


# ENVIRONMENTAL HAZARDS AND RISK MANAGEMENT IN THE FINANCIAL SECTOR: A SYSTEMATIC LITERATURE REVIEW

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**Abstract.** We conduct a systematic literature review on environmental and climate-related risk management in the financial sector. We classify the current literature into three categories: (i) the impact of environmental concerns on financial risk; (ii) the current state of environmental risk practices in the financial sector; and (iii) measures to assess the financial exposure to environmental risks. We find that financial institutions can reduce their risk exposure by highly committing with environmental responsibility and performance. Moreover, the increase in willingness to assess climate-related financial risk incentivizes corporate managers to adopt more proactive environmental policies and practices.

**Keywords.** Banking; Climate; Environment; Financial Institutions; Risk Management

## 1. Introduction

As science and society become increasingly aware of the risks that climate change can induce, the impact of environmental hazards on the financial sector subsequently comes into focus. Financial institutions are exposed to these climate or environment-related financial risks through their loan portfolios and other invested capital. Investment decisions and environmental risk management thus need to take exposures to environmental hazards into account (Boermans and Galema, 2019; Braun *et al.*, 2019). The Carbon Disclosure Project (2019) reports that the financial sector estimates U.S.\$693 billion at risk from climate change impacts and that most of the risks are going to materialize within the next five years. Dietz *et al.* (2016) find an expected “climate Value-at-Risk” of U.S.\$2.5 trillion for global financial assets

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under their business as usual scenario. Similarly, Battiston *et al.* (2017) emphasize on the existence of an interdependence between exposure of financial portfolios and climate policy.

To date, environmental issues have increasingly gained attention from financial sector actors. Corporations started addressing their exposures to climate change and other environmental hazards by enabling banks and insurance companies to access relevant data (Ilhan *et al.*, 2020a). Institutional investors established organizational dedicated frameworks, strategies, and research for environmental issues and related risks. For example, the Climate Action 100 or Global Investor Coalition on Climate Change call for carbon pricing in order to more adequately allocate capital across lesser environmental risk-impacted investments (De Jong and Nguyen, 2016; Krueger *et al.*, 2020). However, while financial institutions recognize environmental risks, studies find that they encounter difficulties with regards to data availability, to pricing and hedging of environmental risks, and appropriate assessment within their risk management (G20 Green Finance Study Group, 2017; Basel Committee on Banking Supervision, 2020; Krueger *et al.*, 2020). Individual issues of climate-related risk faced at the institutional level might sum up to a systemic vulnerability of the financial system and thus become relevant to national central banks and supervisors (Batten *et al.*, 2016; Campiglio *et al.*, 2018). Central banks and supervisors have warned of climate risks and highlighted the importance of the financial risk assessment and management in banks as this can mitigate the threats of climate change on the financial industry (Bank of England and Banque de France, 2019; NGFS, 2019). Despite considering climate change hazards as financial risk, the European Central Bank (ECB) fails to account for environmental risks and excludes it in both, supervision and monetary policy (Sustainable Finance Lab, 2018).

In this paper, we examine the fundamental research on the environmental risk and its impact on financial performance, current practices of environmental risk management within the financial sector, and tools to assess or hedge environmental risk. We particularly focus on two questions. First, how is environmental risk approached to and practiced within the current risk management framework in the financial industry? Second, what are the current challenges to environmental risk management and sustainable businesses? We also discuss research paths that can potentially be investigated in future research. To accomplish our objective, a systematic literature review is conducted to identify and discuss relevant quality research. Our literature review presents evidence of dependency of a firm's financial risk on environmental concerns and its engagement in environmental responsibility. The reason is that firms with environmental responsibility and higher environmental performance exhibit lower market risk characteristics. Moreover, environmental risks are found to be negatively associated with financial performance. In addition, we find that current practices of environmental risk assessment indicate a clear increase in awareness and willingness to assess climate-related financial risk. The latter has shifted from no recognition of financial impacts of environmental risks in 2011 to advanced knowledge about the urgency to address climate risks in financial institutions in 2018. Another important fact is that most investors face difficulties when approaching climate-related financial risk since the basic approaches such as carbon footprint analyses are not efficient enough. The issues and challenges ahead include disclosure of firm data, suitable assessment, and pricing instruments.

Our findings have important implications for corporate environmental behavior, to the extent that investors pay more attention to financial risk and performance effects of environmental quality. This can lead to positive changes in attitudes toward environment and environmental protection intentions of corporate executives and managers, which push firms to more proactive environmental practices. For instance, Liston-Heyes and Vazquez Brust (2016) show, from a multistage model of corporate environmental behavior where environmental attitudes are allowed to directly affect firms' environmental intentions and performance, that pressures from stakeholders can lead to the development of managerial proenvironmental attitudes.

The rest of the paper is structured as follows. Section 2 briefly reviews the concept of environmental risk and hazards as well as the theoretical foundations of risk management processes in financial institutions. Section 3 introduces the systematic literature research approach and presents a preliminary

quantitative analysis of the research identified. Section 4 provides insights into the impact of environmental risk on financial performance and current practices of environmental risk management in the financial sector. Section 5 presents possible paths for further research. Concluding remarks are provided in Section 6.

## 2. Theoretical Background

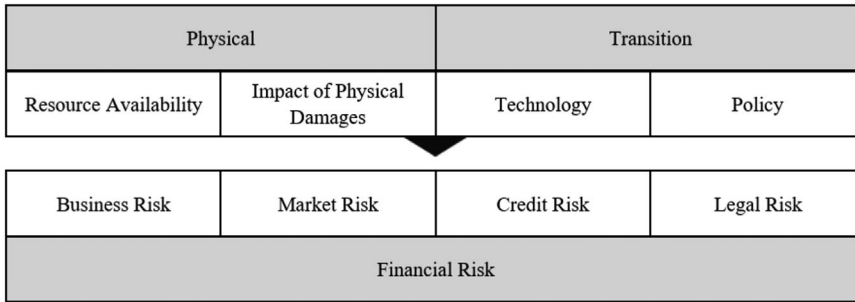
As far as the research topic of environmental risk management is concerned, critical issues such as financial risk management and the framework of environmental hazards as well as its classification within the financial sector are of paramount importance.

Taking risk management within the financial sector into consideration, European regulations have been developed to ensure compliant protection against financial risks. Several regulatory mechanisms are equally employed to improve financial risk management. For example, the Basel Accords ensure capital requirements for market and credit risks, which are among the essential components of risk management. Solvency II presents a risk-based capital regulation framework that applies to insurance companies (Gatzert and Wesker, 2012). It is however worth noting that Basel III currently supports risk management in taking a short-term view on financial risk, which contradicts the long-term impacts of climate-related risks (D'Orazio and Popoyan, 2019).

With respect to the analysis of risk, Muralikrishna and Manickam (2017) highlight the process of identifying and assessing environmental risk. It consists of several steps starting with the problem formulation which serves as a basis for the subsequent identification of the adequate risk assessment type and level. Accordingly, it is essential to define the problem, its boundaries and the constraints of the assessment. This step also involves the modeling of the source-pathway-receptor relation that describes the course of risk from the hazard to the eventually affected group of receptors. An example for this modeling could be rainfall (hazard) that causes high water in rivers followed by overtopping, failure of flood defenses, and inundation (pathways), and ultimately harms infrastructure, private/public properties, people, and possibly the ecosystem as well (receptors). Risk assessment contains two key components, namely, hazard assessment and environmental exposure assessment. Hazard assessment addresses the identification of the potential adverse impact on receptors through collecting and evaluating relevant data. The exposure assessment identifies the direct/indirect vulnerability to the hazards (e.g., chemicals) and defines to what extent (e.g., dose, concentration) the human population, environment, or industry sector is exposed to. These analyses feed into risk characterization which qualitatively and quantitatively determine the chance and extent of harmful impact to receptors under hazard exposures.

In this context, the term “environmental hazards” defines threats to humans or nature that are potentially caused by the natural or built environment. This research topic has recently received increased attention because environmental threats develop through climate change and they are voluntarily encouraged by humans under societal pressures (Smith, 2004). Few different concepts were developed to define and classify these environmental sources of risk (Smith, 2004; Caldecott and McDaniels, 2014; Bank of England, 2015). This literature review follows Cambridge Centre for Sustainable Finance (2016) and Mercer Investment Consulting (2015) in classifying environmental hazards.

