Investors' carbon risk exposure and their potential for shareholder engagement

Lukas Benz, Stefan Paulus, Julia Scherer, Janik Syryca, Stefan Trück

Angaben zur Veröffentlichung / Publication details:

Benz, Lukas, Stefan Paulus, Julia Scherer, Janik Syryca, and Stefan Trück. 2021. "Investors' carbon risk exposure and their potential for shareholder engagement." *Business Strategy and the Environment* 30 (1): 282–301. https://doi.org/10.1002/bse.2621.

Received: 11 February 2020 | Revised: 27 July 2020 | Accepted: 8 August 2020

DOI: 10.1002/bse.2621

RESEARCH ARTICLE

Business Strategy and the Environment

WILEY

Investors' carbon risk exposure and their potential for shareholder engagement

Lukas Benz[1] | Stefan Paulus[1] | Julia Scherer[1] | Janik Syryca[1] | Stefan Trück[2]

[1]Chair of Finance and Banking, University of Augsburg, Augsburg, Germany

[2]Centre for Financial Risk, Macquarie University, Sydney, New South Wales, Australia

Correspondence
Lukas Benz, University of Augsburg, Chair of Finance and Banking, Universitätstr. 16, 86159 Augsburg, Germany.
Email: lukas.benz@wiwi.uni-augsburg.de

Funding information
Bundesministerium für Bildung und Forschung

Abstract

This article examines the exposure to and management of carbon risks of different investor types. Considering the dual role as portfolio manager and partial owner, we analyze carbon risk for investors both in terms of exposure to portfolio values and in terms of responsibility as shareholder of carbon-intensive firms. We show that among various investor types, the preference for holding carbon-intensive stocks differs substantially, even when considering traditional investment decision parameters. In particular, it is governments whose portfolio values are most threatened by a carbon risk exposure of 49%, but at the same time, they prefer larger ownership shares in polluting firms. In contrast, individual investors, investment advisors, and mutual funds avoid holding stakes in these firms, while revealing only a moderate exposure of their assets to carbon risk. In view of the Paris Agreement, which includes the consistent steering of financial flows towards a low carbon transformation of the economy, our study provides policymakers with important implications regarding the coverage and effects of respective regulations. By identifying the ownership structures of carbon-intensive firms and respective owners' portfolio compositions, we also offer implications for further research on portfolio decarbonization and shareholders' influence of corporate carbon management.

KEYWORDS

carbon risk, corporate carbon emissions, decarbonization, institutional ownership, investor behavior, shareholder engagement

1 | INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), Carbon Dioxide (CO_2) accounts for about three quarters of global greenhouse gas (*GHG*) emissions and is likely to be the main driver for anthropogenic global warming (IPCC, 2014). As a result, policymakers around the world are considering various plans for reducing carbon emissions and aim to mitigate the detrimental consequences of rising temperatures for business and society. Even though there have been some significant achievements, such as the Paris Agreement (UNFCCC, 2015), the implementation process of the agreed measures for carbon emission reductions is rather lengthy, difficult to enforce, and subject to regular changes. Especially due to the discrepancy between the primary emitters and those who are already suffering from climate change, combating climate change is one of the most difficult ethical issues facing today's economy and society (Dahlmann, Branicki, & Brammer, 2019). Furthermore, the cost of carbon as well as the decarbonization of key

[Correction added on August 31, 2020, after first online publication: Projekt Deal funding statement has been added.]

industries is expected to lead to significant economic and societal changes in the long run (Nordhaus, 2017).

It has been argued that the dependence on carbon emissions for businesses will be quite substantial (Carbon Tracker Initiative, 2013; Stern & Stern, 2007). The uncertainty about how upcoming actions on reducing carbon emissions will impact firms' future cash flow is often referred to as carbon risk (Dupré et al., 2015). Estimates suggest that in order to achieve the 2°C-goal set in Paris, about three quarters of all remaining coal, oil, and gas reserves should not be exploited (Le Quéré et al., 2015). Such a scenario will create so-called stranded assets, that is, assets losing their economic value well ahead of their anticipated useful lifetime. This situation could create a "carbon bubble" in the valuation of carbon-intensive companies. Furthermore, corporate management also needs to handle possible changes in customer demand or reputational risk related to being classified as unsustainable or high-polluting. The negative effects of carbon emissions are becoming increasingly clear to society and policymakers so that investors and shareholders must also respond to these environmental demands and handle associated risks (Cubas-Díaz & Sedano, 2018). With the growth in environmentally responsible investments and the emergence of voluntary initiatives such as the Portfolio Decarbonization Coalition (PDC, 2020) or Principles of Responsible Investment (PRI, 2020), a growing number of institutional and also individual investors are becoming aware of the risks associated with climate change and increasingly integrate environmental criteria into their investment decisions.

Aim of this article is to analyze the behavior of different investor types in dealing with these risks and changes. According to the dual function as a portfolio manager and partial owner, we analyze an investor's carbon risk from both perspectives. In addition to evaluating the carbon risk at the investor portfolio level, we provide important insights into the ownership structure of carbon-intensive firms. Furthermore, we reveal that the carbon intensity of a firm, in addition to the conventional risk–return based firm characteristics, is a relevant factor in the investment decision process of most investors.

In particular, we first analyze the extent to which the portfolio values of the investor types are threatened by carbon risks. We show that government agencies account for by far the largest share of carbon-intensive portfolio values, averaging 49.45%. In contrast, the remaining types of investors have a relatively low carbon risk exposure, averaging between 15.27% and 24.34%, and thus tend to be below the market-inherent exposure to carbon risks. Our analysis also shows that all investor types are pursuing a steady reduction in the carbon exposure of their portfolio values from 2012 onwards.

In parallel to their function as portfolio managers, investors also play an important role in the ownership structure and thus as potential influencers of corporate management. We show that here, too, governments hold the largest ownership share (over 27%) of the carbon-intensive companies held in their portfolios.

However, considering the aggregated total value of all carbon-intensive companies, governments represent a rather subordinate group of owners with 2.29%. Hedge funds and investment advisors are particularly dominant in this view, each with around 13% ownership in carbon-intensive firms.

To make a reliable assessment of whether an investor type has a preference for or against carbon-intensive investments, we include corporate carbon intensity alongside the traditional risk–return based firm characteristics to explain the variation in ownership shares per investor type. We find that exclusively governments exhibit a significant preference for carbon-intensive firms, whereas individuals, investment advisors, and mutual funds generally show a significant aversion to carbon-intensive firms.

The remainder of the paper is structured as follows. Section 2 discusses the theoretical background as well as related literature. Section 3 presents the identification of carbon-intensive firms. Section 4 explains the methodology applied to evaluate investors' carbon risk and to investigate the carbon-related preferences of different owner types. Section 5 provides summary statistics of our sample. Section 6 provides the results of our empirical analysis, and Section 7 contains conclusions, implications, and limitations of the study.

2 | BACKGROUND AND RELATED LITERATURE

The need for decarbonization of the global economy to limit the impacts of climatic change has become an increasingly important topic over the last decades. Already in 2011, estimates suggested only 20% of all remaining coal, oil and gas reserves could be burned unabated by 2050 to reduce the chance of exceeding 2°C global warming (Leaton, Campanale, & Leggett, 2011). This scenario will create so-called stranded assets, i.e. the 80% remaining assets lose their economic value well ahead of their anticipated useful lifetime, leading to a carbon bubble in the valuation of carbon-intensive companies (Ritchie & Dowlatabadi, 2015). As companies generate a significant amount of carbon emissions through the production and supply of goods and services, it has long been the aim to reduce these emissions. Several emissions trading schemes such as, for example, the European Union Emissions Trading Scheme (EUETS) have been implemented worldwide, some of which follow the Kyoto commitments and others by countries that have not signed the Kyoto protocol (Perdan & Azapagic, 2011). A previously more or less free or low-cost activity has, therefore, become costly, and companies are now faced with potential additional costs due to carbon taxes or the requirement to provide allowances based on their carbon emissions (Cook, 2009). The uncertainty about how upcoming actions on reducing carbon emissions will impact firms is often referred to as carbon risk and is expected to have high impact and relevance for companies with exposure to carbon emissions in any part of their business (Leaton et al., 2011).

Investors such as institutionals,[1] hedge funds, individuals, governmental agencies, investment advisors, and mutual funds function as capital provider for companies. Since our analysis focuses on the carbon risk intensity of the portfolios of these investor groups, it is

[1]In this article, the collective term "institutionals" is used for the following institutional investors: banks, trusts, insurances, pension as well as endowment funds, and foundations.

crucial to first understand how carbon risk affects the investee companies. Accordingly, we give a brief overview of the literature relating to the influence of different carbon risk aspects on firms' characteristics such as risk, cost of capital, market value, and different kind of financial performance measures such as the stock return, risk-adjusted returns, return on equity (ROE), return on assets (ROA), and Tobin's *Q*.

In general, a firm's exposure to carbon risk is determined by its dependence on carbon-based materials, such that carbon risk as a new type of corporate risk could lead to an increase in the firm's overall risk. As a consequence, investors should require a higher return, which increases both the cost of equity (Kim, An, & Kim, 2015) and the cost of debt financing (Jung, Herbohn, & Clarkson, 2018) for carbon-intensive firms. However, if a firm manages its carbon risk professionally and pursues a long-term reduction strategy, it may be able to lower their overall corporate risk (Cai, Cui, & Jo, 2016). The same conclusion was reached by Xue, Zhang, and Li (2019) who find a significant impact of environmental management performance (a firm's environmental policy or processes) and an insignificant impact of environmental operational performance (a firm's carbon emissions) on firm-specific risk. Investors should therefore bear in mind that the increased carbon risk of the companies they are invested in also affects their risk structure. At the same time, investors could also use their role as owners to monitor carbon risk management and thus reduce this type of risk.

As shown by Oestreich and Tsiakas (2015), emissions trading schemes such as the EUETS have a vast impact on the carbon management of firms. To emit CO_2, firms must be in possession of emission certificates, typically leading to additional costs for emitting firms. Often, a share of the certificates is "grandfathered," that is, allocated freely to companies based on past emissions, while permits are traded by emitters who are liable to hold a sufficient number of certificates for their emissions. Oestreich and Tsiakas (2015) show a large and statistically significant carbon premium in stock returns for companies that were able to sell the initially free emission allowances in Germany and the United Kingdom from 2003 to 2009. At the same time, they find that companies that did not have this opportunity had their returns reduced by the costs. A similar relation was found by Brouwers, Schoubben, and van Hulle (2018) who show that some companies can pass on the cost of carbon to their customers because they have no competing companies in their field and can set their own prices. According to their study, a good carbon performance (lower emissions) only leads to better financial performance for companies that are not able to pass on their carbon costs. As emission trading schemes are on the rise (Tuerk & Zelljadt, 2016) and more and more countries and regions develop emissions trading schemes, investors need to be aware of this additional cost factor, which could directly reduce the return of the companies invested.

