in %) for European banks and insurers (annual and sustainability reports combined) from 2017 to 2022.

	2017		2018		2019		2020		2021		2022	
	Banks	Insurers	Banks	Insurers	Banks	Insurers	Banks	Insurers	Banks	Insurers	Banks	Insurers
1. Keywords and synonyms related to stranded asset risks												
Stranded assets	0.00021	0.00056	0.00017	0.000578	0.00019	0.00063	0.00028	0.00114	0.00035	0.00117	0.00042	0.00106
Divestment	0.00020	0.00069	0.00018	0.00062	0.00023	0.00105	0.00022	0.00160	0.00024	0.00123	0.00026	0.00169
Carbon bubble	0.00160	0.00256	0.00134	0.00344	0.00207	0.00639	0.00355	0.01147	0.00650	0.01104	0.00723	0.01421
2. Keywords and synonyms related to transition risks												
Gen. trans. risks	0.00016	0.00028	0.00030	0.00068	0.00082	0.00160	0.00199	0.00371	0.00402	0.00332	0.00579	0.00385
Policy risks	0.00140	0.00195	0.00135	0.00195	0.00152	0.00218	0.00152	0.00251	0.00192	0.00247	0.00223	0.00307
Market risks	0.00180	0.00067	0.00136	0.00074	0.00148	0.00088	0.00137	0.00106	0.00152	0.00085	0.00188	0.00096
Technology risks	0.00008	0.00002	0.00006	0.00004	0.00011	0.00004	0.00013	0.00016	0.00018	0.00012	0.00024	0.00018
Legal risks	0.00033	0.00032	0.00026	0.00038	0.00032	0.00047	0.00024	0.00102	0.00026	0.00067	0.00043	0.00127
Reputational risks	0.00139	0.00075	0.00113	0.00064	0.00119	0.00098	0.00130	0.00132	0.00191	0.00132	0.00207	0.00171
3. Keywords and synonyms related to physical risks												
Gen. phys. risks	0.00091	0.00232	0.00098	0.00251	0.00204	0.00353	0.00319	0.00648	0.00696	0.00687	0.00948	0.00825
Acute phys. risks	0.00075	0.01195	0.00070	0.01146	0.00121	0.01113	0.00197	0.01544	0.00392	0.01563	0.00502	0.01700
Chr. phys. risks	0.00027	0.00046	0.00032	0.00072	0.00044	0.00114	0.00056	0.00231	0.00116	0.00201	0.00132	0.00233
Median	0.00054	0.00068	0.00051	0.00070	0.00101	0.00110	0.00134	0.00196	0.00171	0.00167	0.00197	0.00202
Mean	0.00076	0.00188	0.00068	0.00198	0.00097	0.00250	0.00136	0.00402	0.00241	0.00389	0.00303	0.00463

exhibit the highest number of mean absolute word hits within the banking industry, encompassing a relatively high number of firms included per classification. Considering relative results, the highest mean word hits can be observed for the classifications “Wealth management”, “Investment management”, and “Investment management & fund operators”. A possible explanation for the disparity in absolute and relative values stems from the mean number of analyzed tokens per report, which is especially high for “Banks” and “Corporate banks”, leading to a high number of absolute word occurrences but rather low relative word hits. Conversely, for the insurance sector, the majority of references stems from the subsectors “Reinsurance”, “Life & health insurance”, and “Property & casualty reinsurance”, which holds for both absolute and relative word hits (see Table A3b in the Appendix). Consequently, reinsurance companies tend to disclose more information on climate-related risks than primary insurers.

### 3.3 | Differences between annual and sustainability reports

To evaluate aggregated occurrences of climate-related terms by distinguishing between ARs and SRs, Figure 2 displays median relative word hits of the three categories *Stranded assets*, *Transition risks*, and *Physical risks*. It becomes evident that SRs contain higher median relative word hits for each sample year and each single category than ARs. Moreover, *Physical risks* seem to be the most relevant category with regard to climate-related risks, followed by *Transition risks*. Thus, the aggregated category *Stranded assets* with its respective keywords and synonyms represents the lowest number of relative word hits throughout the whole sample period. This low number of references could result from European banks' and insurers' assumption that fossil fuel industries are primarily affected, so that their own exposure is considered to be low due to their low proportion of brown assets, which can be confirmed by stress tests of EIOPA for Occupational Retirement Provisions (IORPs), resulting in a small exposure towards stranded assets (see European Insurance and Occupational Pensions Authority EIOPA, 2022). Nevertheless, financial institutions might exhibit a high indirect exposure due to investments in equities, corporate and government bonds (see Battiston et al., 2017), which emphasizes the need for stranded asset risks not to be neglected.