The Cambridge Centre for Sustainable Finance defines a broad categorization of environmental hazards. Banks are exposed to financial risk caused by acute or chronic physical environmental events but also to appertaining risks of transition (Cambridge Centre for Sustainable Finance, 2016). This framework has originally been developed by Mercer Investment Consulting (2015) which outlines the so-called Technology, Resource Availability, Impact of Physical Damages, Policy (TRIP) framework in more details. The TRIP framework divides the previously mentioned physical events into resource availability and physical damages. Catastrophic physical damages represent “acute” physical events such as floods or hurricanes. Resource availability comprises all “chronic” and long-term environmental changes having



**Figure 1.** Categorization of Environmental Risk Sources and Conformity of TRIP Framework and G20 Approach (Cambridge Centre for Sustainable Finance, 2016).

an impact on investments. It includes impacts that are initially caused by climate change such as water scarcity and changes in weather patterns. These weather patterns may result in positive as well as negative impacts at different times of development. Moreover, the category of transition hazards is split into policy and technology categories. As climate change increasingly influences political decisions, policies, and economic developments, banks are not only affected by the environment itself but also by climate change transition. The policy risk source, which is related to both national and international measures to support energy transformation and reduce the steady impact of climate change, implies different kinds of legislation, regulation, mandates, or targets concerning direct and indirect pricing mechanisms, and research and development.<sup>1</sup>

Further classification differentiates between demand-side and supply-side policies aiming at either promoting low-carbon alternatives or reducing carbon emissions. On the supply side, low-carbon technologies and products are encouraged to provide consumers with less carbon-intensive products and services. On the demand side, implemented policies decrease the consumption of high-carbon products through pricing or nonmonetary disincentives (e.g., labeling). Finally, technological hazards include technological advancement, disruption, and changes in the energy, specifically low-carbon, industries. The focus is on technologies to transform, transmit, and use energy (Mercer Investment Consulting, 2015).

These environmental hazards eventually result in specific financial risks that – in this case – are faced by institutions in the financial sector. There is no consistent distinction between financial and nonfinancial risk in literature. Financial risk implies an adverse impact on the profitability of a financial institution through, for example, an increase in costs or a decrease in revenues. Through climate change, financial risk exhibits specific distinctive characteristics. Within the financial sector's classification of risk, environmental hazards affect the key risk areas (business, market, credit, and legal risk) as identified by Cambridge Centre for Sustainable Finance (2016). Figure 1 gives an overview of the different categories of hazards that can impact the outlined categories of financial risk.

### 3. Systematic Literature Review

#### 3.1 Methodology

The systematic literature review is based on the procedure of Tranfield *et al.* (2003). It begins with the identification of suitable keywords and search terms resulting from the research question and the literature that has been reviewed up to that point. In addition, only publications with a publication

date starting in 2008 are examined in order to identify current approaches to environmental risk management.<sup>2</sup> This time frame follows the study by Delis *et al.* (2020) who argue for the novelty of this research strand. The number of search results in Figure A.1 in the Appendix witnesses the increased frequency of this topic starting from 2008. The keywords used are intended to identify approaches to assess and manage environmental risks in the financial sector, specifically banks. Consequently, the keywords contain synonyms related to environmental risks themselves (e.g., climate risk, climate-related risk, climate change risk, environmental risk, environmental, social, and governance [ESG] risk, and transition risk) as well as synonyms related to concepts of management (e.g., approach, assessment, and management). In our study, we focus on risk management and thus did not include studies connected to ESG disclosure in the literature review, unless linked to specific terms of risk management. Moreover, the search includes keywords related to the financial sector and uses relevant synonyms (e.g., bank, banking, banking industry, banking sector, financial industry, financial institution, financial sector, and institutional investor). The search strings connect these three categories with the Boolean operator AND and additionally refer to the use of the truncation “\*,” if possible. This minimizes the number of searches to be carried out and double counting. These search strings are quite precise in order to focus on environmental risks and exclude other climate change-relevant topics that do not deal with risk management concepts.

Table A.2 provides an overview of the associated number of search results. The search is conducted on the three electronic databases EBSCOhost, Emerald Insight, and ScienceDirect, whereby for EBSCOhost the sub databases “Business Source Complete” and “EconLit with Full Text” are used. The use of these three different databases, in turn, ensures the holistic and comprehensive nature of the research and is intended to prevent subject-relevant literature from not being recorded in the search due to limitations of individual databases.

Using suitable inclusion and exclusion criteria, the results of the search are filtered according to their relevance. For this purpose, the title and abstract of all articles are reviewed and examined with regard to the defined criteria. In this way, literature that is not sufficiently concerned with the subject is excluded. In order to create a shortlist, a detailed full-text analysis is carried out in the next step. The result is a list of articles that are thematically relevant to the research question considered. All articles of the narrower selection are then evaluated in terms of its scientific quality and, if necessary, further filtered in order to guarantee an adequate quality of the underlying data. In particular, the use of the journal ranking JOURQUAL 3.0 is appropriate in terms of its scientific relevance and international recognition.<sup>3</sup> The final outcome is a selection of publications that meet the previously defined standards in terms of both content and scientific quality.

After entering the search strings, a total of 378 potentially relevant English-language publications could initially be identified, of which 296 were published from 2008 onward and thus meet the first two selection criteria (including duplication). By gradually analyzing the titles, abstracts, and keywords of all 296 studies identified, a narrower selection of sources could first be determined, which was subsequently subjected to a full-text analysis to exclude subject-irrelevant research. In this way, the selection could be limited to 64 articles. Removing duplication eventually led to an interim result of 35 articles relevant to the content. In the final step of literature selection, the corresponding journals were evaluated with regard to the JOURQUAL 3.0 rating. In order to ensure the quality of the scientific statements in this work, only articles with a rating of at least C are further considered. Finally, we yield a selection of 19 relevant articles meeting all four of the above-specified selection criteria. Figure 2 summarizes the procedure scheme of the literature research including the articles left after each step.<sup>4</sup>

In order to collect further subject-relevant literature, a backward reference search, also referred to as snowball principle, is carried out. It specifically analyzes the bibliography of each study. We start the systematic snowball literature search with Ilhan *et al.* (2020a). The criteria for choice of literature remain mostly unchanged, focusing on English literature from 2008 onward and relying on scientific publications in journals with a JOURQUAL 3.0 rating of at least C.<sup>5</sup> It is important to note that three quality working

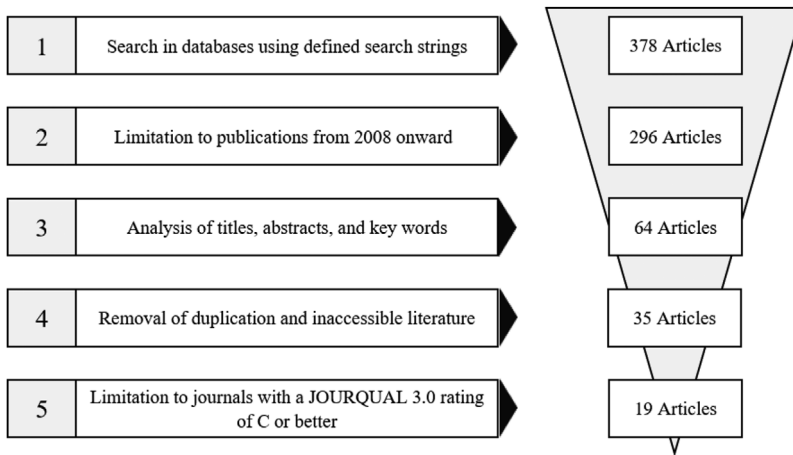


Figure 2. Process Scheme of the Systematic Literature Research.

papers have been included in this research selection. Appearing later on in the snowball research, Krueger *et al.* (2020) cover literature resulting from the *Review of Financial Studies* (RFS) Climate Finance Initiative to a great extent. The RFS Climate Finance Initiative encourages further research in the field of climate finance, including environmental risk management. Since the RFS obtains an A+ rating and the corresponding literature is already conditionally accepted, the snowball literature review also considers publications from the RFS Climate Finance Initiative. Excluding already identified publications through the previous literature research, the snowball principle research adds 19 articles to the existing list of results, leading to a total of 38 articles in our final sample. We provide a list of our sample and a more detailed summary of the process in Table A.1 and A.3, respectively.