A theoretical framework for the relation between the level of carbon emissions and financial performance was developed by Busch and Hoffmann (2011). They show a positive relationship between a better carbon performance and Tobin's *Q*, which they attribute to increased market value for firms with lower emissions. This is supported by many studies, for example, Aggarwal and Dow (2011) as well as Saka and Oshika (2014) who also find a negative relation between carbon emissions and the equity value of a firm. Gallego-Álvarez, Segura, and Martínez-Ferrero (2015) measure the influence of carbon reduction on financial (ROE) and operational performance and find a positive influence of the first and no significant impact of the latter. Reducing carbon emissions is associated with increasing environmental costs that drive the asymmetric relationship between carbon emissions and Tobins' *Q*, as suggested by Misani and Pogutz (2015). The authors show an increase in carbon performance leading to a better financial performance up to a certain point; after this point, the cost of reduction exceeds the added value. A more linear relation was found by Delmas, Nairn-Birch, and Lim (2015), showing a higher long-term performance measured by Tobin's *Q* for firms with improved carbon performance. They further show that in the short term, the costs exceed the return leading to a negative relation of carbon performance and short-term financial performance, measured by ROA. A similar relation between carbon and financial performance was proposed by Trumpp and Guenther (2017). According to their "too-little-of-a-good-thing" framework, it only pays to be green after exceeding a minimum level of carbon performance. These findings are supported by Lewandowski (2017), who shows a positive (negative) financial performance for firms with superior (inferior) carbon performance. An exception to these results is provided by Wang, Li, and Gao (2014), who find a positive effect of high emissions on Tobin's *Q* for Australian firms. This could be explained by the importance of the mining industry for the Australian economy. As shown above, most studies find a negative (positive) relation between carbon emissions (carbon management) and a firm's performance.

Overall, existing research suggests that companies, and therefore their investors, are largely affected by carbon emissions and carbon management. First, investors are largely negatively influenced by the level of carbon emissions. Investors of carbon-intensive companies must bear these risks and should, therefore, be concerned about the carbon risk exposure build up in their portfolio. The negative impact of firms' carbon emissions is becoming increasingly clear to institutional but also individual investors, leading to a growing number of investor initiatives such as the PDC or Climate Action 100+. More and more investors are taking a closer look at the environmental disclosures of firms and incorporate social, governmental, or, in the case of this study, environmental criteria into their investment process (Cunha et al., 2019). Many data providers (e.g., Refinitiv) have started to assess investment opportunities based on their carbon performance. This offers investors a transparent way to compare their environmental and carbon performance (Ceccarelli, Ramelli, & Wagner, 2020), and as shown by Riedl and Smeets (2017), investors prefer sustainable mutual funds, despite their lower returns and higher management fees. Investors are probably willing to waive financial performance to support their individual social beliefs. Screening mechanisms based on the firm's emissions are also implemented by institutional investors who underweight high emission firms in their investment process (Bolton & Kacperczyk, 2020). In addition to screening mechanisms aimed at excluding carbon-intensive companies, investors could also engage in trading in the sense of

decarbonization, therefore selling carbon-intensive and buying non carbon-intensive firms. Benz, Jacob, Paulus, and Wilkens (2020) even show that trading in the sense of decarbonization triggers follow-up trades by other investors, which represents herding behavior. The increasing interest of investors in sustainable investment opportunities leads consequently to a growing number of green investment vehicles that seek to incorporate not only financial but also social and environmental aspects in their investment process. As a result, the market for green investments and green label bonds has grown rapidly in recent years due to increased investor interest in both the European as well as the U.S. market (UNEP, 2020).

Second, in addition to the level of emissions, investors are also affected by a firm's management of carbon risks. Since investors can also be considered as partial owners of a company, they might be able to influence corporate policy through their participation rights. Institutional investors can therefore also influence the management of carbon risks and, as shown by Dyck, Lins, Roth, and Wagner (2019), institutional ownership is positively related to future environmental and social performance. This suggests that institutional investors could also use their voting rights to improve the processes of corporate emissions management and thus reduce the long-term emissions risk of the investees and therefore their portfolio.

Interestingly, the academic literature has not yet fully explored the question of which type of investor is most invested in carbon-intensive stocks and, therefore, is exposed to the highest share of carbon risk. With our research, we contribute to the literature and thoroughly analyze investor behavior and changes in the ownership structure of carbon-intensive stocks for different investor types.

More precisely, we contribute to the literature by examining the level of carbon risk intensity in portfolios of different types of investors. We expect these investor types to be exposed to carbon risk differently: sophisticated asset managers such as hedge funds, mutual funds, and investment advisors are aware of the risks associated with an increased level of carbon emissions (Bolton & Kacperczyk, 2020), which leads us to the hypothesis, that they will show a moderate carbon risk exposure. Similar expectations are drawn for norm-constrained institutions such as pension funds and insurances (in this research grouped as institutional investors). Hong and Kacperczyk (2009) show that sin stocks (tobacco, alcohol, and gambling) are held less often by these investors due to social norms. As environmental aspects are becoming increasingly more relevant for society, we expect to find similar relations concerning carbon-intensive stocks. The investor structure of companies varies depending on the industry in which the firm is active. Due to legal framework conditions or security aspects, the share of state-owned enterprises in strategic industries has been high in the past or is still high. Strategic industries are mostly defined as financial, mining, utilities, oil, military-related, or transportation, and as shown by Boubakri, Cosset, and Guedhami (2009), the percentage of state-owned companies is high in these sectors. We later show that carbon-intensive companies are strongly represented in these industries. Even though we are only considering publicly traded companies for this study, we expect governmental agencies to have a high carbon risk exposure due to their selective investments in certain firms. Overall, we formulate the hypothesis that due to the above-mentioned increasing awareness of all investors, the carbon risk exposure of all investor groups will decrease in the more recent years of the study.

We further analyze the ownership structure of carbon-intensive firms to measure the potential to influence corporate decisions for different owner types, for example, in a vote on a specifically submitted shareholder proposal. It seems plausible that not all institutional investors are the same and their relation to their investee firms differs. As shown by Almazan, Hartzell, and Starks (2005) and Chen, Harford, and Li (2007), some institutional investors (such as insurance companies or bank trusts departments) have either existing or potential business relationships with the companies they hold and may be less willing to challenge management decisions to protect those relationships, while other investor groups (such as investment advisors and investment firms) are more willing to challenge management decisions. Many investment managers integrate ESG criteria in their investment process (van Duuren, Plantinga, & Scholtens, 2016) and are also more willing to use their voting rights to have an impact on the investee's management. Thus, investment advisors, hedge funds, and mutual funds who typically have high ownership shares could use these voting rights to improve the corporate emission management. Furthermore, as mentioned above, there are a lot of state-owned firms in carbon-intensive industries. Therefore, we also expect governmental agencies to hold a high percentage of outstanding shares of carbon-intensive stocks in their portfolio.

Finally, we also examine how the overall universe of carbon-intensive stocks is distributed between investors types. Hedge funds, mutual funds, and investment advisors have the highest investment volume and should therefore on average hold a higher proportion of all potential shares. Government agencies, on the other hand, have a low investment volume and tend to hold specific companies rather than a broad portfolio. We, therefore, expect that hedge funds, mutual funds, and investment advisors do hold the highest share of the market capitalization of all carbon-intensive stocks in our sample. The carbon-intensive holdings of governmental agencies should mainly come from selected investments and therefore the ownership of carbon-intensive stocks concerning the overall stock universe should be rather small.

Overall, this study contributes to the analysis of ownership and carbon risk by examining which type of investors are most exposed to this type of risk within their portfolios, who has the highest level of ownership in carbon-intensive stocks and thus the highest voting rights and, finally, who holds the largest share of carbon risk when the entire market is considered.

3 | IDENTIFICATION OF CARBON-INTENSIVE FIRMS

In our main analysis, we use a portfolio-based approach to determine the extent to which investor types are exposed to carbon risk. This involves aggregating carbon risks to which firms in a portfolio are

exposed to at the level of the investor or investor type. Accordingly, the firm-specific carbon measures form the basis of our calculations. This bottom-up approach, therefore, requires the identification of carbon-intensive firms as a first step. So far, academic research has not contributed much to help investors to manage the complexity of identifying an asset's exposure to carbon risk. However, the Portfolio Carbon Initiative (PCI, 2020) set up by the United Nations Environment Finance Initiative (UNEP FI) develops a rather practical framework and argues that carbon risk does not only comprise quantifiable but also non-quantifiable components. In our study, we aim to gather a comprehensive picture of a firm's exposure to carbon risk, by including both quantitative and qualitative aspects. Therefore, we define three metrics to classify carbon-intensive stocks: an industry-based carbon risk definition, the carbon footprint of a firm, and a measure based on a carbon emission-related score.

3.1 | Industry-based carbon risk definition (industry affiliation)

To break down the complexity of identifying carbon risk exposure, we start with the most intuitive approach. We use the Thomson Reuters Business Classification (TRBC, 2020) to classify all stocks based on their industry affiliation. This seems reasonable, given that sectors are affected differently by the transformation into a carbon-constrained world (Labatt & White, 2002). This method has also been used by Gallego-Álvarez et al. (2015) and Misani and Pogutz (2015) to select *GHG* sensitive firms. The sector that is typically considered the most sensitive to carbon risk is the energy industry, including oil, gas, coal, and power utilities,[2] see, for example, Lewandowski (2017).

However, firms that belong to energy-intensive industries such as chemicals, iron, steel, cement, and metallurgy[3] are also expected to be significantly affected by carbon risk. These basic resources companies typically have a high consumption of fossil fuels (Dell'Aringa & van Ast, 2009). Besides direct CO_2 emissions, the amount of carbon emitted during downstream activities is also relevant. Therefore, we also classify producers and users of energy-consuming products, that is, the automobile and transportation industry[4] as carbon-intensive. Firms within these industries are very vulnerable, especially to technology risk (e.g., fuel efficiency) as pointed out by Labatt and White (2007) and Goodstein (2011).

Additionally, we include the sector "Paper and Forest Products" into the list of CO_2-heavy industries. This takes into account that deforestation does not only lead to releases of CO_2 stored in the terrestrial biosphere, but also reduces the ability to absorb emitted greenhouse gases (IPCC, 2014). Hence, the industry also has the potential to worsen global warming and is subject to potential regulatory actions. This leaves us with 15 carbon-intensive industries that are presented in Table 1.

TABLE 1 Carbon-intensive industries

Energy industry	Energy-intensive industry	Energy-consuming products
Coal	Chemicals	Aerospace and defense
Electric utilities and IPPs	Construction materials	Automobile and parts
Natural gas utilities	Metals and mining	Freight and logistics services
Multiline utilities		Passenger transportation services
Oil and gas		Transport infrastructure
Oil and gas—equipment and services		
Paper and forest products		

Note: This table includes 14 industries from three categories that are most sensitive to carbon risk. In addition to the sectors provided, we also include the "Paper & Forest Products" industry into the list of CO_2-intensive industries. Every firm in Asset4 that belongs to one of these 15 industries is categorized as carbon-intensive in our analysis.