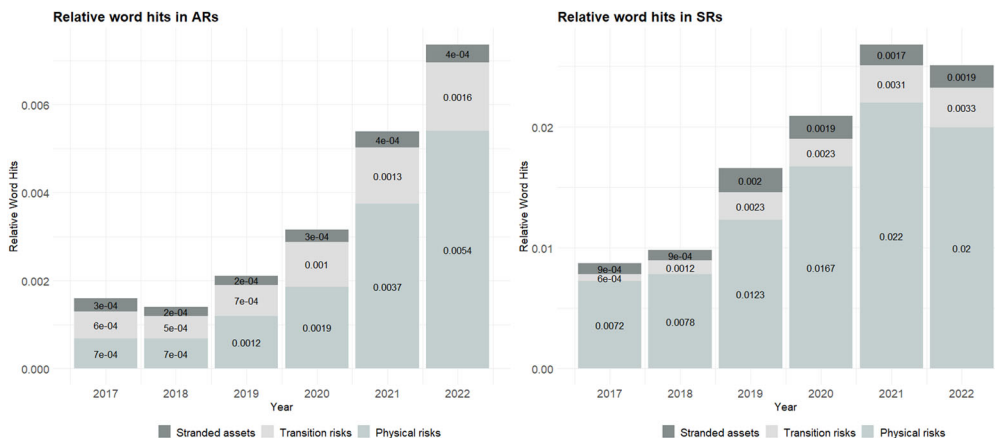


FIGURE 2 Median relative word hits in ARs and SRs with regard to the three examined risk categories.



To provide a more detailed analysis of single keywords that contribute most to the overall results, Table A4 in the Appendix summarizes the relative references per keyword and type of report. Accordingly, the most frequently investigated risk types relative to the number of analyzed tokens relate to *General physical risks* and *Acute physical risks* for ARs, while SRs show the highest amount of relative word hits for *Carbon bubble* and *Acute physical risks*. What further becomes obvious is that *Market risks* in the context of transition risks have predominately been mentioned in ARs, since they represent a considerably important business risk, with mandatory reporting requirements to integrate sustainability risks in established risk classes as set out in the Solvency II regulation for insurance undertakings (see European Commission EC, 2021) and the Basel III framework for banks (see European Banking Authority EBA, 2022; European Central Bank ECB, 2020; European Central Bank ECB, 2022). Thus, regulatory developments seem to be effective with regard to the reporting intensiveness of certain risk categories. To investigate recently emerging risk types in more detail, the percentage change of word hits from 2022 as compared to 2017 shows that *General transition risks* (2399.35% in SRs) and *General physical risks* (805.35% in ARs) exhibit the largest relative increase. Conversely, the lowest percentage increase can be observed for *Market risks* (0.1% in ARs) and *Reputational risks* (11.6% in SRs), which confirms their conventional nature as established risk types.

Overall, SRs report more on climate-related risks in relative terms compared to ARs and thus exhibit higher median relative words hits for the aggregated categories *Stranded assets*, *Transition risks* and *Physical risks* than ARs. In addition to the observations on mean results showing higher values than median results in Section 3.2, the difference between mean and median values is particularly pronounced for SRs, implying that SRs exhibit a heightened propensity towards being driven by outliers. This can additionally be confirmed by the larger interquartile ranges when comparing ARs and SRs of banks and insurance companies (see Figure 3), whereby SRs of insurance companies are most susceptible to outliers. Thus, heterogenous results can be derived: while SRs account for a higher number of relative word

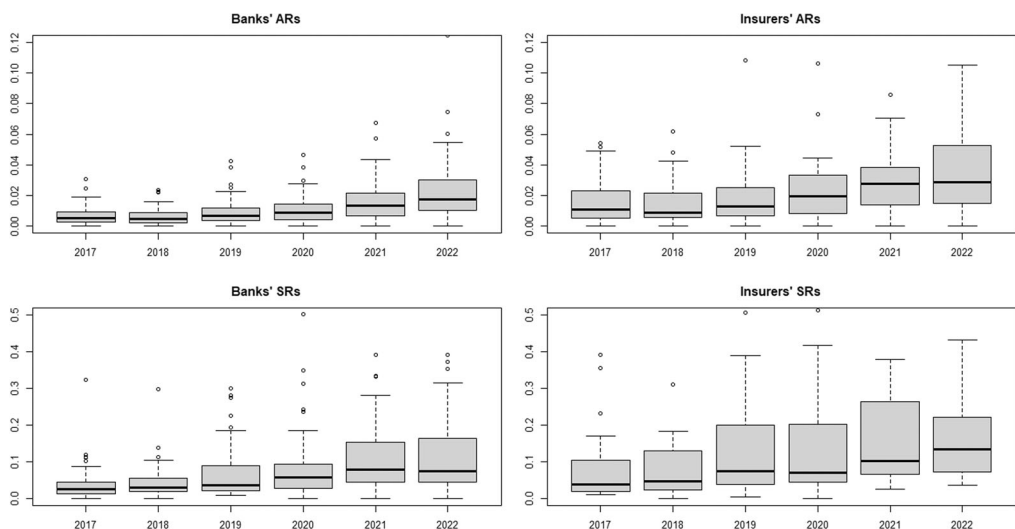


FIGURE 3 Development of relative word hits (in %) for banks' and insurers' annual and sustainability reports.

hits, this type of report at the same time exhibits larger interquartile ranges than ARs. Consequently, ARs are characterized by a lower propensity towards being driven by outliers, with overall lower relative word hits (which especially holds true when comparing ARs and SRs of banks).