### 3.2 Quantitative Results of the Literature Review

Following the explanation of the general methodology and the precise approach of literature research, the results of our study are reviewed hereafter. Before examining what are the current challenges to environmental risk management and considering the state of research, a brief analysis of the general characteristics of the selected literature is carried out. Such an analysis is important in order to classify the statements expressed in the literature in terms of their scientific quality and relevance to the subject, and thus to enable a better interpretation of the results.

Figure 3 illustrates the JOURQUAL 3.0 ratings of the final articles. Most of the literature identified within literature research, namely, 64%, have been ranked with at least B or above. It is important to highlight the high number of journals with an A-rating or higher (29%), which ensures a high quality of the studies examined. Within the range of journals classified as outstanding and world-leading, it is striking that six studies originate from the RFS Climate Finance Initiative eventually being published in the RFS. However, the results of the literature also include eight studies that only have a rating of C and are thus titled “recognized scientific journals.” Note also that four of the selected articles have not been published in a scientific journal and are therefore left without a ranking.

The studies can be classified according to the subject area of the journals in which they are published. Most studies appear in journals with a specific relation to the thematic field of financing and banking. This finding matches with the formulated research questions that aim at environmental risk management in the financial sector. As the consideration of financial risk also evolves from an increased sustainability

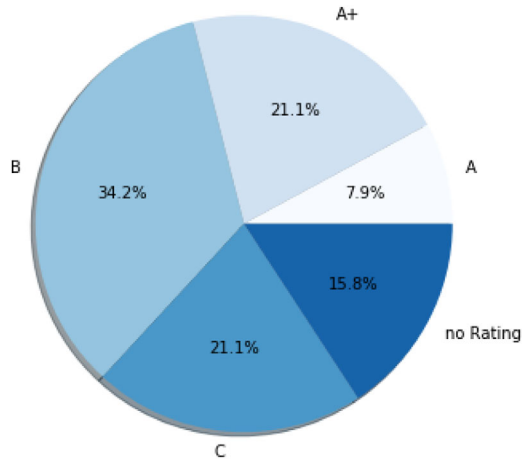


Figure 3. JOURQUAL 3.0 Ratings and Number of Journals of Final Selection. [Colour figure can be viewed at wileyonlinelibrary.com]

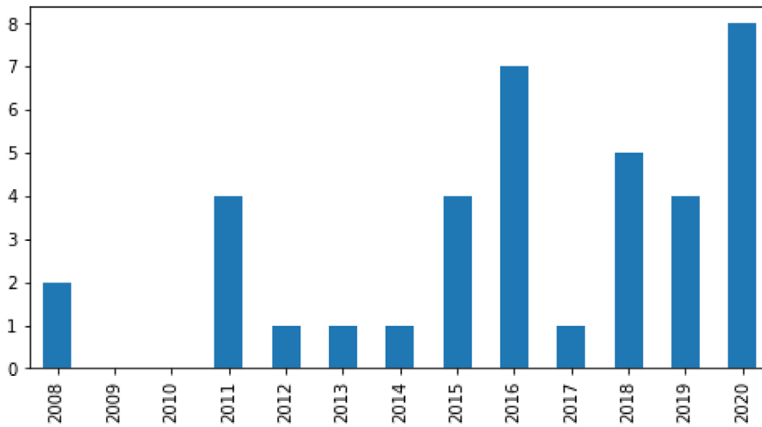


Figure 4. Chronology of Relevant Research Literature with Corresponding Number of Studies. [Colour figure can be viewed at wileyonlinelibrary.com]

and climate change awareness of the financial sector, around nine studies can be assigned to the category of sustainability management. At the same time, the subject seems to be highly relevant for corporate management due to the comparatively high number of articles in the management area. Figure 4 presents the distribution of the articles over time. We find an increase in relevant literature starting around 2015 which marks the year of the 2015 Paris Climate Conference.

#### 4. Research in Environmental Risk and Current Approaches to Environmental Risk Management

This section reviews the current approaches of scientific and business practices to assess environmental risks. It conduces to create a comprehensive understanding of current challenges and potential paths of research that are addressed in Section 5.

**Table 1.** Overview and Classification of Studies Extracted from the Systematic Literature Research.

No.	Author	Impact of environmental risk	Current practices	Assessment
1	Addoum <i>et al.</i> (2020)	X		
2	Alok <i>et al.</i> (2020)		X	
3	Barnett <i>et al.</i> (2020)			X
4	Delis <i>et al.</i> (2020)	X		
5	Engle <i>et al.</i> (2020)			X
6	Ilhan <i>et al.</i> (2020a)		X	
7	Ilhan <i>et al.</i> (2020b)	X		
8	Krueger <i>et al.</i> (2020)		X	
9	Addoum <i>et al.</i> (2019)	X		
10	D’Orazio and Popoyan (2019)			X
11	Görgen <i>et al.</i> (2019)			X
12	Hong <i>et al.</i> (2019)		X	
13	Eccles and Krzus (2018)	X		
14	Huang <i>et al.</i> (2018)	X		
15	Jung <i>et al.</i> (2018)	X		
16	Nguyen (2018)	X		
17	Thistlethwaite and Wood (2018)		X	
18	Fernando <i>et al.</i> (2017)	X		
19	Andersson <i>et al.</i> (2016a)		X	
20	Andersson <i>et al.</i> (2016b)			X
21	Bansal <i>et al.</i> (2016)			X
22	De Jong and Nguyen (2016)			X
23	Sassen <i>et al.</i> (2016)	X		
24	Semenova and Hassel (2016)	X		
25	Verheyden <i>et al.</i> (2016)	X		
26	Georgopoulou <i>et al.</i> (2015)			X
27	Kim <i>et al.</i> (2015)	X		
28	Muhammad <i>et al.</i> (2015)	X		
29	Nikolaou <i>et al.</i> (2015)	X		X
30	Chava (2014)	X	X	
31	Flammer (2013)	X		
32	Weber (2012)		X	
33	Campbell and Slack (2011)		X	
34	Litterman (2011)		X	
35	Salama <i>et al.</i> (2011)	X		
36	Solomon <i>et al.</i> (2011)		X	
37	Sharfman and Fernando (2008)	X		
38	Weber <i>et al.</i> (2008)		X	

We conduct a qualitative coding through content analysis to draw conclusions from the systematic literature review. In this regard, a categorical framework outlines and classifies the extracted studies. The overview presented in Table 1 shows the key topics and research aspects of each study. The articles are classified into three categories:



1. The impact of environmental risk: this category comprises studies which address the relationship between environmental risks, environmental engagement, and financial performance.
2. Current practices: this category covers studies that either outline current practices of environmental risk management or propose approaches to assess the relevance of environmental hazards in the financial sector.
3. Environmental risk assessment: this category includes studies with focus on measuring the impact of environmental hazards.

Presented chronologically by date of publication, Table 1 highlights the distribution of thematic aspects of research. For example, research in environmental risk assessment only starts 2015, whereas the other topics are rather spread over the chosen time period of literature research starting in 2008. In what follows, we successively review these three categories of research.

#### 4.1 *Impact of Environmental Risk on Financial Performance*

The relevance of environmental responsibility of corporations in general has become a popular topic of research over the last decades. This development has been motivated by environmental and social concerns, and most definitely by the potential impact of environmental risk on financial performance (Salama *et al.*, 2011). The roots of environmental risk management lie in concepts such as corporate environmental performance (CEP) and ESG criteria. These concepts describe business activities in accordance with its stakeholders, namely, societies and the environment (Jin, 2018).

The relationship between a firm's environmental performance and its financial performance forms the basis for research on environmental risk since it implies that environmental hazards are reflected in current and past financial performance. It also gives incentives to assessing and managing environmental risks. We find five studies which investigate the impact of CEP on corporate financial performance (CFP). Except for the research conducted by Semenova and Hassel (2016), all articles focus on market risks of firms exhibiting different levels of environmental performance. The studies have similar methodological settings including the type of analyses and investigated dependent variable. Employing regression analyses, all studies test the systematic risk proxied through the market beta. While Salama *et al.* (2011) only test the systematic risk, all other studies test the total risk proxied through standard deviation. In addition, some studies consider the idiosyncratic risk (Sassen *et al.*, 2016; Verheyden *et al.*, 2016) or downside risk (Muhammad *et al.*, 2015; Verheyden *et al.*, 2016). Verheyden *et al.* (2016) stand out due to their complex measurement of risk-return characteristics not only on the stock level, but further on the portfolio level. The time periods in total range from 1994 to 2015 and include time overlaps that simplify the comparison of the empirical analyses.