3.2 | Carbon footprint

By simply using the industry affiliation as a classification scheme, all companies that belong to one of the 15 carbon-intensive industries will be characterized as having high exposure to carbon risk. However, not all companies within the same industry will face the same level of carbon risk, as they emit different amounts of CO_2.

To achieve a more precise distinction, we, therefore, follow Hoffmann and Busch (2008) and additionally compute a firm's carbon footprint. The carbon footprint is defined as a firm's total CO_2 emissions[5] standardized by some proxy of size. In line with Saka and Oshika (2014), Kim et al. (2015), Misani and Pogutz (2015), we use the market capitalization ($market\ cap_{s,t}$) in U.S. dollar as proxy[6] to gain comparability among the global sample of firms:

$$carbon\ footprint_{s,t} = \frac{carbon\ emissionss_{s,t}}{market\ cap_{s,t}}. \quad (1)$$

[2]Corresponding to the Thomson Reuters industry groups oil and gas, oil and gas related equipment and services, natural gas utilities, coal, electric utilities and IPPs, and multiline utilities.

[3]Corresponding to the Thomson Reuters industry groups chemicals, metals and mining and construction materials.

[4]Corresponding to the Thomson Reuters industry groups aerospace and defense, automobile and parts, freight and logistics services, passenger transportation, and transport infrastructure.

[5]To overcome the problem of an imperfect time series, we calculate the averages of all normalized CO_2 emissions from 2008 to 2015 for each firm. Working with a limited period allows us to create a static sample of CO_2 heavy firms, which can be analyzed over time. Thereby we assume that the average behavior is representative for the whole time period of 2000–2015. We exclude companies without any emission data.

[6]We also standardize carbon emissions by using total net assets as well as sales of a company, instead of using market capitalization. Results for these conducted robustness checks suggest that our main findings on carbon risk exposure and investor ownership were not affected by the way we calculate the carbon footprint of a company. Therefore, the additional results are not reported in this paper but are available upon request to the authors.

Hereby, *carbon emissions*$_{s,t}$ include CO_2 emissions from Scope 1 (emissions from sources directly owned and controlled by the firm) and Scope 2 (indirect emissions from the generation of purchased electricity) for each firm *s* in year *t*. We neglect Scope 3 emissions (all other indirect emissions, not controlled by the firm) in line with previous studies (e.g., Lewandowski, 2017; Misani & Pogutz, 2015), due to the lack of data availability and data quality (Carbon Trust, 2018).

It is important to note that few regulatory bodies require mandatory *GHG* disclosure, while disclosure requirements are typically imposed only on companies with specific features. As a result, the coverage of total CO_2 emissions data is sparse, especially in the early 2000s. However, Figure 1 shows that lately coverage has increased significantly. In 2015, around 50% of all companies from carbon-intensive industries provide data for total CO_2 emissions.

To further differentiate carbon-intensive stocks, we use a "worst-in-class" approach; that is, we rank all companies within each carbon-intensive industry based on their carbon footprint (Labatt & White, 2002). Firms with carbon footprints in the highest 50% of each industry are then classified as "worst emitters."[7]

3.3 | Emission scoring

Earlier academic studies have mainly neglected the fact that a firm's carbon risk exposure is not solely a question of its quantifiable carbon footprint. If a firm wants to reduce its risk, cutting down carbon emissions is only one step. We additionally identify firms with high carbon risk exposure by applying an emission-related score. For this study, we use the emission-score (e-score), a subscore from the environmental pillar of the Refinitiv Asset4 ESG database.[8] Within the environmental pillar, companies are classified according to their resource usage and degree of environmental innovation, as well as their efforts to reduce emissions. According to Refinitiv (2020), the e-score "measures a company's commitment and effectiveness towards reducing environmental emissions in the production and operational processes." This allows us to offer a more comprehensive and future-oriented picture of how a firm deals with carbon risk exposure, which also includes qualitative factors.

As indicated in Figure 1, e-score coverage at the beginning of the sample period is rather sparse, while in recent years, the score is available for a relatively high share of companies. In the first step, for each firm, we calculate the average of all reported e-scores between 2008 and 2015. We then rank all firms within each of the industries and classify the lowest 50% in each industry as the worst e-score emitters.

4 | METHODOLOGY

According to the dual function as a portfolio manager and partial owner, we analyze an investor's carbon risk from both perspectives. First, we examine the extent to which the respective portfolio values are determined by investments in carbon-intensive companies, thus providing information on the exposure of assets under management to the inherent carbon risk of these companies. And second, we investigate the ownership structure of carbon-intensive companies to determine which investors are the major shareholders and thus the main risk-takers.

4.1 | Carbon risk exposure

To measure the portfolio-related carbon risk for each investor type, namely, institutional investors, hedge funds, individuals, government agencies, investment advisors, and mutual funds, we compute the carbon risk exposure $CRE_{i,t}$ of the investor *i* in *t* as

$$CRE_{i,t} = \frac{\sum_{s \in P_{i,t}^{DS}} value\ held_{i,s,t}}{\sum_{s \in \left(P_{i,t}^{DS+NDS}\right)} value\ held_{i,s,t}}, \quad (2)$$

where $s \epsilon P_{i,t}^{DS}$ describes all "dirty," that is, carbon-intensive, stocks (*DS*) in portfolio *P* of investor *i* in year *t*. Analogously, $s \epsilon \left(P_{i,t}^{DS+NDS}\right)$ describes all stocks, that is, dirty and non-dirty stocks (*NDS*), in the investor's portfolio. The U.S. dollar value of stock *s* held by the investor is denoted by $value\ held_{i,s,t}$. Accordingly, the $CRE_{i,t}$ can be interpreted as the fraction of carbon-intensive investments of the total portfolio value—the higher the $CRE_{i,t}$, the more exposed the investor is to carbon risk. To enable the comparison between different investor types, we compute the aggregated carbon risk exposure as

$$aggr.CRE_{j,t} = \sum_{i \in O_j} \frac{\sum_{\left(s \in P_{i,t}^{DS}\right)} value\ held_{i,s,t}}{\sum_{s \in \left(P_{i,t}^{DS+NDS}\right)} value\ held_{i,s,t}} \quad (3)$$

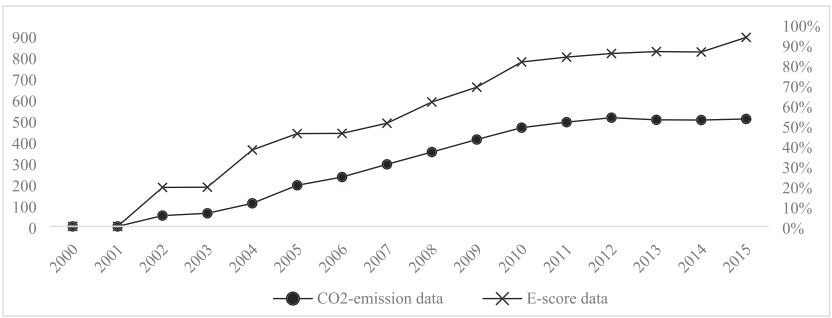

FIGURE 1 Available CO_2 emission reportings and e-scores. The number (left *y*-axis) and the percentage (right *y*-axis) of firms from carbon-intensive industries with available CO_2-emission reportings or emission scores from 2000 to 2015

where $i \in O_j$ describes the affiliation of investor i to respective owner type j. Consequently, $aggr.\ CRE_{j,t}$ represents the carbon risk exposure of the aggregated portfolios of the respective investor type. An $aggr.\ CRE_{j,t}$ of 0.3, therefore, indicates that all investors of owner type j (e.g. all hedge funds) have 30% of their total assets invested in carbon-intensive stocks.

To rule out passive investment behavior and a consequential indifference to carbon risk, in the next step we compute the carbon risk exposure of each investor in excess to the carbon risk exposure of the entire Asset4 market portfolio. Our measure for excess carbon risk exposure for investor i is defined as follows:

$$ex.CRE_{i,t} = CRE_{i,t} - \frac{\sum_{s \in DS_t} market\ cap_{s,t}}{\sum_{s \in DS_t + NDS_t} market\ cap_{s,t}}. \quad (4)$$

Subsequently, we test each year and for each investor type whether the average carbon risk exposure of the associated investors i is equal to the carbon risk exposure of the entire Asset4 universe.

4.2 | Ownership of carbon-intensive stocks

To examine the ownership structure of carbon-intensive companies, we first determine the average ownership share in a carbon-intensive stock in each owner type's portfolio j as

$$ownership^{shares}_{j,t} = \frac{1}{N^{DS}_{j,t}} \sum_{s \in P^{DS}_{i,t}} \frac{\sum_{i \in O_j} shares\ held_{i,s,t}}{shares\ outstanding_{s,t}} = \frac{1}{N^{DS}_{j,t}} \sum_{s \in P^{DS}_{i,t}} ownership^{shares}_{j,s,t}, \quad (5)$$

where $i \in O_j$ contains all investors i that belong to owner type j and $N^{DS}_{j,t}$ denotes the number of stocks held by owner type j at time t. Therefore, a value of 0.25 for $ownership^{shares}_{j,t}$ means that owner type j owns on average one quarter of the shares outstanding of the carbon-intensive stocks in its portfolio P. By focusing exclusively on the companies held in the respective owner type portfolio, this measure reflects the potential of an owner type to influence corporate decisions according to its risk preference, for example, in a vote on a specifically submitted shareholder proposal.

It should be noted that $ownership^{shares}_{j,t}$ does not take into account that some of the carbon-intensive companies might be completely ignored by the different owner types. To illustrate this difference, imagine a universe with 100 carbon-intensive stocks. If hedge funds only invest in one of these companies (e.g., with ownership = 100%), $ownership^{shares}_{j,t}$ correctly detects that the hedge funds possess 100% of the carbon-intensive stocks in their portfolio. However, it does not take into account that there are 99 additional carbon-intensive companies in which their share is 0%.

In the following, we consider the entire carbon-intensive stock universe potentially available for purchase to gain an insight into the distribution of ownership among owner types. Accordingly, we put the aggregated value held of carbon-intensive stocks of each owner type in relation to the total market capitalization of all carbon-intensive stocks. We define

$$ownership^{value}_{j,t} = \frac{\sum_{i \in O_j} \sum_{s \in P^{DS}_{i,t}} value\ held_{i,s,t}}{\sum_{s \in DS_t} market\ cap_{s,t}}, \quad (6)$$

where $s \in DS_t$ contains all stocks in the carbon-intensive stocks available in the Asset4 universe at time t. Thus, a value of 0.25 for $ownership^{value}_{j,t}$ indicates that owner type j (e.g., hedge funds) owns 25% of the aggregated value of carbon-intensive companies in the entire Asset4 universe.