### 3.4 | Differences between small and large firms

Regarding the impact of firm size, the sample has been split into small and large firms contingent upon their market capitalization. Since large European financial institutions have already announced to increase sustainable infrastructure investments and consider possible risks of stranded assets by divesting from industries that are at risk of becoming stranded, for example, coal or oil industries (see e.g., Mielke, 2019), it might be expected that larger firms report more on climate-related sustainability risks. This can be confirmed by our analysis, as stated in Table 5, where mean and median absolute word hits of the small (large) group of firms below-median (above-median) market capitalization are compared across all years. It can be derived that larger European banks and insurers exhibit statistically significant higher absolute mean and median word hits, which additionally holds true when examining ARs and SRs separately. Krueger et al. (2020) corroborate our results by stating that large investors show a higher exposure to adverse climate effects, leading to a higher reporting intensiveness in our case. Moreover, the results are in line with Gatzert and Reichel (2024) as well as Andersson and Arvidsson (2022), who find that firms reporting on sustainable investments and climate-related risks are significantly larger on average. Thus, the size bias observed for ESG ratings by Dobrick et al. (2023) and Drempetic et al. (2020) can be transferred to the disclosure of climate-related risks in public reports of European insurers and banks.

To verify the observed size effect, we replaced the variable market capitalization by total assets. Through this adjustment, we find that firms with above-median total assets again show a statistically significant higher number of word hits as compared to the smaller sample group, whereby the difference in mean absolute word hits is higher for market capitalization as a proxy of firm size than for total assets. However, it is worth noting that the disparity in mean

**TABLE 5** Correlation coefficients and differences in mean and median absolute word hits between small and large firms.

	Firms with mean firm size ≤4432.8 Mio. EUR ( <i>n</i> = 68)		Firms with mean firm size >4432.8 Mio. EUR ( <i>n</i> = 72)		Difference in means and medians	
Word hits	Mean	Median	Mean	Median	In means	In medians
AR + SR	21.68	11.	69.73	41.50	−48.05***	−30.5***
Pearson's correlation	−0.0154 ( <i>p</i> = 0.9008)		0.4778*** ( <i>p</i> < 0.0001)			
Spearman's correlation	−0.0453 ( <i>p</i> = 0.7137)		0.5136*** ( <i>p</i> < 0.0001)			

*Note:* Note that two firms have been excluded from the analysis of firm size due to missing data on market capitalization for all years.

\*\*\*denote statistical significance at the 1% level. Differences in means are based on t-tests and differences in medians are based on nonparametric Wilcoxon rank sum tests.

word hits between these two groups was only marginally reduced when controlling for total assets instead of market capitalization.

## 4 | FURTHER ANALYSES

### 4.1 | Environmental pillar score

To investigate whether there is a correlation between firms reporting on climate-related risks and employing best practices to manage environmental risks, we revert to the Environmental (E) pillar score derived from LSEG Workspace,<sup>15</sup> which—amongst other—measures to what extent a firm considers environmental criteria. Thus, the higher (lower) the E score, the better (worse) the environmental management. A robust E pillar rating can serve as an indicator of committing to the proactive management of associated risks, potentially creating a favorable perception among relevant stakeholders (see Di Tommaso & Mazzuca, 2023). Regarding further analyses on ESG sub-scores, Brogi et al. (2022), for example, find that a higher E score is positively associated with an insurer's profitability and solvency ratio. Table A5 in the Appendix provides an overview of ranges and assigned rating grades for the respective scores. As can be derived from Table 6,<sup>16</sup> firms that achieve mean E pillar grades over the considered reporting period of at least B- (or at least a score >50) report more on climate-related risks as compared to sample firms with a mean rating grade of C+ or worse (indicating scores from 50 to 0). Resulting *t* tests on the differences in means and Wilcoxon rank sum tests on the differences in medians confirm the statistical significance of firms with better E pillar scores to exhibit higher absolute word hits on climate-related risks. In addition, Pearson's and Spearman's coefficients show a statistically significant positive correlation, indicating that the higher the mean rating, the more word hits can be observed.

As a robustness check, we separately examine the influence of E pillar scores on absolute word hits for ARs and SRs, whereby the results reveal smaller differences in means and medians. For SRs of firms with a mean E pillar score from A+ to B−, a weak negative correlation can be observed, indicating that SRs of firms with a high E pillar score do not necessarily exhibit a higher number of word hits than firms with a low E pillar score.

### 4.2 | Regression analyses

We further apply a multiple linear regression model to investigate whether the relative number of word hits as a dependent variable can be explained by the previously examined differences. Therefore, we revert to the following regression equation:

$$WordHits_{i,t}^{Rel} = \alpha_{i,t} + \beta_1 Bank_{i,t} + \beta_2 Report_{i,t} + \beta_3 Size_{i,t} + \beta_4 Escore_{i,t} + \beta_{5-10} Year_t + \varepsilon_{i,t}, \quad (1)$$

<sup>15</sup>The environmental pillar measures a company's impact on natural systems, such as air, land, and water, as well as entire ecosystems by reflecting how well a company uses best management practices to avoid environmental risks and exploit environmental opportunities (see London Stock Exchange Group LSEG, 2023).