The analysis of empirical results shows that the CEP is, in general, negatively associated with the market risk of companies. In particular, the total risk is lower for firms that have a higher CEP (Muhammad *et al.*, 2015; Verheyden *et al.*, 2016). The evidence presented in Sassen *et al.* (2016) for environmentally-sensitive industries (e.g., the engineering or transportation industries) also corroborates this finding. Regarding systematic risk, there is evidence to suggest that social and environmental engagement of firms lowers the systematic risk (Salama *et al.*, 2011; Sassen *et al.*, 2016). This finding is, however, not in line with Muhammad *et al.* (2015) whose results do not support this statement. Considering the impact of firms' environmental responsibility on downside risks, Muhammad *et al.* (2015) and Verheyden *et al.* (2016) show that CEP and ESG screenings decrease downside risk for both individual stock and portfolio levels. Two studies document opposing evidence for idiosyncratic risk. While Sassen *et al.* (2016) find that environmental performance decreases the firm's idiosyncratic risk, Verheyden *et al.* (2016) report slightly increased idiosyncratic risks for ESG screened portfolios, despite the fact that they both consider ESG ratings as a choice of CEP proxy. The main difference between their research design is the study period, from 2002 to 2014 for Sassen *et al.* (2016) and from 2010 to 2015 for

Verheyden *et al.* (2016), as well as the use of either the ESG-rated individual stock level or ESG-rated portfolio level. The increased idiosyncratic portfolio-level risk can be balanced by increased returns that overall positively impact risk-adjusted returns. This finding is especially important for the construction of environmental risk concerned hedge portfolios, as it highlights differences in the ESG-rated stock and portfolio characteristics.

Beyond its impact on market risk, the environmental performance of a firm is found to increase its market value. More specifically, news about environmental responsibility can increase the shareholder value, while negative information about a firm's environmental responsibility can negatively affect its shareholder value. There is evidence of rising relevance of shareholders' environmental concerns causing an increase in negative reactions toward harmful environmental behavior over time (Flammer, 2013). Regarding corporate environmental policies, the results reported in Fernando *et al.* (2017) show that both "toxic" and green firms have low institutional ownership, suggesting that shareholder value creation is associated with less environmental risk exposure, but does not increase with more environmental friendliness of firms.

The findings discussed above are further corroborated by research that directly investigates the impact of environmental hazards and environmental performance on financial downside (tail) risk. Ilhan *et al.* (2020a) use carbon emissions from the S&P 500 companies disclosed by the Carbon Disclosure Project to measure the consequences of emission volatility on downside risk. The authors measure downside risk as the average tail loss of out-of-the-money put options because they capture the market expectation of jump risks. Their results show that an increase in the carbon emissions' standard deviation raises the tail risk standard deviation by 13% drawing a positive relationship between carbon emissions and tail risk. Moreover, the tail risk of carbon-intensive firms increased after the 2015 Paris Climate Agreement, which implies that regulations and technology connected with climate change influence financial risk.

Nguyen (2018) and Huang *et al.* (2018) investigate the effect of environmental hazards on financial risk characteristics, more specifically the volatility of earnings and cash flows measured by standard deviation of probability of loss and pretax income, respectively. These studies show that companies exposed to environmental or carbon emission hazards carry higher financial risk. Firms with high climate risk indices exhibit lower and more volatile earnings and cash flows (Huang *et al.*, 2018), while firms with high carbon emissions are exposed to an increased probability of loss (Nguyen, 2018). In addition, Addoum *et al.* (2019) provide evidence that earnings are significantly affected by environmental hazards. Using U.S. firms and their locations to investigate how the exposure to temperatures over a 26-year period, they find that extreme temperatures affected the earnings per share of 40% of sample firms. However, temperature shocks do not significantly impact sales and productivity, even for industries that are considered to be heat-sensitive. This finding contradicts Nikolaou *et al.* (2015) who report strong effects of physical hazards on economic performance due to significantly increased costs. Both studies note that the extent of financial damage depends on the specific industry. Severe weather events also impact financing choices, as businesses in such regions hold more cash, less short-term and more long-term debt (Huang *et al.*, 2018). These findings thus highlight the necessity of firms and financial services industry to account for environmental hazards regarding acute and chronic climate change events such as heat, drought, and other severe weather events.

Another stream of studies examines the impact of environmental risks on the cost of capital, as investors and lenders may mirror their perceived increased financial risk. The financial industry can thereby play a key role in incentivizing environmental responsibility and engagement of companies. Chava (2014) analyzes how environmental hazards impact the cost of equity and debt. The exposure to specific environmental hazards is estimated by three concerns, namely, exposure to excessive waste, emissions of toxic chemicals, and direct and indirect generation of revenues from fossil fuel products. The cost of equity is estimated by expected returns of stocks and the cost of debt is measured by bank loan spreads. The study documents an increased cost of equity as well as a higher interest rate on bank loans for firms with exposure to environmental hazards. This implies that firms with environmental

concerns carry specific risks from the investors' perspective and that default risk is not a simple function of higher interest rates. Other studies (Sharfman and Fernando, 2008; Kim *et al.*, 2015; Jung *et al.*, 2018) confirm the findings on cost of equity and show the positive association with carbon intensity as a proxy for carbon risk. This again pronounces the increased total risk of firms for which investors require higher compensation.

Finally, Kim *et al.* (2015) and Sharfman and Fernando (2008) outline the importance of environmental risk management, as it decreases the cost of capital. They conclude that the environmental-economic performance does improve through both better resource utilization and the engagement in environmental risk management. The only partially contradictory result is offered by Delis *et al.* (2020) who report no significant differences between loan spreads of fossil fuel firms and nonfossil fuel firms until 2015. However, this study's dependent variable differs, as it distinguishes firms with fossil fuel reserves from firms without reserves which nonetheless may greatly use fossil fuels.

Two studies are pronouncing the environmental risk of the industry as a contingency for the CEP–CFP relationship at the company level. Semenova and Hassel (2016) test the effect of environmental management and environmental risk policies (primarily reporting efforts) on the market value in industries with low or high environmental risk. The authors find that the effect itself and its strength differ for the various industries. Environmental management and environmental policy exhibit a stronger (positive) effect on market values when the environmental risk of the industry is low. This raises the question of whether risk management is attributed higher importance than the risk itself. Kim *et al.* (2015) argue that the association between environmental risk and firm-level cost of equity is stronger for industries with low greenhouse gas emissions since firms from the sector are just as much exposed to regulatory risk as companies from carbon-intensive sectors. The directive effect of industry membership is important to investors in decision making and assessing not only climate risks at the firm but also industry levels.

The outlined research above provides evidence that firms with environmental responsibility and higher environmental performance exhibit lower market risk characteristics. It therefore pronounces the dependency of a company's financial risk on environmental concerns and its engagement in environmental responsibility. Moreover, studies directly consider environmental risk and its impact on financial performance, especially corporate earnings and cost of capital. The outcomes confirm findings on CEP contributing to the overall conclusion that environmental risks are negatively associated with financial performance. Environmental hazards pose a significant financial risk to companies and the financial sector, but at the same time provide incentives to improve financial performance metrics.

#### 4.2 *Insight into Current Practices and Investors' Views*

As mentioned previously, enhanced financial performance characteristics of firms with lower environmental risk or an improved environmental risk management outline the need for the integration of environmental risk assessment in risk management processes. In particular, the cost of capital as a key element of capital budgeting is also driven by investors and lenders of the finance sector. It thus gives an indication of current practices in the banking sector and how investors potentially screen out stocks with environmental concerns implying lower institutional ownership and higher expected equity returns (Chava, 2014).

In this regard, several studies have conducted interviews, content, or literature analyses to find evidence for and information about current assessment of environmental risks in the financial sector. Those surveys are specifically relevant to current research because environmental risk management practices are difficult to derive from other empirical methods (Krueger *et al.*, 2020).