4.3 | Regression analysis

In the previous subsection, we introduced measures for a univariate examination of the ownership structure of carbon-intensive firms. To make a reliable assessment of whether an investor type has a preference for or an aversion against carbon-intensive equity holdings, we include a firm's carbon intensity alongside firm characteristics that are focused on the traditional investment decision-making process to explain the variation in ownership shares per investor type.

In particular, we estimate the relationship between the firm's carbon intensity and the ownership share of each investor type, using the following regression model:

$$ownership^{shares}_{j,s,t} = \alpha + \beta_j\, carbon\bar{intensive}_{s,t} + \sum_{u=2}^{6} \beta_u\, controls_{i,t} + \tau + \lambda + \varepsilon_{i,t}, \quad (7)$$

where the independent variable $ownership^{shares}_{j,s,t}$ denotes the ownership share of investor type j in firm s at the end of year t. The binary variable $carbon^{-}\ intensive_{s,t}$ indicates whether the firm is identified as carbon-intensive (1) or non-carbon-intensive (0). A coefficient estimate β_j with a positive (negative) sign, therefore, reflects a preference (aversion) of respective investor type j towards carbon-intensive firms. We control for a set of firm-level variables ($controls_{i,t}$) as well as for year (τ) and country (λ) fixed effects. As firm-level control variables, we include firm size, financial performance, leverage, and asset tangibility. Among others, Duggal and Millar (1999) reveal that firm size, due to legal and liquidity reasons, predicts institutional ownership. We, therefore, consider firm *size* as the natural logarithm of market capitalization. To capture the impact of financial performance, we follow Dyck et al. (2019) and include *Tobin's Q* and a firm's annual *stock*

[8]Note that in the second half of 2018, the Financial and Risk Business of Thomson Reuters was renamed Refinitiv, after a strategic partnership transaction between Thomson Reuters and private equity funds managed by Blackstone. As a result of the renaming, Refinitiv also now refers to the former Asset4 ESG database as ESG data. Given that the data used in our analysis (as well as the documentation for the data) were sourced before the renaming, in the following, we will typically refer to Asset4.

[8]Note that in the second half of 2018, the Financial and Risk Business of Thomson Reuters was renamed Refinitiv, after a strategic partnership transaction between Thomson Reuters and private equity funds managed by Blackstone. As a result of the renaming, Refinitiv also now refers to the former Asset4 ESG database as ESG data. Given that the data used in our analysis (as well as the documentation for the data) were sourced before the renaming, in the following, we will typically refer to Asset4.

return. Grier and Zychowicz (1994) observe a negative relationship between debt and the ownership share of institutional investors, justifying this by the closer monitoring by creditors, which reduces the need for institutional monitoring. To capture this effect, we include the commonly used control variables *leverage* (as the ratio of total debt to common equity) and *asset tangibility* (as the ratio of total fixed assets to total assets). Lastly, we control for year- and country-specific variation of investor types' ownership shares (e.g., due to varying legal frameworks) and estimate robust standard errors according to White (1980).

5 | DATA AND SUMMARY STATISTICS

5.1 | Firms with high carbon risk exposure

We obtain data on CO_2 emissions and e-scores from the Refinitiv Asset4 ESG database. The database covers the most important shares traded on global stock markets[9] and, therefore, serves as a good proxy for the worldwide investment universe. Data on market capitalization, common shares outstanding, stock returns, Tobin's *Q*, assets tangibility, leverage, and industry affiliation are sourced from Thomson Reuters Datastream.

Since Asset4 obtains its CO_2 data, inter alia, from the Carbon Disclosure Project, we have to work with voluntarily reported data, which might be unreliable, inconsistent, and not validated by a third party, according to Calvello (2009). Furthermore, it also poses the risk of a self-selection bias, where, for example, bad environmental performers consciously do not report emissions to minimize their reputational risks. However, due to the lack of mandatory ESG disclosure, these weaknesses cannot be ruled out even with an alternative data provider. Asset4 offers comparatively broad coverage (Escrig-Olmedo, Fernández-Izquierdo, Ferrero-Ferrero, Rivera-Lirio, & Muñoz-Torres, 2019) and is used in several studies, for example, Matsumura, Prakash, and Vera-Muñoz (2014) and Lewandowski (2017). We, therefore, rely on the data available from Asset4, while acknowledging the potential limitations of this dataset.

Out of the full sample of 3,353 firms or 41,687 firm-years, we obtain 954 firms from carbon-intensive industries that have been active for the entire sample period 2000 to 2015. Companies that have entered the stock market later or have been delisted due to mergers or bankruptcy are excluded. By doing so, we create an Asset4 universe in which investors could, theoretically, have been invested in any share at any time of the considered sample period. For the other two definitions of carbon-intensive firms, due to the smaller coverage of available data, we have 312 firms ranked as worst emitters based on their carbon footprint and 452 firms categorized as "worst e-Score based emitters."

An overview of the industry and country distribution of these subsamples is presented in Table 2. Panel B illustrates that with 254 carbon-intensive companies, or almost one third of the market capitalization of all carbon-intensive companies, the United States has the highest share of polluting companies. This is also true for the "worst in class" classification of CO_2 heavy companies based on their emission score, where 130 out of 452 companies are based in the United States. Panel C illustrates that the polluting industries are typically Oil and Gas, Chemicals, and Metals and Mining. Our summary also shows that the selected 954 carbon-intensive stocks correspond to approximately 26% of the total market capitalization of all Asset4 firms in the sample. Stocks identified as having the worst carbon footprint or the worst emission score correspond to approximately 11% (4%) of the total market capitalization of the Asset4 universe.

5.2 | Ownership holdings

Our data on ownership structure are sourced from the Thomson Reuters' Global Equity Ownership database. We use year-end ownership information for 3,135 distinct firms with available Asset4 data. On average, we observe 12,698 distinct investors from 2000 to 2015, which we categorize into six investor types: institutional investors (including banks, trusts, insurances, pension as well as endowment funds, and foundations), hedge funds, mutual funds, and investment advisors, as well as individuals and government agencies.

Table 3 shows the distribution of held companies among the different types of investors. The average value held by all investors adds up to 12 trillion USD, which corresponds to a coverage of 42% of the total Asset4 market capitalization. Both Investment Advisors and Hedge Funds hold around one sixth of this value and form the largest investor groups, while governments and individuals are the least potent investor types, accounting for 1.17% and 1.97% of the total market capitalization of the Asset4 universe.

6 | RESULTS

6.1 | The exposure of investors' portfolio values to carbon risks

Table 4 illustrates the development of *aggr.* $CRE_{j,t}$ for the various investor types over time. Interestingly, the most noteworthy disparity in investment preferences among the different investor types can be observed in government agencies and individual investors. We first consider the results that are based on an industry-based definition of the companies, that is, carbon risk exposure for carbon-intensive stocks from CO_2-intensive industries in panel A. The results show that between 2000 and 2015, an average of 49% of the portfolio value of government agencies consists of carbon-intensive assets, ranging from 35% in 2004 to a maximum of 65% in 2011. By contrast, the carbon risk exposure of individual investors is relatively low, with an average of approximately 15%, while the remaining investor types typically hold similar shares of carbon-intensive stocks between 20% and 25% on average. Table 4 further reveals that carbon risk exposure

[9]MSCI Emerging Markets, MSCI World, CAC40, DAX, FTSE250, S&P 500, NASDAQ 100, STOXX 600, ASX 300, SMI, and Bovespa.

TABLE 2 Firm-level summary statistics

Panel A: Summary statistics

Variable	*N*	Mean	Median	p5	p95
Firm size (Tsd. $)	41,687	8,470,000	2,530,000	163,000	37,300,000
Stock return	41,687	0.15	0.11	−0.52	0.97
Tobin's *Q*	41,687	1.38	1.04	0.25	3.72
Leverage	41,687	1.06	0.55	0.00	3.97
Asset tangibility	41,687	0.43	0.41	0.07	0.87

Panel B: Distribution of carbon-intensive firms by country

Country	Industry affiliation		Worst carbon footprint		Worst emission score	
	Number of firms	% market cap. of all dirty stocks	Number of firms	% market cap. of all dirty stocks	Number of firms	% market cap. of all dirty stocks
Australia	82	2.88%	13	1.64%	51	2.62%
Brazil	6	1.50%	1	1.66%	2	0.96%
Canada	101	5.25%	21	4.41%	65	6.92%
Chile	9	0.65%	3	0.24%	4	1.23%
China	34	2.05%	5	0.50%	23	6.04%
European Union	166	28.57%	72	39.16%	46	10.10%
India	27	2.04%	12	2.47%	9	1.34%
Indonesia	8	0.36%	4	0.56%	3	1.23%
Japan	108	12.07%	58	10.40%	43	20.07%
Korea	23	1.68%	11	2.12%	8	1.24%
Malaysia	12	0.61%	7	0.86%	8	2.56%
Mexico	6	0.45%	1	0.38%	2	0.20%
New Zealand	11	0.14%	1	0.03%	6	0.32%
Norway	9	0.40%	3	0.61%	4	0.60%
Others	14	1.53%	2	2.03%	10	2.28%
Russia	4	2.35%	1	2.97%	0	0.00%
Singapore	8	0.47%	1	0.36%	4	1.08%
South Africa	24	1.17%	16	2.31%	7	0.39%
Switzerland	11	1.26%	1	0.52%	2	0.70%
Taiwan	25	0.99%	12	1.32%	21	5.05%
Thailand	6	0.24%	2	0.11%	1	0.12%
Turkey	6	0.21%	1	0.14%	3	0.54%
United States	254	33.14%	64	25.20%	130	34.42%
Total	954	100.00%	312	100.00%	452	100.00%

Panel C: Distribution of carbon-intensive firms by industry

Industry	Industry affiliation		Worst carbon footprint		Worst emission score	
	Number of firms	% market cap. of all dirty stocks	Number of firms	% market cap. of all dirty stocks	Number of firms	% market cap. of all dirty stocks
Aerospace and defense	45	5.97%	14	5.93%	20	5.03%
Automobiles and auto parts	95	12.11%	34	8.94%	45	13.42%
Chemicals	113	8.26%	41	8.83%	53	12.15%
Coal	13	0.28%	2	0.05%	6	0.50%
	33	1.96%	13	2.52%	17	3.22%

TABLE 2 (Continued)

Panel C: Distribution of carbon-intensive firms by industry						
	Industry affiliation		Worst carbon footprint		Worst emission score	
Industry	Number of firms	% market cap. of all dirty stocks	Number of firms	% market cap. of all dirty stocks	Number of firms	% market cap. of all dirty stocks
Construction materials						
Electrical utilities and IPPs	80	10.72%	34	11.19%	39	19.17%
Freight and logistics Svcs.	61	4.81%	16	5.19%	30	4.76%
Metals and mining	176	10.85%	50	12.23%	83	7.49%
Multiline utilities	27	2.51%	11	2.77%	13	3.75%
Natural gas utilities	26	1.43%	6	1.13%	12	2.25%
Oil and gas	131	31.49%	44	33.57%	63	10.26%
Oil and gas equipment and Svcs.	60	4.45%	15	3.65%	27	5.30%
Paper and forest products	18	0.65%	6	0.66%	8	0.70%
Passenger transportation Svcs.	48	3.35%	17	2.56%	23	9.98%
Transport infrastructure	28	1.18%	9	0.77%	13	2.03%
Total	954	100.00%	312	100.00%	452	100.00%
Aggregated market cap. (bn $)	7,304		3,121		1,143	
% of total Asset4 market cap.	26.00%		10.97%		4.02%	

Note: Panel A contains summary statistics for firm-level controls for the entire sample of 41,687 firm years. Panels B and C include the number of carbon-intensive stocks and their proportion of the market capitalization of all carbon-intensive stocks, which are covered in the subsample after selecting 954 Asset4 companies that belong to the 15 most CO_2-sensitive industries and after applying the "worst-in-class" approach for carbon and emission scoring. Panel B shows the geographical distribution of these companies, and Panel C shows the distribution among the considered carbon-intensive industries. All variables are defined as described in the text.