<sup>16</sup>Note that six firms have been excluded from the analysis due to missing E pillar scores.

**TABLE 6** Correlation coefficients and differences in absolute word hits between firms with mean E score ratings from A+ to B− and firms with mean ratings from C+ to D−.

	Firms with mean E pillar score rating A+ to B− (100 to >50) ( <i>n</i> = 77)		Firms with mean E pillar score rating C+ to D− (50 to 0) ( <i>n</i> = 59)		Difference in means and medians	
<b>Word hits AR + SR</b>	Mean	Median	Mean	Median	In means	In medians
	67.0325	40.5	22.4463	13.5	44.5862***	27.0***
<b>Pearson's correlation</b>	0.2315** ( <i>p</i> = 0.0428)		0.4426*** ( <i>p</i> = 0.0005)			
<b>Spearman's correlation</b>	0.3545*** ( <i>p</i> = 0.0016)		0.5178*** ( <i>p</i> = 0.0001)			

\*\* and \*\*\* denote statistical significance at the 5% and 1% level. Differences in means are based on *t* tests and differences in medians are based on nonparametric Wilcoxon rank sum tests.

**TABLE 7** Summary statistics of regression variables.

		Mean	Median	Std.	Min.	Max.
Relative word hits (dependent variable)	Overall relative hits	0.0476	0.01713	0.0803	0	0.8114
	Relative word hits Stranded assets	0.0152	0.0030	0.0323	0	0.3536
	Relative word hits Transition risks	0.0113	0.0058	0.0202	0	0.2690
	Relative word hits Physical risks	0.0212	0.0054	0.0458	0	0.5747
Bank		0.74	1	0.44	0	1
Report		0.60	1	0.49	0	1
Size		8.6451	8.5686	1.4377	1.1725	12.0595
E score		55.58	59.66	30.03	0	98.85

*Note:* *Bank* is a binary variable that takes the value 1 for banks and the value 0 for insurance companies. *Report* is a binary variable that takes the value 1 for ARs and the value 0 for SRs. *Size* is equal to the natural logarithm of the end-of-period market capitalization in Mio. EUR regarding the respective year to which the publication refers to. *E score* ranges from 0 to 100 (see Table A5).

whereby the dependent variable  $WordHits_{i,t}^{Rel}$  either refers to overall relative word hits of a report or is examined separately with regard to the three categories *Stranded assets*, *Transition risks*, and *Physical risks*. Table 7 contains an overview of resulting summary statistics. To address endogeneity, we make use of year fixed effects and control for time-invariant unobserved characteristics. Therefore, we integrate dummy variables for the respective year of disclosure and cluster robust standard errors at the firm level to mitigate heteroscedasticity and autocorrelation concerns.

The results of the regression analyses are displayed in Table 8 as well as Table 9, which confirm the observed differences between banks and insurers, differences between ARs and SRs as well as

**TABLE 8** Results of the multiple linear regression (relative word hits as dependent variable).

	Regression coefficient	p value	Standardized regression coefficient <sup>1</sup>
<i>Bank</i>	−0.02201***	<0.0001	−0.1206
<i>Report</i>	−0.07844***	<0.0001	−0.4785
<i>Size</i>	0.00885***	<0.0001	0.1584
<i>E score</i>	0.00009	0.2655	0.0336
<i>Year FE</i>	Yes		
<i>Intercept</i>	0.00776	0.6096	
$R^2 = 0.3423$			
$\text{Adj. } R^2 = 0.3376$			
$n = 1288^2$			

*Note:* *Bank* is a binary variable that takes the value 1 for banks and the value 0 for insurance companies. *Report* is a binary variable that takes the value 1 for ARs and the value 0 for SRs. *Size* is equal to the natural logarithm of the end-of-period market capitalization in Mio. EUR regarding the respective year to which the publication refers to. *E score* ranges from 0 to 100 (see Table A5). Dummy variables are considered to control for year fixed effects without being reported in the table. Robust standard errors are clustered at the firm-level. \*\*\* denote statistical significance at the 1% and 10% level.

<sup>1</sup>Standardized regression coefficients are calculated to compare the magnitude of the effects of the independent variables on relative word hits. An increase of one standard deviation in the independent variable results in an increase of the standardized regression coefficient times the standard deviation of the dependent variable (see, e.g., Heidinger & Gatzert, 2018).

<sup>2</sup>Note that in total, 123 firm-year observations have been omitted due to missing data for the applied E Score.

the investigated size effect. We find statistical support for a change from insurer to bank as well as from SR to AR to be associated with a significant decrease in relative word hits. Moreover, a larger firm size has a statistically significant positive influence on relative word hits. The coefficient for *E score* indicates a positive relationship with overall no statistical support.