Analyses on the financial sector come to ambiguous results highlighting the role of analysts and investors as individual decision makers. Providing negative conclusions on the question of current assessment, Campbell and Slack (2011) state that none of the 19 interviewed analysts considers

environmental risks within the risk assessment decision-making process. In addition, an analysis of the 2012 and 2015 Climate Risk Disclosure Survey of U.S. insurers indicates that most insurance companies do not account for environmental risk resulting from climate change in their main operations. The 2012 survey reports that 11% of insurance companies adapt climate risk assessment versus 39% in 2015 (Thistlethwaite and Wood, 2018). Somewhat negative feedback is reported by Weber *et al.* (2008) who received completed questionnaires from 50 of 205 European banks and find that more than 80% of the sample banks integrate environmental risks into the credit risk management process. Rather positive outcomes are presented by (Krueger *et al.*, 2020) who conclude from their interviews that only 7% of 439 analysts have shown no efforts to account for climate risks within the last five years. At the firm level, Weber (2012) analyzes the social responsibility reports of nine Canadian banks and finds that all banks systematically integrate environmental risks into their credit management, but do not publish further information about the financial risk induced by environmental hazards.

Over time, the collected studies suggest progress in environmental risk assessment driven by increasing relevance of climate change and environmental concerns of firms. For the insurance sector, Thistlethwaite and Wood (2018) confirm an increase in assessment from 11% to 39% in only four years (2012–2015). Delis *et al.* (2020) report evidence that investors increasingly considered the climate policy risk of fossil fuel firms in the cost of borrowing from 2015 onward (year of the Paris Agreement), even though the increase is not of significant economic relevance. A similar conclusion is reached by the comparison of results reported in Campbell and Slack (2011) and Krueger *et al.* (2020) since the conducted interviews resemble each other closely, specifically on the subjects of qualitative outcomes.<sup>6</sup> The studies reveal an increase from no assessment approaches at all in 2011 to 93% in 2018. However, it is striking that over 21% of the interview partners of Krueger *et al.* (2020) state that they started assessing environmental risks over 10 years ago which contradicts the qualitative findings of Campbell and Slack (2011).

Further evidence from these studies also portrays investors' perception toward environmental risk and its integration into the risk management process. Campbell and Slack (2011) find that environmental statements of banks generally remained unread and were considered the most immaterial section of annual reports. This is in line with some analysts' perception that environmental risk is not associated with a bank's risk at all. Some analysts regard the relevance of environmental reporting to potentially increase due to clients' concerns and valuation, but they screen out the potential materiality of environmental risk to be important for banks in general. Analysts did not find firms' environmental exposures to affect portfolios or forecasts, and environmental risk management to be important for risk assessment. In contrast, Solomon *et al.* (2011) report that investors see direct implications of climate change in that it represents a material risk. Krueger *et al.* (2020) confirm this outcome through interviews, which is in accordance with increasing awareness of investors toward environmental developments and climate change over the last decade. Accordingly, investors find environmental risks to have financial implications for portfolios and the corresponding portfolio firms. Most investors also report that climate risks have already begun to materialize and around 10–25% of them believe that the risk of assets becoming stranded for different electricity industry companies is "very high" (Krueger *et al.*, 2020). Even though banks perceive risk to already materialize today, they expect the overall risk pricing to be overvalued.

Provided that banks assess environmental risk, it is not genuinely incorporated in all phases of risk management processes. Weber *et al.* (2008) address the incorporation into the credit risk management of banks and note that environmental risks are mostly considered in the risk identification phase (rating phase), but are less considered in risk evaluation and risk controlling.

Environmental risks are less likely to be considered in the process steps of costing and pricing. This shows a lack in systematic and quantitative incorporation throughout the entire risk management process. Krueger *et al.* (2020) further address tools used to identify and evaluate climate risks. In a broader view, banks take various approaches to cover climate risk management in the investment process, including carbon footprint analyses of portfolio firms and reduction of portfolio footprint as well as analyses and

reduction of stranded asset risk. Still, the two mostly used approaches, analyses of carbon footprints and stranded asset risks, have been employed by less than 40% of interviewed investors.

Other approaches are portfolio diversification, ESG and ESG rating integration, firm valuation models, and climate risk hedging. In order to directly assess potential impacts of climate risk on portfolios, investors rely on carbon footprint measurements, return impact measurements of climate risk, scenario analyses, and stress tests considering climate scenarios. The data used to assess the carbon footprint of portfolio firms is derived from corporate disclosures (self-collected), private reporting channels, the MSCI ESG database, or the Carbon Disclosure Project database (Solomon *et al.*, 2011; Krueger *et al.*, 2020). Further relevant data about greenhouse gas emissions is disclosed by Trucost or the South Pole Group (Andersson *et al.*, 2016a).

Regarding public disclosures in 2011, investors state that, due to a lack in public corporate disclosures, they heavily rely on the private reporting channels of companies to receive relevant data about environmental concerns (Solomon *et al.*, 2011). Even though policies regarding the disclosure commitment of firms were introduced and improved access to relevant environmental data since 2011, investors still report lacks in environmental public disclosure. They equally criticize the current level of mandatory disclosure and call for standardized and more precise quantitative information on firm climate risk (Ilhan *et al.*, 2020a).

Eccles and Krzus (2018) examine how companies can meet the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) in order to make more comprehensive data available to investors. They analyze financial and voluntary reports of three oil and gas companies and find that most sophisticated environmental disclosure is found within the voluntary sustainability reports. Only few companies voluntarily published data from scenario analyses, as most companies worry that these analyses are perceived as forecasts by investors and could therefore negatively impact the companies.<sup>7</sup> Eccles and Krzus (2018) highly suggest the compulsory integration of comprehensive environment- and sustainability-related data into financial reports to increase the quality of disclosures. In the knowledge of the disclosure gap, 60% of investors disclose or plan to disclose the overall portfolio carbon footprint (Ilhan *et al.*, 2020a). Due to this poor disclosure, food stock prices are found to underreact to climate-related risks such as droughts and are thus mispriced by the markets (Hong *et al.*, 2019). For their part, Alok *et al.* (2020) investigate the potential overreaction of professional money managers to climatic disasters and find that investors misestimate climate risks and hold underweight positions in stocks located in disaster zones. Furthermore, this misperception of disaster-driven financial impacts decreases over time and is not related to any information advantages. Indeed, the underweighting of stocks located in climate disaster zones is refuted by the positive risk-adjusted returns of a portfolio that goes long in the most underweight stocks and short in the least underweight stocks.

Overall, current practices of environmental risk assessment give a mixed picture, ranging from no recognition of financial impacts of environmental risks in 2011 to advanced knowledge about the urgency to address climate risks in financial institutions in 2018. This clearly shows a development and moreover an increase in awareness and willingness to assess climate-related financial risk. Although most investors care about climate-related financial risk today, they face difficulties even with basic approaches such as carbon footprint analyses. The current challenges that remain to be overcome include disclosures of firm data, suitable risk assessment, and pricing instruments. Furthermore, characteristics of climate risks are needed to better understand the impact of environmental hazards on financial risk of firms and portfolios.

### 4.3 Assessment Approaches

As reported by Krueger *et al.* (2020), research addressing general risk management approaches mainly focuses on portfolio strategies (hedging, diversification) and risk measurement methods (carbon footprint, stranded assets, ESG rating, and firm valuation).

Regarding risk measurement methods and specifically the carbon footprint, Grger *et al.* (2019) construct measures of carbon risk. The authors use four ESG databases to construct the “Brown-Green-Score” as an advanced approach to carbon risk. The Brown-Green-Score includes three indicators describing a firm’s sensitivity to carbon risk (policy). This score is used to compute the “Brown-Minus-Green” portfolio that reflects the global market carbon risk. The “carbon beta” of a firm describes the firm’s sensitivity to the global market carbon risk. Moreover, Grger *et al.* (2019) calculated the carbon beta for both countries and industries. While there is a wide range of negative to positive sensitivity of various industries, energy, basic materials, and utilities industries exhibit the highest carbon risk sensitivities. The authors also highlight the impact of carbon risk on financial sector, with a high sensitivity depending on the carbon beta of the country. The carbon beta serves as a measure for firms, investors, and analysts to further understanding of specific carbon risk sensitivity.

Other studies combine carbon footprint measurement and hedging strategies to alleviate financial impacts of environmental hazards on portfolios. The modification of risk indices allows one to form index-tracking portfolios where the invested capital is protected against future negative events associated with climate change. Andersson *et al.* (2016b) and De Jong and Nguyen (2016) construct measures of low carbon intensity to foster portfolio decarbonization. These low-carbon indices modify the weighting of index components that exhibit high carbon intensity. The carbon intensity for the portfolios is defined by carbon footprints extracted from the MSCI ESG database (originally collected by the Carbon Disclosure Project). The outcomes of the studies show that the low-carbon index-tracking portfolios achieve a reduction in carbon emissions of 50–60%. Both studies find no difference in the risk-adjusted return between their low-carbon portfolios and a benchmark portfolio.