TABLE 3 Comparison of different investor types

	Institutionals	Hedge funds	Individuals	Governments	Investment advisors	Mutual funds	All investors
Number of investors	594	1,464	7,309	42	1,923	1,366	12,698
Number of held firms	2,786	3,053	1,092	91	2,232	3,031	3,135
Value held (bn $)	1,177	4,423	577	336	4,522	928	11,963
% of Asset4 market cap.	4.16%	15.27%	1.97%	1.17%	15.81%	3.15%	41.52%

Note: This table shows the number of investors, the number of companies held, the value held, and the corresponding percentage of the total market capitalization of the Asset4 universe. The statistics are presented as an average based on the year-end data between 2000 and 2015 for each investor type.

is more volatile in the portfolio of governmental agencies in comparison with the remaining investor types. This could be due to the smaller number of firms in the portfolios of government agencies, who are rather invested in selected firms and do not have a widely diversified portfolio.

For most types of investors, the carbon risk in their portfolio increases from 2000 and peaks in 2011. From 2012, we observe a change in investment behavior as the proportion of carbon-intensive stocks in investors' portfolios declines. One explanation for this could be the growing social awareness of climate risks associated with CO_2 emissions and the resulting pressure on investors in carbon-intensive companies, which, for example, resulted in the establishment of the PDC in 2014. Given the Paris Agreement in 2015, this trend towards decarbonization can be expected to continue in the future.

TABLE 4 Aggregated carbon risk exposure in different investor portfolios

Panel A: Firms from carbon-intensive industries							
Year	**Institutionals**	**Hedge funds**	**Individuals**	**Governments**	**Investment advisors**	**Mutual funds**	**All investors**
2000	13.27%	15.13%	10.97%	36.53%	14.95%	15.48%	15.43%
2001	14.14%	15.81%	7.64%	55.36%	14.97%	18.77%	15.94%
2002	16.56%	18.14%	12.78%	45.29%	16.55%	22.83%	18.07%
2003	16.59%	17.46%	13.21%	40.55%	16.47%	22.66%	17.72%
2004	18.30%	20.07%	12.13%	35.07%	18.82%	24.19%	19.65%
2005	20.97%	22.36%	14.18%	47.33%	21.71%	28.18%	22.48%
2006	23.02%	23.10%	14.45%	42.41%	22.39%	26.46%	23.08%
2007	26.52%	28.08%	15.87%	60.43%	26.65%	27.71%	27.83%
2008	26.02%	26.83%	15.42%	54.15%	25.85%	26.30%	26.73%
2009	26.43%	25.80%	16.04%	56.75%	25.32%	27.42%	26.59%
2010	27.72%	26.91%	19.85%	53.95%	26.33%	27.19%	27.55%
2011	26.58%	26.78%	17.28%	65.49%	26.39%	27.45%	27.43%
2012	24.29%	24.61%	18.18%	50.16%	23.98%	25.94%	24.78%
2013	24.14%	23.56%	19.98%	56.69%	22.55%	24.59%	23.98%
2014	22.40%	21.87%	18.93%	51.34%	21.23%	22.87%	22.33%
2015	19.71%	19.69%	17.35%	39.67%	18.96%	21.42%	19.88%
Mean	21.67%	22.26%	15.27%	49.45%	21.44%	24.34%	22.47%
Median	22.71%	22.73%	15.64%	50.75%	22.05%	25.26%	22.78%
Std. deviation	4.58%	4.04%	3.29%	8.60%	4.06%	3.44%	4.12%
Min	13.27%	15.13%	7.64%	35.07%	14.95%	15.48%	15.43%
Max	27.72%	28.08%	19.98%	65.49%	26.65%	28.18%	27.83%
Panel B: Stocks with worst carbon footprint ranking							
Year	**Institutionals**	**Hedge funds**	**Individuals**	**Governments**	**Investment advisors**	**Mutual funds**	**All investors**
2000	5.15%	6.58%	4.52%	20.53%	6.01%	6.68%	6.58%
2001	5.34%	6.88%	2.86%	33.96%	5.94%	8.38%	6.79%
2002	6.39%	7.80%	2.45%	29.12%	6.53%	9.69%	7.55%
2003	6.06%	7.18%	3.26%	27.86%	6.42%	9.78%	7.29%
2004	6.49%	8.25%	2.26%	18.94%	7.31%	10.53%	7.82%
2005	7.79%	9.17%	2.91%	29.92%	8.75%	12.04%	9.20%
2006	8.33%	9.16%	1.98%	17.57%	8.68%	12.43%	8.97%
2007	9.81%	11.12%	3.42%	26.20%	10.13%	12.81%	10.92%
2008	9.32%	9.79%	2.75%	26.01%	9.08%	11.28%	9.82%
2009	10.17%	9.52%	3.29%	30.39%	9.18%	11.72%	10.17%
2010	10.26%	9.45%	4.77%	27.28%	9.69%	11.66%	10.29%
2011	9.96%	9.13%	3.48%	37.62%	9.09%	11.38%	10.00%
2012	9.41%	8.62%	3.65%	29.75%	8.15%	10.80%	8.99%
2013	9.12%	8.15%	3.95%	31.08%	7.75%	10.00%	8.61%
2014	8.81%	8.08%	4.23%	23.54%	7.97%	8.55%	8.34%
2015	7.73%	7.22%	4.00%	19.48%	7.21%	7.50%	7.40%
Mean	8.13%	8.51%	3.36%	26.83%	7.99%	10.33%	8.67%
Median	8.57%	8.43%	3.36%	27.57%	8.06%	10.66%	8.79%
Std. deviation	1.70%	1.18%	0.78%	5.46%	1.28%	1.74%	1.30%
Min	5.15%	6.58%	1.98%	17.57%	5.94%	6.68%	6.58%
Max	10.26%	11.12%	4.77%	37.62%	10.13%	12.81%	10.92%

TABLE 4 (Continued)

Panel C: Stocks with worst e-score ranking							
Year	Institutionals	Hedge funds	Individuals	Governments	Investment advisors	Mutual funds	All investors
Panel C: Stocks with worst e-score ranking							
Year	**Institutionals**	**Hedge funds**	**Individuals**	**Governments**	**Investment advisors**	**Mutual funds**	**All investors**
2000	2.10%	2.00%	3.38%	0.03%	1.80%	1.21%	1.86%
2001	2.09%	2.16%	2.23%	0.28%	1.94%	1.40%	1.97%
2002	1.93%	2.30%	2.74%	1.63%	1.96%	2.09%	2.11%
2003	2.00%	2.46%	4.05%	0.94%	2.28%	2.25%	2.35%
2004	2.43%	2.94%	2.33%	1.69%	2.78%	2.68%	2.75%
2005	2.67%	3.24%	3.44%	1.56%	2.94%	2.77%	3.01%
2006	3.00%	3.26%	3.07%	1.20%	2.91%	2.89%	3.02%
2007	3.59%	3.70%	3.45%	0.31%	3.29%	3.77%	3.43%
2008	3.09%	3.11%	3.61%	1.64%	3.06%	3.40%	3.09%
2009	3.57%	3.34%	3.53%	1.24%	3.36%	3.60%	3.31%
2010	3.51%	4.07%	5.97%	1.20%	3.79%	4.59%	3.94%
2011	3.49%	4.45%	5.04%	3.54%	4.07%	4.70%	4.23%
2012	3.45%	4.34%	5.01%	3.50%	3.94%	4.69%	4.15%
2013	3.47%	4.52%	5.55%	3.40%	4.20%	4.49%	4.33%
2014	3.26%	4.30%	5.41%	2.58%	3.88%	4.67%	4.08%
2015	2.86%	3.77%	5.57%	1.96%	3.39%	4.22%	3.63%
Mean	2.91%	3.37%	4.02%	1.67%	3.10%	3.34%	3.20%
Median	3.05%	3.30%	3.57%	1.59%	3.17%	3.50%	3.20%
Std. deviation	0.60%	0.82%	1.19%	1.07%	0.76%	1.16%	0.80%
Min	1.93%	2.00%	2.23%	0.03%	1.80%	1.21%	1.86%
Max	3.59%	4.52%	5.97%	3.54%	4.20%	4.70%	4.33%

Note: The table illustrates the development of the aggregated carbon risk exposure (*aggr.* $CRE_{j,t}$) for each of the investor types over time. Results in each panel vary due to the different categories of carbon-intensive stocks. Panel A represents the results for the carbon-intensive stocks from the carbon-intensive industries. Panel B represents the results for the worst emitters according to the ranking of their carbon footprint. Panel C represents the results for the worst emitters according to the ranking of their e-score.

In panels B and C, the exposure to carbon-intensive stocks is further disentangled by examining investments into the "dirtiest" stocks within the carbon-intensive stock category. For this purpose, the worst emitters are defined as the 50% of companies with the highest carbon footprints (panel B) or the 50% of companies with the worst emission scores (panel C). While panel B confirms the relatively high carbon risk exposure of governments, panel C shows a more homogeneous exposure of the individual owner types.

To draw inferences as to whether the different carbon risk exposures of each type of investor are based on corresponding preferences, we use the carbon risk exposure of the overall market as a benchmark. A significant deviation, therefore, indicates an active overweighting or underweighting of carbon-intensive stock holdings.[10] Table 5 presents the carbon risk in excess to the carbon risk exposure of the Asset4 market portfolio (*ex.* $CRE_{i,t}$). The high carbon risk exposure of government agencies is confirmed by significant values between 20 and more than 30 percentage points (pp) in excess to the exposure of the Asset4 market portfolio. Interestingly, except for mutual funds, all other types of investors tend to avoid carbon risk in the allocation of their portfolios compared to the market-inherent exposure (each significant at the 1% level).

6.2 | The ownership structure of carbon-intensive firms

Hereafter, we focus on the ownership level of the different investor types regarding carbon-intensive stocks. The level of ownership shares indicates the balance of power between various types of investors and determines the prospects of a forced change in corporate policy direction, for example, in a vote on a shareholder proposal to reduce emissions.