When separately controlling for the relative word hits of the three risk types *Stranded assets*, *Transition risks*, and *Physical risks* in Table 9, the observed size effect is significant for relative word hits of all three categories at least at the 5% level. Moreover, the binary variable *Bank* shows a nonsignificant positive coefficient, so that a change from insurer to bank might be associated with an increase in relative word hits of *Transition risks*, whereas *Bank* yields a significant negative coefficient in Table 8. This supports the findings on banks to be more likely to report on transition risks than insurers (see Section 3.2), while a change from insurers to banks results in a decrease of relative word hits with regard to the categories *Stranded assets* and *Physical risks*. Finally, we find statistical support for firms with higher E scores to exhibit higher relative word hits on *Transition risks*, which does not hold for *Stranded assets* and *Physical risks*, all else being equal.

### 4.3 | Verification of keyword approach

To verify the results of the applied KWIC, we additionally run the text mining analysis without controlling for the sustainability-related context. Analyzing the difference in results between these two approaches shows how well the KWIC approach improves the relevance and

**TABLE 9** Regression coefficients of multiple linear regressions with relative word hits for stranded assets, transition risks, and physical risks as dependent variables.

	Rel. word hits <i>Stranded assets</i>		Rel. word hits <i>Transition risks</i>		Rel. word hits <i>Physical risks</i>	
		<i>p</i> value		<i>p</i> value		<i>p</i> value
<i>Bank</i>	−0.00528***	0.0039	0.00082	0.4943	−0.01770***	<0.0001
<i>Report</i>	−0.02877***	<0.0001	−0.01323***	<0.0001	−0.03568***	<0.0001
<i>Size</i>	0.00163**	0.0210	0.00164***	0.0004	0.00541***	<0.0001
<i>E score</i>	0.00002	0.5804	0.00006**	0.0150	0.00003	0.6003
<i>Year FE</i>	Yes		Yes		Yes	
<i>Intercept</i>	0.01418**	0.0291	0.00396	0.3559	0.00149	0.8704
	$R^2 = 0.2466$		$R^2 = 0.1779$		$R^2 = 0.2572$	
	<i>Adj. R</i> <sup>2</sup> = 0.2413		<i>Adj. R</i> <sup>2</sup> = 0.1741		<i>Adj. R</i> <sup>2</sup> = 0.2520	
	<i>n</i> = 1288		<i>n</i> = 1288		<i>n</i> = 1288	

*Note:* *Bank* is a binary variable that takes the value 1 for banks and the value 0 for insurance companies. *Report* is a binary variable that takes the value 1 for ARs and the value 0 for SRs. *Size* is equal to the natural logarithm of the end-of-period market capitalization in Mio. EUR regarding the respective year to which the publication refers to. *E score* ranges from 0 to 100 (see Table A5). Dummy variables are considered to control for year fixed effects without being reported in the table. Robust standard errors are clustered at the firm-level. \*\* and \*\*\* denote statistical significance at the 10%, 5% and 1% level.

accuracy of the extracted information. In summary, mean relative (absolute) word hits over all years and investigated reports considerably increased from 0.0472% to 0.1507% (from 28.33 to 168.57) without KWIC.

When distinguishing between ARs and SRs, it can be observed that the application of KWIC especially led to a significant reduction in word hits for ARs (mean relative (absolute) word hits over all years decreased from 0.1415% (240.76) with KWIC to 0.0143% (25.42) without KWIC). In this regard, many false positive results can be observed, e.g., for the term *Market risks*, which is mentioned quite often in ARs but not in a sustainability-related context. The reduction in mean relative (absolute) word hits for SRs is generally lower but still remarkable, with a decrease of 0.1648% (56.95) without KWIC to 0.0980% (32.84) when ensuring a sustainability-related context. Overall, controlling for a direct relation to environmental sustainability considerably increases the quality and reliability of the text-mining results.

As a validation of the keywords' relative importance and coverage within the entire set of analyzed reports, Term Frequency – Inverse Document Frequency (TF-IDF) scores<sup>17</sup> are computed (see, e.g., Loughran & McDonald, 2011). This allows for an examination of how important selected keywords are within a report in relation to its occurrence in the remaining documents.<sup>18</sup> A high TF-IDF score thereby indicates that a keyword is more important or specific to a document. Table 10 provides aggregated results of the computed TF-IDF scores.

<sup>17</sup>TF-IDF scores are calculated by multiplying the term frequency (i.e., relative word hits per keyword) with the inverse document frequency (see, e.g., Loughran & McDonald, 2011). The inverse document frequency is defined as the natural logarithm of the total number of documents in the sample relative to number of documents in which a respective keyword appears.

<sup>18</sup>Note that KWIC have been applied for the calculation of TF-IDF scores to ensure a direct relation to sustainability.