For their part, Engle *et al.* (2020) consider the possibility of carbon emissions pricing and report an outperformance of the low-carbon portfolio compared to its benchmark. However, they do not construct an index tracking portfolio but an equity portfolio that overweighs stocks that positively react to climate change news. Relying on the assumption that low-carbon stock price increases when news about growing climate risk are announced, they do the portfolio sorting and weighting of components with respect to ESG scores from MSCI and Sustainalytics. The study uses two climate change indices which are derived from *Wall Street Journal* climate change and Crimson Hexagon negative climate change news articles. The portfolio can successfully hedge climate change news out-of-sample, whereby the portfolio using Sustainalytics outperforms the one using MSCI data. Thus, the performance of a hedge portfolio would depend on the adequate measure of environmental performance.

Barnett *et al.* (2020) introduce a theoretical framework to assess the social cost of carbon under uncertainty. They employ a dynamic stochastic equilibrium model that considers uncertainties from climate and economic modeling. Climate-related uncertainty concerns the transmission mechanism of human activity onto climate. Economic uncertainty results from the impact of uncertain climate damages on human welfare. Accounting for both sources of uncertainty, Barnett *et al.* (2020) find a substantial increase in the social cost of carbon. Bansal *et al.* (2016) also make use of the social cost of carbon in order to measure uncertainty induced by climate change. Testing U.S. equity portfolios, the study finds negative elasticity to temperature shifts and thus argues that the social cost of carbon represents present negative impacts on economic growth and equity valuations.

Georgopoulou *et al.* (2015) propose a methodological framework as well as a tool called “CLIMA-RISK” to quantitatively assess climate risks, and test their tool for a Greek bank. Interestingly, as it might potentially affect banks, D’Orazio and Popoyan (2019) address prudential approaches and regulation to incentivize banks in decarbonization including policies that reduce risks resulting from climate change and other environmental hazards. The so-called “green supporting factors” is a measure to foster lending to green sectors. This factor can be combined with adjustments in the minimum capital adequacy requirement of banks. These measures together can enhance investment in green sectors, as they are perceived less-risky (or derisking) assets and thus receive lower capital requirements. Similar to the green supporting factor, the “brown penalizing factor” works quite oppositely, requiring more capital reserves

for assets from carbon-intensive industries. This policy can furthermore cover banks, as the capital can account for more losses in case of a carbon bubble or stranded assets.

Other regulations, such as large exposure limits (e.g., credit limits) and the sectoral leverage ratio, can also contribute to decreasing financial risk. Exposure limits for banks will restrict the maximum amount of losses resulting from counterparty failure which is one of the potential financial risks induced by climate change. The sectoral leverage ratio restricts overleveraged asset positions of specific sectors and can also decrease exposure to climate risks (D'Orazio and Popoyan, 2019).

In summary, the development of climate risk measures can be relevant to investors and analysts as they see challenges in the assessment of environmental risks. Carbon risk measures such as the carbon beta can be considered in analysts' forecasts, investment and portfolio allocation decisions. However, research on this topic is still scarce and needs to be advanced along with the assessment of other, noncarbon and nonpolicy related, hazards as well as quantitative and financial analyses.

## 5. Looking to the Future

Emerging debates about climate change, policy measures on environmental disclosure, and rising awareness of institutional investors regarding environmental risks have enhanced research on the financial aspects of climate change within the last decade. The results of our systematic literature review thus enable the discussions about the current state of research and challenges of actual approaches for environmental risk assessment as well as the potential aspects that need to be addressed in the future.

A series of fundamental research addresses not only positive financial implications of CEP, but also their negative financial impacts for companies if they are exposed to environmental risks. Even though most research does assess market risk, the combination of environmental concerns (instead of environmental engagement) and financial risk is rarely investigated. Additional studies focusing on the characteristics of climate-related financial risk are obviously required in order to adequately estimate and assess financial consequences of environmental hazards. Future research can also be extended to directly examine the links between environmental concerns and financial risk. Bansal *et al.* (2016) already started to account for that by investigating the impact of temperature risk on risk premium in equity markets and its impact on equity price elasticity. Moreover, the distribution of returns can be further investigated regarding not only fat tails but also the skewness of distribution. Another intriguing question is the time horizon of when financial risk of environmental hazards will materialize, in the spirit of Giglio *et al.* (2015)'s study which investigates the impact of physical climate change risk on discount rate of real estate for the long run. Note that current research can hardly address materialization because it also depends on future developments of political and economic reaction to climate change (Bank of England, 2018; 2° Investing Initiative, 2015).

The literature on current practices of environmental risk management exclusively elaborates quantitative and qualitative interviews. It shows the development from a minor, dispensable role a decade ago to the recognition of relevance and engagement among investors and analysts in the most recent interview conducted in 2018. However, there is a lack of studies aiming at directly identifying and evaluating concepts of assessment, tools, and the monitoring process of climate-related risks in financial institutions. The main reason is that current approaches depend not only on banks' and individual investors' perception of climate risk, but also on the level of regulation and requirements for financial institutions in terms of assessment and disclosure of financial risks related to climate change.

It is equally important to acknowledge that research on environmental risk assessment remains scarce and inconsistent with only few relevant qualitative studies. This aspect of research generally needs to be addressed further. Quantitative studies are particularly needed in order to estimate not only carbon emissions and intensities, but also physical and transition risk measures. For example, carbon intensity has to account for different levels of policy risk across countries and sectors, technology advancement,

and profit margins. These factors capture more specifically the sensitivity to legislation and policy actions. In addition, carbon emissions data are in their origin backward-looking and fails to display the current and future development and alignment of financial and nonfinancial firms. A forward-looking measure such as the assessment of stranded assets and stress testing has not been considered in the extracted studies of our literature review. Complementary to transitional risk hazards, physical climate change hazards can harm firms' operating and financial performance and pose a severe financial risk to banks. Physical risks of climate change have not been measured at the firm level but need to be considered through the geographic location of firms in disaster zones.

Key open questions remain especially with respect to the estimation and accessibility of environmental risk-related data which has not been directly addressed within the three topics due to missing discussions in research. One reason is the magnitude of climate change that is inconceivable and therefore difficult to estimate or model. This includes, for example, natural disaster probability modeling, water resources, and pollution (G20 Green Finance Study Group, 2017). Publicly available environmental data set the basis for all further research including the assessment of financial risk and poses a limitation toward the financial sector, as it impairs investors in addressing and pricing environment-driven financial risk. Besides, research must investigate how data on environmental concerns of companies can be disclosed more proficiently and standardized to derive quantitative statements from it (TCFD, 2017), and what quantitative statements about environmental hazards can impact investment decisions from a risk perspective. Both aspects require that there is a comprehensive understanding of scientific environmental data, and in the meanwhile banks and firms are able to define the economic meaning thereof.

Noteworthy, additional profound and topical research by institutions or initiatives (e.g., Bank of England, Mercer Consulting or the G20 Green Finance Study Group) also offer practical connections to current practices in the financial sector, illustrating the current state of risk assessment approaches and tools implemented (G20 Green Finance Study Group, 2017).

## 6. Conclusion

The aim of this study was to thematically discuss environmental risk management in the financial sector. We particularly examine what impact environmental risks have on firms' financial performance and exposure to financial risk, as well as what approaches are taken to assess these environmental risks.

Besides a theoretical background that contributes to solid understanding and delimitation of environmental risks, the main part of the study provides a broad analysis of the state-of-the-art research on environmental risks and their assessment in the financial sector. A systematic literature review identified a total of 38 relevant articles which are classified into three categories: (i) the impact of environmental concerns on financial performance; (ii) the current state of environmental risk management practices in the financial sector; and (iii) measures to assess those risks within financial institutions. Finally, we discuss the results on environmental risk management, focus on current challenges, and put forward potential alleys of further research.

The procedure of the systematic literature review in this work is to be reflected critically. By restricting the research to three databases and the exclusive use of English search terms and results, a holistic nature of the investigation cannot be guaranteed. By formulating selection criteria and limiting them to ranked journals, further filtering of the results also eliminated potential research. In order to achieve a scope of the study as holistic as possible, a snowball principle research was carried out in addition to the systematic literature review. While employing both research processes to select the final set of suitable and relevant articles, a subjective assessment of the journal articles cannot be ruled out. Moreover, the focus on peer-reviewed studies may result in a publication bias of addressing only confirmatory results and neglecting of null or nonconfirmatory findings.