Table 6 illustrates the average ownership of a carbon-intensive stock in the portfolio of the respective owner types as defined in

[10]Statistical significance is measured by one sample *t* tests against zero.

TABLE 5 Excess carbon risk exposure in different investor portfolios

Year	Institutionals	Hedge funds	Individuals	Governments	Investment advisors	Mutual funds	All investors
2000	−1.56*	0.09	−2.42***	25.67***	−2.04***	1.61***	−1.17***
2001	−2.49***	−1.65**	−0.34	34.78***	−3.87***	1.28**	−0.98***
2002	−1.04	−0.42	−3.47***	26.34***	−4.71***	3.15***	−2.03***
2003	−0.36	−0.82	−1.96***	31.32***	−3.50***	3.27***	−1.25***
2004	−2.82***	0.07	−3.70***	31.16***	−3.15***	2.11***	−2.28***
2005	−2.15**	0.88	−4.69***	23.48***	−4.65***	1.10*	−3.16***
2006	−4.16***	−1.03*	−4.52***	26.72***	−5.55***	1.19**	−3.50***
2007	−4.32***	−1.72***	−8.08***	24.94***	−4.95***	0.10	−5.59***
2008	−2.22**	−2.01***	−6.61***	21.01***	−4.80***	0.20	−4.91***
2009	−2.23**	−3.66***	−7.39***	20.29***	−5.70***	0.79	−5.70***
2010	−2.70***	−1.40**	−6.76***	20.06***	−5.68***	−0.83	−5.19***
2011	−1.35	−1.65***	−6.14***	19.90***	−3.62***	1.22**	−4.26***
2012	0.55	−2.37***	−1.81***	23.28***	−3.00***	1.01**	−1.57***
2013	2.08*	−0.38	−0.11	28.06***	−2.22***	0.76*	−0.19
2014	4.62***	−0.49	3.71***	31.45***	−1.63***	1.61***	2.28***
2015	4.72***	−1.41***	1.47***	29.80***	−1.91***	2.51***	0.98***
All years	−0.98***	−1.20***	−3.26***	25.58***	−3.70***	1.27***	−2.40***

Note: For each year and investor group, the following table shows their average carbon risk exposure in excess of the carbon risk exposure of the overall Asset4 market (*ex. $CRE_{i,t}$*). Statistical significance is measured by one sample *t* tests against zero.
*Statistical significance at the 10% level.
**Statistical significance at the 5% level.
***Statistical significance at the 1% level.

Equation 5. Our expectations regarding the ownership structure are being met: while institutional and individual investors play a relatively minor but still evident role in terms of the ownership distribution, the significance of government agencies is once again evident. On average, government agencies hold around 27% of outstanding shares of a carbon-intensive stock in their portfolio. The main driver is probably the high occurrence of state-ownership within CO_2 heavy sectors. This hypothesis is supported by a report of the OECD (2014), which shows that electricity and gas is one of the most dominant sectors among state-owned listed entities. As expected, hedge funds and investment advisors are also relevant shareholder groups with average ownership of 13% and 18%, respectively. Overall, our results suggest that these three types of investors in particular could influence environmental awareness and the behavior of carbon-intensive companies in which they are invested, due to their high level of ownership.

To draw inferences about the total exposure to carbon risk for investors, in the following, we consider the entire universe of CO_2-intensive stocks. Table 7 reports how the ownership of carbon-intensive stocks as defined in Equation 6 is distributed among the different types of investors. Our results illustrate that investment advisors and hedge funds are the strongest owner groups, each holding around 13% of the market capitalization of all carbon-intensive stocks in our sample. In contrast to the previous analysis, government agencies play a subordinate role from this perspective: only about 2% of the market capitalization of all carbon-intensive companies are owned by governments. Overall, we see their role as a carbon risk-taker mainly stemming from state-ownership of selected carbon-intensive firms and less through broadly based investments. In total, Table 7 reveals that hedge funds and investment advisors hold the highest proportion of the "carbon risk bomb." This might not only be interesting for clients of these investors, but also for policymakers, who are thinking of controlling the sponsors of carbon-intensive companies. It also highlights the relevance of some of these investor groups' voluntary commitments[11] to tackle climate change by decarbonizing their portfolios.

6.3 | Investor preferences towards carbon-intensive firms

To substantiate the conclusions, we draw about an investor type's preference for carbon-intensive companies, we use a multivariate regression model to investigate the relationship between the ownership structure and the carbon intensity of a firm.

Table 8 presents pairwise correlations for dependent, explanatory, and control variables adopted in estimating the relationship between ownership share and carbon intensity. All variables of

[11]For example, the "The Global Investor Statement on Climate Change," which was facilitated by the UNEP FI.

TABLE 6 Carbon stock ownership of the different investor types

Panel A: Stocks from carbon-intensive industries							
Year	**Institutionals**	**Hedge funds**	**Individuals**	**Governments**	**Investment advisors**	**Mutual funds**	**All investors**
2000	3.20%	9.29%	9.29%	25.25%	12.14%	2.21%	20.54%
2001	3.04%	9.77%	9.26%	27.90%	16.80%	2.50%	21.17%
2002	3.37%	10.64%	9.42%	21.94%	15.79%	2.61%	23.03%
2003	3.34%	10.98%	8.79%	21.24%	16.05%	2.72%	24.90%
2004	3.00%	12.06%	7.64%	19.84%	16.73%	2.48%	25.91%
2005	3.05%	12.62%	8.21%	24.25%	17.24%	2.42%	27.86%
2006	3.29%	13.45%	7.27%	22.81%	17.71%	2.52%	29.89%
2007	3.14%	14.90%	7.08%	27.35%	16.64%	3.88%	33.39%
2008	2.75%	13.30%	6.26%	29.36%	19.07%	3.18%	31.63%
2009	3.10%	13.28%	6.53%	30.87%	18.58%	2.97%	32.18%
2010	3.04%	13.72%	6.59%	33.31%	17.58%	3.31%	32.92%
2011	3.30%	13.99%	6.12%	32.22%	18.46%	3.30%	33.38%
2012	3.22%	14.16%	6.25%	29.34%	18.52%	3.44%	33.84%
2013	3.14%	14.43%	6.13%	29.51%	19.44%	4.13%	34.93%
2014	3.42%	15.37%	5.26%	32.12%	20.24%	4.62%	36.74%
2015	3.28%	15.55%	5.50%	32.47%	21.47%	4.74%	36.95%
Mean	3.17%	12.97%	7.22%	27.49%	17.65%	3.19%	29.95%
Median	3.17%	13.37%	6.84%	28.62%	17.65%	3.07%	31.90%
Std. deviation	0.17%	1.87%	1.34%	4.26%	2.06%	0.77%	5.21%
Min	2.75%	9.29%	5.26%	19.84%	12.14%	2.21%	20.54%
Max	3.42%	15.55%	9.42%	33.31%	21.47%	4.74%	36.95%
Panel B: Stocks with worst carbon footprint ranking							
Year	**Institutionals**	**Hedge funds**	**Individuals**	**Governments**	**Investment advisors**	**Mutual funds**	**All investors**
2000	2.89%	7.37%	3.91%	24.37%	9.23%	2.27%	17.40%
2001	2.66%	7.50%	5.60%	18.31%	14.42%	2.70%	17.54%
2002	3.07%	8.10%	5.48%	16.06%	12.21%	2.60%	18.36%
2003	2.87%	8.36%	5.02%	11.65%	12.58%	2.72%	19.59%
2004	2.44%	9.14%	3.51%	10.37%	13.25%	2.67%	20.44%
2005	2.89%	9.69%	4.80%	13.94%	13.83%	2.47%	22.39%
2006	3.11%	10.40%	3.10%	10.92%	15.16%	2.62%	23.41%
2007	2.84%	12.10%	3.70%	18.86%	13.56%	4.15%	27.17%
2008	2.51%	10.76%	3.61%	18.13%	15.82%	3.31%	25.27%
2009	3.09%	10.83%	4.35%	24.45%	15.30%	3.13%	26.51%
2010	2.86%	10.85%	4.64%	24.87%	15.40%	3.46%	26.70%
2011	3.33%	11.02%	3.94%	24.44%	15.60%	3.36%	26.41%
2012	3.55%	11.60%	4.72%	25.66%	15.68%	3.63%	27.98%
2013	3.31%	12.07%	4.69%	26.21%	16.19%	4.16%	28.67%
2014	3.66%	12.63%	4.70%	25.89%	17.74%	4.47%	30.41%
2015	3.32%	12.91%	4.13%	28.23%	19.04%	4.45%	30.51%
Mean	3.02%	10.33%	4.37%	20.15%	14.69%	3.26%	24.30%
Median	2.98%	10.80%	4.49%	21.62%	15.23%	3.22%	25.84%
Std. deviation	0.34%	1.74%	0.69%	5.91%	2.23%	0.71%	4.35%
Min	2.44%	7.37%	3.10%	10.37%	9.23%	2.27%	17.40%
Max	3.66%	12.91%	5.60%	28.23%	19.04%	4.47%	30.51%

(Continues)

TABLE 6 (Continued)

Panel C: Stocks with worst e-score ranking							
Year	Institutionals	Hedge funds	Individuals	Governments	Investment advisors	Mutual funds	All investors
Panel C: Stocks with worst e-score ranking							
Year	**Institutionals**	**Hedge funds**	**Individuals**	**Governments**	**Investment advisors**	**Mutual funds**	**All investors**
2000	3.79%	10.24%	10.76%	20.69%	12.22%	1.98%	19.02%
2001	3.51%	10.60%	10.39%	22.58%	17.57%	2.15%	19.72%
2002	3.52%	11.64%	10.49%	18.25%	17.32%	2.39%	21.96%
2003	3.38%	11.80%	10.39%	20.45%	17.79%	2.65%	24.46%
2004	3.21%	13.24%	8.83%	21.38%	19.35%	2.29%	25.66%
2005	3.04%	13.66%	9.85%	34.58%	19.44%	2.32%	27.70%
2006	3.20%	14.63%	8.69%	38.70%	19.37%	2.55%	29.91%
2007	3.21%	15.53%	7.98%	37.56%	18.01%	3.95%	33.42%
2008	2.73%	13.73%	6.93%	38.12%	21.02%	3.19%	31.47%
2009	3.13%	13.73%	7.98%	32.19%	20.67%	2.82%	32.11%
2010	2.82%	14.42%	8.13%	31.91%	19.26%	3.39%	33.43%
2011	3.07%	15.01%	7.22%	36.01%	21.19%	3.33%	34.17%
2012	2.84%	15.05%	6.80%	31.17%	19.83%	3.44%	34.04%
2013	2.78%	15.11%	6.34%	31.10%	21.85%	4.10%	35.06%
2014	3.09%	16.37%	5.33%	31.13%	21.73%	4.71%	36.86%
2015	2.94%	16.07%	6.08%	30.39%	23.22%	4.83%	36.74%
Mean	3.14%	13.80%	8.26%	29.76%	19.37%	3.13%	29.73%
Median	3.11%	14.08%	8.06%	31.15%	19.40%	3.00%	31.79%
Std. deviation	0.29%	1.81%	1.69%	6.68%	2.47%	0.87%	5.74%
Min	2.73%	10.24%	5.33%	18.25%	12.22%	1.98%	19.02%
Max	3.79%	16.37%	10.76%	38.70%	23.22%	4.83%	36.86%

Note: The table shows the average ownership ($ownership_{j,t}^{shares}$) in carbon-intensive companies of each investor group as the number of shares held in relation to the stocks' outstanding shares. The results in each panel vary due to the different categories of carbon-intensive stocks. Panel A represents the results for the carbon-intensive stocks from the carbon-intensive industries. Panel B represents the results for the worst emitters according to the ranking of their carbon footprint. Panel C represents the results for the worst emitters according to the ranking of their emission score.

interest, that is, the ownership shares of the investor types, exhibit a significant correlation with carbon intensity. Here, only mutual funds and governments show a positive correlation, while the remaining investor types seem to have a negative relationship to corporate carbon intensity. The correlation matrix does not include high levels of correlation between the explanatory variables, confirming the assumption that there is no multicollinearity.