**TABLE 10** Summary statistics of TF-IDF scores.

Keyword	Sum of TF-IDF scores over all documents	Mean TF-IDF score	Max. recorded TF-IDF score
<i>Stranded assets</i>	2.7437	0.0019	0.1166
<i>Divestment</i>	3.9000	0.0028	0.2965
<i>Carbon bubble</i>	14.2066	0.0101	0.2719
<i>General transition risks</i>	11.0459	0.0078	0.6724
<i>Policy risks</i>	3.2493	0.0023	0.0442
<i>Market risks</i>	2.6991	0.0019	0.0582
<i>Technology risks</i>	1.0435	0.0007	0.0443
<i>Legal risks</i>	2.3607	0.0017	0.1519
<i>Reputational risks</i>	6.2524	0.0044	0.2234
<i>General physical risks</i>	11.1064	0.0079	0.2039
<i>Acute physical risks</i>	16.5956	0.0118	0.4962
<i>Chronic physical risks</i>	5.5535	0.0039	0.1029

It can be derived from Table 10 that *Acute physical risks* and *Carbon bubble* show the highest sum over all documents as well as mean TF-IDF scores, which at the same time exhibit the highest relative word hits in SRs as shown in Table A4 in the Appendix. The highest maximum TF-IDF score for a respective report can be observed for the keyword *General transition risks*, which simultaneously exhibits the fourth highest sum of TF-IDF scores over all documents. The lowest mean TF-IDF scores are displayed for *Technology risks* and *Legal risks* in line with the distribution of relative word hits in ARs (see Table A4). Consequently, these two risk types not only occur rarely in just one document, but in the majority of analyzed reports. However, they nevertheless represent important climate-related risks, since *Legal risks* are especially relevant in the context of climate lawsuits, and *Technology risks* comprise, for example, energy disruptions as one of the most important global business risks (see Allianz Global Corporate & Specialty, 2023). In general, the computed TF-IDF scores are in line with the observed relative word hits, so that the results remain robust when additionally considering a keyword's uniqueness across the entire set of analyzed reports.

## 5 | SUMMARY

This paper empirically examines reporting activities of European banks and insurance undertakings on climate-related risks in terms of stranded assets, transition risks, and physical risks. To the best of our knowledge, this is the first study that compares reporting on sustainability risks between European banks and insurers by using a text mining approach. The results of our analysis reveal that the disclosure of climate-related sustainability risks considerably increased from 2017 to 2022, with insurers' SRs exhibiting the highest relative word hits over time. Moreover, we find that European banks disclose more information on keywords related to transition risks than insurers, whereby the difference in word hits is not



statistically significant. European financial institutions have increasingly recognized climate-related risks, whereby the terms *Carbon bubble*, *General physical risks*, and *Acute physical risks* (*Technology risks*, *Legal risks*, *Stranded assets*) have been mentioned most (least) often in absolute terms. Moreover, we find that *General transition risks* and *General physical risks* emerge as a rather new risk types, whereas *Market risks* and *Reputational risks* can be considered as established risk categories. Nevertheless, reporting on stranded assets is still in early stages, even though this risk type can have a considerable impact on the composition of investment portfolios, underwriting as well as lending activities. In addition, we observe a size effect for financial institutions reporting on climate-related risks, since European banks and insurers with above-median market capitalization exhibit a significantly higher amount of word hits than firms with below-median market capitalization. We further derive that firms with higher E pillar scores exhibit statistically significant higher relative word hits on transition risks than sample firms with lower scores, which is not significant for aggregated relative word hits as well as the separate categories *Stranded assets* and *Physical risks*. Finally, the applied KWIC approach leads to a significant reduction in word hits and thus a higher reliability of references in the context of environmental sustainability.

To address limitations, the information being disclosed in ARs and SRs does not provide an answer to the question of whether the considered companies are exclusively reporting on the investigated climate-related risks or whether they actually apply risk management strategies to adequately manage these risks. Moreover, standardized context analyses imply that some word combinations count as word hits, even though they would lack a direct association with sustainability upon closer manual inspection. Nevertheless, the automated text mining process allows us to analyze a considerable number of corporate reports (1403 in total) and control for their sustainability-reference in a standardized way, which would not be possible manually. Since transparency plays a major role for the evaluation of risks and prudentially defined requirements on the integration of sustainability risks into corporate reporting continue to grow, we anticipate the number of words related to climate-related risks to further increase. Future research directions include investigating whether the disclosure of climate-related risks may influence market reactions as well as conducting scenario analyses on the financial impact of stranded assets regarding European banks and insurers.

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# SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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# APPENDIX

**TABLE A1** Categorization of annual and sustainability reports.

Annual reports	Sustainability reports	
<ul style="list-style-type: none"> <li>• Annual reports and accounts</li> <li>• Consolidated financial statements, management report and audit report</li> <li>• Financial report</li> <li>• Financial statements as at 31 December</li> <li>• Integrated report</li> <li>• Sustainability and business report</li> <li>• Universal registration document (especially for banks) and annual financial report</li> </ul>	<ul style="list-style-type: none"> <li>• Biodiversity report</li> <li>• Climate analytics and alignment report</li> <li>• Climate-related financial disclosure report</li> <li>• Climate finance report</li> <li>• Climate report</li> <li>• Climate transition plan</li> <li>• Consolidated nonfinancial statement</li> <li>• Corporate governance report</li> <li>• Corporate Social Responsibility (CSR) report</li> <li>• Environmental, Social, Governance (ESG) report</li> <li>• Green business report</li> <li>• Green finance framework</li> </ul>	<ul style="list-style-type: none"> <li>• Impact report</li> <li>• Net zero transition plan</li> <li>• Nonfinancial report</li> <li>• Progress report</li> <li>• Responsible business report</li> <li>• Responsible investments report</li> <li>• Socioeconomic impact report</li> <li>• Sustainable development report</li> <li>• Sustainability factbook</li> <li>• Sustainable investment report</li> <li>• Sustainability report</li> </ul>