Given the speed at which environmental risks have become an important topic, our present research has examined and considered environmental risk and especially its assessment fragmentarily. It is recognizable that research on environmental risk assessment is yet to commence, as the necessity of this subject continuously emerges. This, at the same time, poses opportunities for further research which we suggested in Section 5.

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## Conflict of Interest

The authors do not have any conflict of interest to disclose.

## Data Availability

Data sharing is not applicable to this paper as no new data were created or analyzed in this study.

## Notes

1. For example, Breitenstein *et al.* (2020) analyze the impact on the German coal industry of the governmental decision to phase-out coal.
2. The earliest study we find is Dixon and Coulson (1995), who state that the banking sector "have shown little interest in the environmental posture of organizations [...], but] there are signs that this is beginning to change." Later studies until 2007 comprise the analysis of the performance of ecoefficient funds (Derwall *et al.*, 2005; Hoti *et al.*, 2007), corporate governance-related issues (Cowton and Thompson, 2000; Thompson and Cowton, 2004), and research on the linkage between financial and environmental performance (King and Lenox, 2001).
3. The VHB JOURQUAL 3.0 ranking was conducted in 2012. The webpage states that the ranking does have a correlation of 0.66 and 0.70 with the British Academic Journal Quality Guide and Scimago Journal Rank, respectively. See <https://vhbonline.org/vhb4you/vhb-jourqual/vhb-jourqual-3> (accessed 5 February 2020).
4. The result of the systematic literature research depends heavily on the keywords used, the search strings formulated from them, and the databases employed. This becomes clear when looking at search results per database in Table A.2. While a total of 45 relevant articles could be found via EBSCOhost, the identical searches at Emerald Insight and ScienceDirect provided only 6 and 13 significant publications, respectively.
5. The study by Hong *et al.* (2019) is published in a journal outside of this ranking, but nonetheless comes with an 2018 impact factor of 1.949.
6. Both interviews are conducted with analysts and investors, but differ in the number of interview partners (19 vs. 439) and structure of the interviews (unstructured and qualitatively vs. structured and quantitatively).
7. See also Düsterhöft *et al.* (2020) who show that energy utilities do not disclose climate-related risks at all in the risk section of the note to the annual financial reports for a sample from 2007 to 2017.

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## Appendix A

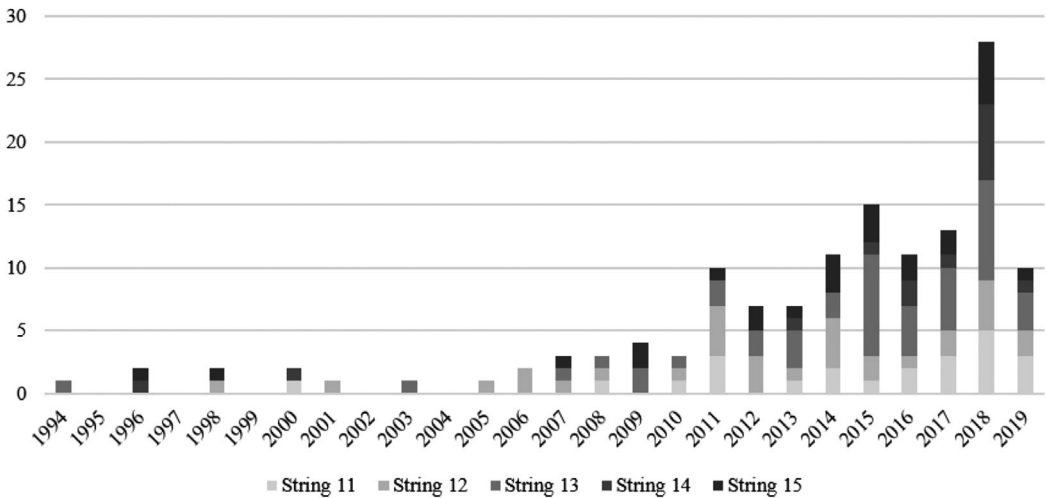


Figure A.1. Historic Classification of Search Results through ScienceDirect Database (Search Strings 11–15).

Table A.1. List of Results from the Systematic Literature Research.

No.	Authors (Year)	Title	Journal	Rating	Time span	#Obs.
1	Addoum <i>et al.</i> (2020)	Temperature Shocks and Establishment Sales	<i>Review of Financial Studies</i>	A+	1990–2015	4,397

(Continued)

**Table A.1.** (Continued).

No.	Authors (Year)	Title	Journal	Rating	Time span	#Obs.
2	Alok <i>et al.</i> (2020)	Do Fund Managers Misestimate Climatic Disaster Risk	<i>Review of Financial Studies</i>	A+	1995–2016	3,268
3	Barnett <i>et al.</i> (2020)	Pricing Uncertainty Induced by Climate Change	<i>Review of Financial Studies</i>	A+	NA	NA
4	Delis <i>et al.</i> (2020)	Being Stranded on the Carbon Bubble? Climate Policy Risk and the Pricing of Bank Loans	Working Paper		2007–2016	72,742
5	Engle <i>et al.</i> (2020)	Hedging Climate Change News	<i>Review of Financial Studies</i>	A+	2009–2016	796
6	Ilhan <i>et al.</i> (2020a)	Climate Risk Disclosure and Institutional Investors	Working Paper		2017–2018	439
7	Ilhan <i>et al.</i> (2020b)	Carbon Tail Risk	<i>Review of Financial Studies</i>	A+	2010–2017	3,206
8	Krueger <i>et al.</i> (2020)	The Importance of Climate Risks for Institutional Investors	<i>Review of Financial Studies</i>	A+	2017–2018	439
9	Addoum <i>et al.</i> (2019)	Temperature Shocks and Industry Earnings News	Working Paper		1990–2015	8,584
10	D’Orazio and Popoyan (2019)	Fostering Green Investments and Tackling Climate-Related Financial Risks: Which Role for Macroprudential Policies?	<i>Ecological Economics</i>	B	NA	NA
11	Görgeu <i>et al.</i> (2019)	Carbon Risk	Working Paper		2010–2016	39,537
12	Hong <i>et al.</i> (2019)	Climate Risks and Market Efficiency	<i>Journal of Econometrics</i>	IF 1.9	1985–2014	>910
13	Eccles and Krzus (2018)	Why Companies Should Report Financial Risks From Climate Change	<i>MIT Sloan Management Review</i>	C	NA	NA
14	Huang <i>et al.</i> (2018)	The Impact of Climate Risk on Firm Performance and Financing Choices: an International Comparison	<i>Journal of International Business Studies</i>	A	1993–2012	353,906
15	Jung <i>et al.</i> (2018)	Carbon Risk, Carbon Risk Awareness and the Cost of Debt Financing	<i>Journal of Business Ethics</i>	B	2009–2013	255

(Continued)

**Table A.1.** (Continued).

No.	Authors (Year)	Title	Journal	Rating	Time span	#Obs.
16	Nguyen (2018)	Carbon Risk and Firm Performance: Evidence From a Quasi-Natural Experiment	<i>Australian Journal of Management</i>	C	2000–2014	24,905
17	Thistlethwaite and Wood (2018)	Insurance and Climate Change Risk Management: Rescaling to Look Beyond the Horizon	<i>British Journal of Management</i>	B	2012, 2015	178, 183
18	Fernando <i>et al.</i> (2017)	Corporate Environmental Policy and Shareholder Value: Following the Smart Money	<i>Journal of Financial and Quantitative Analysis</i>	A	1996–2007	7,324
19	Andersson <i>et al.</i> (2016a)	Governance and Climate Change: A Success Story in Mobilizing Investor Support for Corporate Responses to Climate Change	<i>Journal of Applied Corporate Finance</i>	C	NA	NA
20	Andersson <i>et al.</i> (2016b)	Hedging Climate Risk	<i>Financial Analysts Journal</i>	B	2014–2016	NA
21	Bansal <i>et al.</i> (2016)	Price of Long-Run Temperature Shifts in Capital Markets	Working Paper		1934–2014	35
22	De Jong and Nguyen (2016)	Weathered for Climate Risk: A Bond Investment Proposition	<i>Financial Analysts Journal</i>	B	2011–2014	NA
23	Sassen <i>et al.</i> (2016)	Impact of ESG Factors on Firm Risk in Europe	<i>Journal of Business Economics</i>	B	2002–2014	8,752
24	Semenova and Hassel (2016)	The Moderating Effects of Environmental Risk of the Industry on the Relationship Between Corporate Environmental and Financial Performance	<i>Journal of Applied Accounting Research</i>	C	2003–2011	5,326
25	Verheyden <i>et al.</i> (2016)	ESG for All? The Impact of ESG Screening on Return, Risk, and Diversification	<i>Journal of Applied Corporate Finance</i>	C	2010–2015	2,512
26	Georgopoulou <i>et al.</i> (2015)	A Methodological Framework and Tool for Assessing the Climate Change Related Risks in the Banking Sector	<i>Journal of Environmental Planning and Management</i>	C	NA	NA
27	Kim <i>et al.</i> (2015)	The Effect of Carbon Risk on the Cost of Equity Capital	<i>Journal of Cleaner Production</i>	B	2007–2011	379