The coefficient estimates in Table 9 reveal a significant negative relationship between the ownership share of individuals, investment advisors as well as mutual funds, and corporate carbon intensity. Regarding governmental ownership, our findings from the univariate analysis can be confirmed: government agencies hold a significantly higher ownership share of carbon-intensive firms in comparison to non-carbon-intensive firms even after controlling for other firm characteristics. We do not find a significant preference for or against carbon-intensive companies for institutional investors and hedge funds.

7 | CONCLUSION, IMPLICATIONS, AND LIMITATIONS

We provide one of the first studies to fully examine the exposure of important investors types, namely institutional investors, hedge funds, individuals, investment advisors, mutual funds, and government agencies to carbon-intensive stocks, using a global sample of firms. We combine different metrics to classify carbon-intensive stocks with ownership information over a sample period from 2000 to 2015. The applied approach allows us to investigate the extent to which the portfolio values of these investor types are threatened by carbon risks and to examine the ownership structure of carbon-intensive firms.

Our results reveal that government agencies in particular have high exposure to carbon risk, with an average of 49% of their assets under management invested in companies whose business models are associated with high carbon emissions. Comparable numbers for all other investor types are on a moderate level and average between

TABLE 7 Carbon stock ownership of the different investor types—entire investment universe

Year	Institutionals	Hedge funds	Individuals	Governments	Investment advisors	Mutual funds	All investors
2000	2.93%	10.53%	0.94%	2.52%	12.51%	2.41%	31.85%
2001	3.34%	11.57%	0.56%	2.12%	12.36%	2.79%	32.73%
2002	3.53%	12.02%	0.98%	2.01%	11.83%	2.71%	33.08%
2003	3.55%	11.29%	0.99%	1.89%	11.85%	2.67%	32.23%
2004	3.27%	12.24%	0.90%	1.42%	12.59%	2.58%	33.01%
2005	3.30%	12.65%	0.96%	1.52%	12.86%	2.61%	33.90%
2006	3.43%	12.72%	0.95%	1.40%	12.87%	2.54%	33.90%
2007	3.27%	14.76%	1.03%	2.57%	12.84%	3.71%	38.17%
2008	3.19%	14.07%	0.99%	2.52%	13.77%	3.06%	37.60%
2009	3.38%	13.33%	1.25%	3.43%	13.24%	2.97%	37.60%
2010	3.52%	13.47%	1.46%	3.09%	12.96%	2.85%	37.35%
2011	3.77%	14.16%	1.36%	3.11%	13.96%	2.80%	39.16%
2012	3.78%	14.11%	1.63%	2.14%	13.52%	3.13%	38.31%
2013	3.96%	15.26%	1.79%	2.46%	14.33%	3.69%	41.49%
2014	4.24%	16.41%	1.69%	2.42%	15.90%	3.85%	44.50%
2015	3.90%	16.37%	1.90%	1.94%	16.15%	4.09%	44.36%
Mean	3.52%	13.43%	1.21%	2.29%	13.35%	3.03%	36.83%
Median	3.48%	13.40%	1.01%	2.28%	12.91%	2.83%	37.48%
Std. deviation	0.32%	1.68%	0.37%	0.58%	1.21%	0.51%	4.01%
Min	2.93%	10.53%	0.56%	1.40%	11.83%	2.41%	31.85%
Max	4.24%	16.41%	1.90%	3.43%	16.15%	4.09%	44.50%

Note: For each year and investor group, this table shows their average ownership of carbon-intensive stocks ($ownership_{j,t}^{value}$) as the aggregated value held in relation to the total market capitalization of all carbon-intensive stocks in the entire Asset4 universe.

15% and 25% during the sample period. Overall, we observe a steady reduction in carbon risk exposure for all types of investors from 2012 onwards, which can be attributed to the increasing inclusion of sustainability risks and opportunities into the traditional financial analysis (Friede, Busch, & Bassen, 2015). The results also reflect the increasing number of asset managers who, since the second decade of the 2000s, have joined voluntary associations, for example, like the PDC, with a shared ambition of decarbonizing their portfolios (PDC, 2020).

In addition to the highest (portfolio) carbon risk exposure, governments also represent the largest owner group of carbon-intensive companies held in their portfolios. It is important to note that some of the largest oil and gas companies have not been publicly listed (e.g., Saudi Aramco) but rather were completely in the hands of the state during our observation period. The carbon risk that government agencies build up in their portfolio is therefore likely to be even higher than shown in this study. Thus, we can confirm the dominant role of governments among owners of highly polluting companies, which was already revealed by Earnhart and Lizal (2006) for a sample of Czech companies, on a global level. Accordingly, governments, as the largest shareholder group, would be able to exert influence on corporate management to improve the risk exposure of their portfolios. In this context, Calza, Profumo, and Tutore (2016) empirically show that state ownership has a positive impact on the carbon disclosure score of a firm, which indicates the success of such engagement strategies. Besides, in their executive function, governments represent both sources and key drivers of prospective regulations concerning climate change. Accordingly, to a large extent governments would have to bear the (financial) consequences of such policies themselves, which could be one reason for the inadequate implementation of the Paris climate targets to date (see, e.g., Kollmann & Schneider, 2010).

Considering the entire carbon-intensive equity universe, we find that investment advisors and hedge funds are the major shareholders, with ownership shares averaging around 13% each. Accordingly, these financial intermediaries are the main financing sources and at the same time the beneficiaries of polluting companies. According to Sandberg (2011), a critical factor concerning a possible engagement of these owner groups is the fiduciary duty towards their investors. In this respect, it is unclear whether this duty is consistent with non-financial actions, like, for example, shareholder engagement for a climate-friendly corporate policy. Nevertheless, in the recent past, a stronger reference to sustainability also seems to have prevailed among these investor groups, as expressed, for example, in Larry Fink's highly regarded letter to CEOs. Therein the world's largest asset manager promised to meet his eco-social responsibility as an active owner and investor (BlackRock, 2020). Our results also provide an

TABLE 8 Correlation matrix

	Carbon-intensive	Institutional	Hedge fund	Individual	Government	Investment advisor	Mutual fund	Tobin's Q	Return	Market value	Assets tangibility	Leverage
Carbon-intensive	1											
Institutional	−0.042	1										
	(0.000)											
Hedge fund	−0.085	0.361	1									
	(0.000)	(0.000)										
Individual	−0.044	−0.056	−0.066	1								
	(0.000)	(0.000)	(0.000)									
Government	0.073	0.002	−0.072	−0.020	1							
	(0.000)	(0.590)	(0.000)	(0.000)								
Investment advisor	−0.094	0.408	0.803	−0.081	−0.074	1						
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)							
Mutual fund	0.030	−0.055	−0.219	0.026	0.042	−0.295	1					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)						
Tobin's Q	−0.059	−0.003	0.062	0.042	−0.040	0.078	−0.023	1				
	(0.000)	(0.521)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
Return	−0.003	−0.021	−0.013	0.023	−0.009	−0.023	0.011	0.181	1			
	(0.558)	(0.000)	(0.005)	(0.000)	(0.051)	(0.000)	(0.015)	(0.000)				
Market value	−0.018	0.200	0.101	−0.032	0.079	0.121	0.182	0.028	0.084	1		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
Assets tangibility	0.066	−0.067	0.026	0.037	−0.038	0.021	−0.021	0.450	0.059	−0.193	1	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
Leverage	−0.032	0.005	−0.038	−0.018	0.017	−0.049	−0.009	−0.163	−0.042	0.088	−0.511	1
	(0.000)	(0.304)	(0.000)	(0.000)	(0.000)	(0.000)	(0.042)	(0.000)	(0.000)	(0.000)	(0.000)	

Note: This table reports pairwise (Pearson) correlation coefficients of all variables used to estimate the relationship between ownership structure and carbon intensity. *p* values are reported in parentheses.

TABLE 9 Regression analysis results

	(1)	(2)	(3)	(4)	(5)	(6)
	Ownership share (%)					
Variables	Institutionals	Hedge funds	Individuals	Governments	Investment advisors	Mutual funds
Carbon-intensive	−0.118	−0.008	−0.806***	0.666***	−0.690**	−0.415***
	(0.117)	(0.319)	(0.279)	(0.212)	(0.324)	(0.099)
Tobin's Q	−0.101***	−0.354***	0.313***	−0.191***	−0.147	0.047*
	(0.034)	(0.109)	(0.106)	(0.044)	(0.114)	(0.027)
Stock return	−0.357***	0.556***	0.423***	−0.196***	−0.272**	0.151***
	(0.047)	(0.124)	(0.131)	(0.067)	(0.126)	(0.042)
Firm size	0.498***	0.440***	−0.460***	0.264***	0.906***	0.314***
	(0.032)	(0.098)	(0.072)	(0.056)	(0.100)	(0.023)
Asset tangibility	−0.487*	4.195***	1.212**	0.345	3.215***	0.064
	(0.254)	(0.695)	(0.559)	(0.295)	(0.728)	(0.182)
Leverage	−0.076**	0.069	−0.039	−0.001	−0.119*	−0.059**
	(0.037)	(0.090)	(0.057)	(0.033)	(0.072)	(0.023)
Constant	−7.444***	2.624	11.976***	−5.162***	−7.413***	−3.927***
	(0.706)	(2.214)	(1.611)	(1.200)	(2.250)	(0.512)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	41,671	41,671	41,671	41,671	41,671	41,671
Adjusted R^2	0.210	0.586	0.091	0.076	0.627	0.379

Note: For each of the six investor groups, this table shows regression results where the independent variable $ownership_{j,s,t}^{shares}$ denotes the ownership share of investor type *j* in firm *s* at the end of year *t*. We control for a set of firm-level variables, year, and country fixed effects and the variable of interest, *Carbon-intensive*, indicates, whether the firm *s* is identified as carbon-intensive (1) or non-carbon-intensive (0). We estimate robust standard errors according to White (1980).