**TABLE A2** List of illustrative sustainability-related terms applied to the context analysis.

Sample tokens from the sustainability context dictionary			
Air pollution	Deforestation	Footprint	Oceans
Biodiversity	Ecological	GHG	Sustainable
Carbon	Emission	Green	Renewable energy
Climate change	Energy efficiency	Greenhouse gas	Responsible
Conservation	Environment	Low carbon	Water
Decarbonization	ESG	Nature	Wildlife

**TABLE A3a** Mean absolute and relative word hits of banks sorted by TRBC subsectors (relative word hits in *italics*).

	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>Mean 2017–22</b>
Banks	10.6	11.9	18.55	28.36	45.86	71.14	31.07
	<i>0.0189</i>	<i>0.0214</i>	<i>0.0333</i>	<i>0.0518</i>	<i>0.0668</i>	<i>0.0738</i>	<i>0.0443</i>
Consumer lending	4.33	2.83	4.83	10.5	21.67	27.17	11.89
	<i>0.0198</i>	<i>0.0136</i>	<i>0.0105</i>	<i>0.0189</i>	<i>0.0302</i>	<i>0.0675</i>	<i>0.0268</i>
Corporate banks	5.52	6.36	11.46	13.39	25.95	43.7	17.73
	<i>0.0116</i>	<i>0.0129</i>	<i>0.0170</i>	<i>0.0219</i>	<i>0.0363</i>	<i>0.0425</i>	<i>0.0237</i>
Corporate financial services	1.5	0.83	0.83	1	6.33	5.17	2.61
	<i>0.0051</i>	<i>0.0026</i>	<i>0.0026</i>	<i>0.0029</i>	<i>0.0215</i>	<i>0.0138</i>	<i>0.0081</i>
Investment banking	0.5	1.5	3	3.5	5.5	8.5	3.75
	<i>0.0007</i>	<i>0.0040</i>	<i>0.0074</i>	<i>0.0081</i>	<i>0.0121</i>	<i>0.0181</i>	<i>0.0084</i>
Invest. banking & brok. services	2.5	4.63	5.5	8.75	10	15.13	7.75
	<i>0.0032</i>	<i>0.0134</i>	<i>0.0197</i>	<i>0.0287</i>	<i>0.0349</i>	<i>0.0344</i>	<i>0.0224</i>
Investment management	9.92	9.76	14.8	13.07	17.91	21.59	14.51
	<i>0.0690</i>	<i>0.0604</i>	<i>0.0972</i>	<i>0.0502</i>	<i>0.0779</i>	<i>0.0439</i>	<i>0.0664</i>
Invest. man. & fund operators	9.38	10.05	15.52	22.63	38.45	47.09	23.85
	<i>0.0268</i>	<i>0.0236</i>	<i>0.0518</i>	<i>0.0637</i>	<i>0.0856</i>	<i>0.0730</i>	<i>0.0541</i>
Private banks	4.17	9.83	9.33	13.17	19.42	28.75	14.11
	<i>0.0073</i>	<i>0.0256</i>	<i>0.0190</i>	<i>0.0268</i>	<i>0.0474</i>	<i>0.0514</i>	<i>0.0296</i>
Retail & mortgage banks	5.33	4.83	10.83	8.5	29.5	46.33	17.56
	<i>0.0139</i>	<i>0.0120</i>	<i>0.0244</i>	<i>0.0063</i>	<i>0.0708</i>	<i>0.0950</i>	<i>0.0371</i>
Wealth management	17.75	11.25	11	15.25	16.25	31.17	17.11
	<i>0.0615</i>	<i>0.0459</i>	<i>0.1421</i>	<i>0.0735</i>	<i>0.0485</i>	<i>0.0947</i>	<i>0.0777</i>

**TABLE A3b** Mean absolute and relative word hits of insurance companies sorted by TRBC subsectors (relative word hits in *italics*).