(Continued)

**Table A.1.** (Continued).

No.	Authors (Year)	Title	Journal	Rating	Time span	#Obs.
28	Muhammad <i>et al.</i> (2015)	The Impact of Corporate Environmental Performance on Market Risk: The Australian Industry Case	<i>Journal of Business Ethics</i>	B	2001–2010	760
29	Nikolaou <i>et al.</i> (2015)	A System-Dynamic Approach for Exploring the Effects of Climate Change Risks on Firms' Economic Performance	<i>Journal of Cleaner Production</i>	B	NA	NA
30	Chava (2014)	Environmental Externalities and Cost of Capital	<i>Management Science</i>	A+	1992–2007	13,114
31	Flammer (2013)	Corporate Social Responsibility and Shareholder Reaction: The Environmental Awareness of Investors	<i>Academy of Management Journal</i>	A+	1980–2009	117, 156
32	Weber (2012)	Environmental Credit Risk Management in Banks and Financial Service Institutions	<i>Business Strategy and the Environment</i>	B	2006–2009	71
33	Campbell and Slack (2011)	Environmental disclosure and environmental risk: Sceptical attitudes of UK sell-side bank analysts	<i>British Accounting Review</i>	C	2004–2006	19
34	Litterman (2011)	Pricing Climate Change Risk Appropriately	<i>Financial Analysts Journal</i>	B	NA	NA
35	Salama <i>et al.</i> (2011)	Does Community and Environmental Responsibility Affect Firm Risk? Evidence from UK Panel Data 1994–2006	<i>Business Ethics: A European Review</i>	C	1994–2006	3,153
36	Solomon <i>et al.</i> (2011)	Private Climate Change Reporting: An Emerging Discourse of Risk and Opportunity?	<i>Accounting, Auditing &amp; Accountability Journal</i>	B	2007–2008	20
37	Sharfman and Fernando (2008)	Environmental Risk Management and the Cost of Capital	<i>Strategic Management Journal</i>	A	2002	546
38	Weber <i>et al.</i> (2008)	Empirical Analysis of the Integration of Environmental Risks Into the Credit Risk Management Process of European Banks	<i>Business Strategy and the Environment</i>	B	2005	50



**Table A.2.** Overview of Search Results per Database and Search String (Accessed: May 30, 2019).

ID	Search string	Hits (Engl.)	Hits (≥ 2008)	Hits (Relevant)
	<b>EBSCOhost</b>	191	126	45
1	TI (environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk*) AND AB (financ* OR bank* OR investor*) AND AB approach	27	20	8
2	TI (environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk*) AND AB (financ* OR bank* OR investor*) AND AB assessment	28	13	3
3	TI (environmental risk* OR climate risk* OR ESG risk* OR transition risk*) AND AB (financ* OR bank* OR investor*) AND AB management	94	60	17
4	TI (environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk*) AND AB (financ* OR bank* OR investor*) AND AB performance	31	23	12
5	TI (environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk*) AND AB (financ* OR bank* OR investor*) AND AB pricing	11	10	5
	<b>Emerald Insight</b>	20	17	6
6	[Content Item Title: environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk* ] AND [Abstract: financ* OR bank* OR investor* ] AND [Abstract: approach]	8	8	2
7	[Content Item Title: environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk* ] AND [Abstract: financ* OR bank* OR investor* ] AND [Abstract: assessment]	2	1	0
8	[Content Item Title: environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk* ] AND [Abstract: financ* OR bank* OR investor* ] AND [Abstract: management]	6	4	2
9	[Content Item Title: environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk* ] AND [Abstract: financ* OR bank* OR investor* ] AND [Abstract: performance]	3	3	2
10	[Content Item Title: environmental risk* OR carbon risk* OR climate risk* OR ESG risk* OR transition risk* ] AND [Abstract: financ* OR bank* OR investor* ] AND [Abstract: pricing]	1	1	0
	<b>ScienceDirect</b>	167	151	13
11	TITLE ((environmental risk*) OR (carbon risk*) OR (climate risk*) OR (ESG risk*) OR (transition risk*)) and TITLE-ABSTR-KEY (((financial) OR (finance) OR (bank) OR (banking) OR (investor)) AND (approach))	23	22	3

*(Continued)*

**Table A.2.** *Continued.*

ID	Search string	Hits (Engl.)	Hits (≥ 2008)	Hits (Relevant)
EBSCOhost		191	126	45
12	TITLE ((environmental risk*) OR (carbon risk*) OR (climate risk*) OR (ESG risk*) OR (transition risk*)) and TITLE-ABSTR-KEY (((financial) OR (finance) OR (bank) OR (banking) OR (investor)) AND (assessment))	31	25	2
13	TITLE ((environmental risk*) OR (carbon risk*) OR (climate risk*) OR (ESG risk*) OR (transition risk*)) and TITLE-ABSTR-KEY (((financial) OR (finance) OR (bank) OR (banking) OR (investor)) AND (management))	44	41	5
14	TITLE ((environmental risk*) OR (carbon risk*) OR (climate risk*) OR (ESG risk*) OR (transition risk*)) and TITLE-ABSTR-KEY (((financial) OR (finance) OR (bank) OR (banking) OR (investor)) AND (performance))	14	12	3
15	TITLE ((environmental risk*) OR (carbon risk*) OR (climate risk*) OR (ESG risk*) OR (transition risk*)) and TITLE-ABSTR-KEY (((financial) OR (finance) OR (bank) OR (banking) OR (investor)) AND (pricing))	25	22	0
<b>Sum in total</b>		378	296	64
<b>Sum in total (without duplication)</b>				35
<b>Sum in total (without duplication, VHB rating C+)</b>				19

**Table A.3.** Snowball Principle Literature Overview.

ID	Authors (Year)	Access	Rating	References
1	Ilhan <i>et al.</i> (2020a)	Yes	–	2, 3
2	Solomon <i>et al.</i> (2011)	Yes	B	–
3	Ilhan <i>et al.</i> (2020b)	Yes	A+	4, 7, 12
4	Görge <i>et al.</i> (2019)	Yes	–	5, 6, 7, 8, 9, 10, 11
5	Barnett <i>et al.</i> (2020)	Yes	A+	21
6	Chava (2014)	Yes	A+	19
7	Delis <i>et al.</i> (2020)	Yes	A+	–
8	Engle <i>et al.</i> (2020)	Yes	A+	–
9	Fernando <i>et al.</i> (2017)	Yes	A	–
10	Flammer (2013)	Yes	A+	–
11	Krueger <i>et al.</i> (2020)	Yes	A+	5, 6, 9, 12, 13, 14 <sup>a</sup> , 15, 16, 17, 18, 19, 20
12	Andersson <i>et al.</i> (2016b)	Yes	B	–
13	Andersson <i>et al.</i> (2016a)	Yes	C	12
14	Addoum <i>et al.</i> (2020)	Yes	A+	–

*(Continued)*

**Table A.3.** (Continued).

ID	Authors (Year)	Access	Rating	References
15	Addoum <i>et al.</i> (2019)	Yes	–	–
16	Eccles and Krzus (2018)	Yes	C	–
17	Alok <i>et al.</i> (2020)	Yes	A+	18
18	Hong <i>et al.</i> (2019)	Yes	–	–
19	Litterman (2011)	Yes	B	–
20	Sharfman and Fernando (2008)	Yes	A	–
21	Bansal <i>et al.</i> (2016)	Yes	–	–

<sup>a</sup>The study referenced in Krueger *et al.* (2020) has been split into the two publications, namely, Addoum *et al.* (2020) [14] and Addoum *et al.* (2019) [15].