	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>Mean 2017–22</b>
Insurance–automobile	4.25	4.5	9.5	26	32.75	40.5	19.58
	<i>0.0118</i>	<i>0.0195</i>	<i>0.0357</i>	<i>0.0796</i>	<i>0.1018</i>	<i>0.0913</i>	<i>0.0566</i>
Life & health insurance	11.75	24.5	34.19	57.03	58.33	64.6	41.73
	<i>0.0225</i>	<i>0.1057</i>	<i>0.0966</i>	<i>0.1322</i>	<i>0.1040</i>	<i>0.1181</i>	<i>0.0965</i>
Life insurance	14	12.5	22.5	18	56.5	57	30.08
	<i>0.0518</i>	<i>0.0482</i>	<i>0.1085</i>	<i>0.0733</i>	<i>0.0562</i>	<i>0.0528</i>	<i>0.0651</i>
Multiline insurance & brokers	19.49	21.07	29.77	32.02	47.67	55.58	34.26
	<i>0.0734</i>	<i>0.0418</i>	<i>0.0651</i>	<i>0.0545</i>	<i>0.0550</i>	<i>0.0759</i>	<i>0.1012</i>
Property & casualty insurance	14.36	15.3	15.96	20.37	32.22	38.76	22.83
	<i>0.0306</i>	<i>0.0617</i>	<i>0.0580</i>	<i>0.0358</i>	<i>0.0756</i>	<i>0.0546</i>	<i>0.0527</i>
Property & casualty reinsurance	39.5	15.08	22.33	42.75	38.42	58.25	36.06
	<i>0.0463</i>	<i>0.0387</i>	<i>0.0562</i>	<i>0.0732</i>	<i>0.0962</i>	<i>0.1173</i>	<i>0.0713</i>
Reinsurance	62.75	62	71.5	115	132	103.75	96.17
	<i>0.1198</i>	<i>0.0823</i>	<i>0.0870</i>	<i>0.1882</i>	<i>0.1837</i>	<i>0.1180</i>	<i>0.1298</i>

TABLE A4 Summary statistics for relative word hits (in %) of annual versus sustainability reports.

	2017		2018		2019		2020		2021		2022	
	AR	SR	AR	SR	AR	SR	AR	SR	AR	SR	AR	SR
1. Keywords and synonyms related to stranded asset risks												
Stranded assets	0.00023	0.00088	0.00021	0.00066	0.00020	0.00098	0.00028	0.00144	0.00037	0.00154	0.00041	0.00142
Divestment	0.00029	0.00060	0.00021	0.00085	0.00021	0.00200	0.00025	0.00192	0.00026	0.00173	0.00034	0.00186
Carbon bubble	0.00091	0.01157	0.00077	0.01253	0.00126	0.01768	0.00213	0.02417	0.00313	0.03316	0.00434	0.03274
2. Keywords and synonyms related to transition risks												
Gen. trans. risks	0.00015	0.00066	0.00026	0.00165	0.00063	0.00396	0.00109	0.01053	0.00202	0.01439	0.00331	0.01644
Policy risks	0.00127	0.00422	0.00126	0.00374	0.00142	0.00372	0.00130	0.00413	0.00149	0.00527	0.00192	0.00510
Market risks	0.00165	0.00033	0.00129	0.00066	0.00142	0.00081	0.00138	0.00051	0.00143	0.00095	0.00165	0.00182
Technology risks	0.00006	0.00011	0.00006	0.00005	0.00009	0.00014	0.00012	0.00020	0.00015	0.00025	0.00022	0.00029
Legal risks	0.00031	0.00055	0.00027	0.00047	0.00032	0.00067	0.00030	0.00085	0.00028	0.00076	0.00053	0.00113
Reputational risks	0.00094	0.00433	0.00074	0.00421	0.00078	0.00431	0.00093	0.00371	0.00113	0.00546	0.00146	0.00481
3. Keywords and synonyms related to physical risks												
Gen. phys. risks	0.00068	0.00724	0.00068	0.00780	0.00119	0.01231	0.00187	0.01672	0.00374	0.02535	0.00609	0.02599
Acute phys. risks	0.00234	0.01496	0.00195	0.01272	0.00195	0.01463	0.00229	0.01808	0.00404	0.02202	0.00541	0.01995
Chr. phys. risks	0.00016	0.00192	0.00016	0.00298	0.00027	0.00330	0.00047	0.00354	0.00075	0.00485	0.00085	0.00532
Median	0.00049	0.00140	0.00048	0.00232	0.00071	0.00351	0.00101	0.00362	0.00128	0.00506	0.00155	0.00496
Mean	0.00075	0.00395	0.00066	0.00403	0.00081	0.00538	0.00103	0.00715	0.00157	0.00964	0.00221	0.00974

TABLE A5 Overview of rating grades and Environmental pillar scores (see LSEG, 2023).

Score range	Grade	Score range	Grade
$100.00 \geq \text{Score} > 91.67$	A+	$50.00 \geq \text{Score} > 41.67$	C+
$91.67 \geq \text{Score} > 83.33$	A	$41.67 \geq \text{Score} > 33.33$	C
$83.33 \geq \text{Score} > 75.00$	A–	$33.33 \geq \text{Score} > 25.00$	C–
$75.00 \geq \text{Score} > 66.67$	B+	$25.00 \geq \text{Score} > 16.67$	D+
$66.67 \geq \text{Score} > 58.33$	B	$16.67 \geq \text{Score} > 8.33$	D
$58.33 \geq \text{Score} > 50.00$	B–	$8.33 \geq \text{Score} \geq 0.00$	D–