*Statistical significance at the 10% level.

**Statistical significance at the 5% level.

***Statistical significance at the 1% level.

indication for policymakers about potential addressees of regulation, namely, hedge funds, institutional investors, and governments. These groups will have to play a major role in ensuring that financial flows are consistent with the transformation to a low-carbon economy according to the Paris Agreement (UNFCCC, 2015).

We further test the owner types' preference for or against carbon-intensive firms, controlling for firm characteristics that are at the focus of the traditional, return-oriented investment decision process. Our findings confirm that governments have a significantly higher preference for shareholdings in carbon-intensive companies. In contrast, mutual funds, investment advisors, and individuals show a significant reluctance to hold carbon-intensive stocks.

By classifying into different investor types, we comply with the findings of Hoskisson, Hitt, Johnson, and Grossman (2002) that different investor types do not have homogeneous preferences. However, it should be noted that preferences of distinct investors within these more granular groups cannot be assumed to be completely homogeneous either (see, e.g., Çelik & Isaksson, 2014). As a further limiting factor, it must be mentioned that due to the contemporary setting, we do not provide a causal interpretation as to whether state dominance in the ownership structure has an impact on the prospective environmental performance of these companies. However, recent work by Pan, Chen, Sinha, and Dong (2020) suggests a u-shaped relationship between state ownership and environmental innovation.

In this respect, we hope that this study encourages future research to further investigate the effects of ownership structure on the development of corporate CO_2 emissions. Another suggestion for future work is to examine whether the general tendency towards portfolio decarbonization (see also, e.g., Benz et al., 2020) will lead to a reaction of corporate management in terms of a CO_2-efficient redesign of business processes.

ACKNOWLEDGEMENT

This work was funded by the DAAD (german academic exchange service) with funds from the Federal Ministry of Education and Research.

Open access funding enabled and organized by Projekt DEAL.

ORCID

Lukas Benz https://orcid.org/0000-0002-2002-3555

Stefan Trück https://orcid.org/0000-0002-5302-3850

REFERENCES

Aggarwal, R., Dow, S., 2011. Greenhouse gas emissions mitigation and firm value: A study of large North-American and European firms. Midwest Finance Association 2012 Annual Meetings Paper. https://doi.org/10.2139/ssrn.1929453

Almazan, A., Hartzell, J. C., & Starks, L. T. (2005). Active institutional shareholders and costs of monitoring: Evidence from executive compensation. *Financial Management*, *34*(4), 5–34. https://doi.org/10.1111/j.1755-053X.2005.tb00116.x

Benz, L., Jacob, A., Paulus, S., & Wilkens, M. (2020). Herds on green meadows: The decarbonization of institutional portfolios. *Journal of Asset Management*, *21*(1), 13–31. https://doi.org/10.1057/s41260-019-00147-z

BlackRock, 2020. Larry Fink's letter to CEOs|BlackRock. https://www.blackrock.com/corporate/investor-relations/larry-fink-ceo-letter. Accessed 4 June 2020.

Bolton, P., & Kacperczyk, M. (2020). *Do investors care about carbon risk?* Cambridge: MA.

Boubakri, N., Cosset, J.-C., & Guedhami, O. (2009). From state to private ownership: Issues from strategic industries. *Journal of Banking & Finance*, *33*(2), 367–379. https://doi.org/10.1016/j.jbankfin.2008.08.012

Brouwers, R., Schoubben, F., & van Hulle, C. (2018). The influence of carbon cost pass through on the link between carbon emission and corporate financial performance in the context of the European Union Emission Trading Scheme. *Business Strategy and the Environment*, *27*(8), 1422–1436. https://doi.org/10.1002/bse.2193

Busch, T., & Hoffmann, V. H. (2011). How hot is your bottom line? Linking carbon and financial performance. *Business & Society*, *50*(2), 233–265. https://doi.org/10.1177/0007650311398780

Cai, L., Cui, J., & Jo, H. (2016). Corporate environmental responsibility and firm risk. *Journal of Business Ethics*, *139*(3), 563–594. https://doi.org/10.1007/s10551-015-2630-4

Calvello, A. A. (2009). *Environmental alpha: Institutional investors and climate change* (p. 404). Hoboken, N. J: John Wiley & Sons. https://doi.org/10.1002/9781118266748

Calza, F., Profumo, G., & Tutore, I. (2016). Corporate ownership and environmental proactivity. *Business Strategy and the Environment*, *25*(6), 369–389. https://doi.org/10.1002/bse.1873

Carbon Tracker Initiative, 2013. Unburnable carbon 2013: Wasted capital and stranded assets. http://carbontracker.live.kiln.digital/Unburnable-Carbon-2-Web-Version.pdf. Accessed 3 February 2020.

Carbon Trust, 2018. Carbon footprinting guide. https://www.carbontrust.com/resources/guides/carbon-footprinting-and-reporting/carbon-footprinting/. Accessed 3 February 2020.

Ceccarelli, M., Ramelli, S., Wagner, A.F., 2020. *Low-carbon mutual funds*. https://doi.org/10.2139/ssrn.3353239

Çelik, S., & Isaksson, M. (2014). *Institutional investors and ownership engagement* (Vol. 2013) (pp. 93–114). OECD Journal: Financial Market Trends. https://doi.org/10.1787/fmt-2013-5jz734pwtrkc

Chen, X., Harford, J., & Li, K. (2007). Monitoring: Which institutions matter? *Journal of Financial Economics*, *86*(2), 279–305. https://doi.org/10.1016/j.jfineco.2006.09.005

Cook, A. (2009). Emission rights: From costless activity to market operations. *Accounting, Organizations and Society*, *34*(3–4), 456–468. https://doi.org/10.1016/j.aos.2007.12.001

Cubas-Díaz, M., & Sedano, M. Á. M. (2018). Measures for sustainable investment decisions and business strategy—A triple bottom line approach. *Business Strategy and the Environment*, *27*(1), 16–38. https://doi.org/10.1002/bse.1980

Cunha, F. A. F.d. S., Oliveira, E. M., Orsato, R. J., Klotzle, M. C., Cyrino Oliveira, F. L., & Caiado, R. G. G. (2019). Can sustainable investments outperform traditional benchmarks? Evidence from global stock markets. *Business Strategy and the Environment*, *79*(1), 28–697. https://doi.org/10.1002/bse.2397

Dahlmann, F., Branicki, L., & Brammer, S. (2019). Managing carbon aspirations: The influence of corporate climate change targets on environmental performance. *Journal of Business Ethics*, *158*(1), 1–24. https://doi.org/10.1007/s10551-017-3731-z

Dell'Aringa, S., van Ast, L., 2009. Carbon risks in UK equity funds. http://assets.wwf.org.uk/downloads/carbonrisksinukequityfunds.pdf. Accessed 3 February 2020.

Delmas, M. A., Nairn-Birch, N., & Lim, J. (2015). Dynamics of environmental and financial performance. *Organization & Environment*, *28*(4), 374–393. https://doi.org/10.1177/1086026615620238

Duggal, R., & Millar, J. A. (1999). Institutional ownership and firm performance: The case of bidder returns. *Journal of Corporate Finance*, *5*(2), 103–117. https://doi.org/10.1016/S0929-1199(98)00018-2

Dupré, S., Thomä, J., Dejonckheere, S., Fischer, R., Weber, C., Cummis, C., Srivastava, A., 2015. Climate strategies and metrics: Exploring options for institutional investors.

Dyck, A., Lins, K. V., Roth, L., & Wagner, H. F. (2019). Do institutional investors drive corporate social responsibility? International evidence. *Journal of Financial Economics*, *131*(3), 693–714. https://doi.org/10.1016/j.jfineco.2018.08.013

Earnhart, D., & Lizal, L. (2006). Effects of ownership and financial performance on corporate environmental performance. *Journal of Comparative Economics*, *34*(1), 111–129. https://doi.org/10.1016/j.jce.2005.11.007

Escrig-Olmedo, E., Fernández-Izquierdo, M. Á., Ferrero-Ferrero, I., Rivera-Lirio, J. M., & Muñoz-Torres, M. J. (2019). Rating the raters: Evaluating how ESG rating agencies integrate sustainability principles. *Sustainability*, *11*(3:915), 1–16. https://doi.org/10.3390/su11030915

Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment*, *5*(4), 210–233. https://doi.org/10.1080/20430795.2015.1118917

Gallego-Álvarez, I., Segura, L., & Martínez-Ferrero, J. (2015). Carbon emission reduction: The impact on the financial and operational performance of international companies. *Journal of Cleaner Production*, *103*, 149–159. https://doi.org/10.1016/j.jclepro.2014.08.047

Goodstein, E. S. (2011). *Economics and the environment* (6th ed.) (p. 514). Hoboken, NJ: Wiley.

Grier, P., & Zychowicz, E. J. (1994). Institutional investors, corporate discipline, and the role of debt. *Journal of Economics and Business*, *46*(1), 1–11. https://doi.org/10.1016/0148-6195(94)90017-5

Hoffmann, V. H., & Busch, T. (2008). Corporate carbon performance indicators. *Journal of Industrial Ecology*, *12*(4), 505–520. https://doi.org/10.1111/j.1530-9290.2008.00066.x

Hong, H. G., & Kacperczyk, M. T. (2009). The price of sin: The effects of social norms on markets. *Journal of Financial Economics*, *93*, 15–36. https://doi.org/10.1016/j.jfineco.2008.09.001

Hoskisson, R. E., Hitt, M. A., Johnson, R. A., & Grossman, W. (2002). Conflicting voices: The effects of institutional ownership heterogeneity and internal governance on corporate innovation strategies. *Academy of Management Journal*, *45*(4), 697–716. https://doi.org/10.5465/3069305

IPCC. (2014). Climate change 2014: Synthesis report. In *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Synthesis report* (p. 151). Intergovernmental Panel on: Climate Change, Geneva, Switzerland.

Jung, J., Herbohn, K., & Clarkson, P. (2018). Carbon risk, carbon risk awareness and the cost of debt financing. *Journal of Business Ethics*, *150*(4), 1151–1171. https://doi.org/10.1007/s10551-016-3207-6

Kim, Y.-B., An, H. T., & Kim, J. D. (2015). The effect of carbon risk on the cost of equity capital. *Journal of Cleaner Production*, *93*, 279–287. https://doi.org/10.1016/j.jclepro.2015.01.006

Kollmann, A., & Schneider, F. (2010). Why does environmental policy in representative democracies tend to be inadequate? A preliminary

public choice analysis. *Sustainability*, *2*(12), 3710–3734. https://doi.org/10.3390/su2123710

Labatt, S., & White, R. R. (2002). *Environmental finance: A guide to environmental risk assessment and financial products* (p. 366). Hoboken, N. J: John Wiley & Sons.

Labatt, S., & White, R. R. (2007). *Carbon finance: The financial implications of climate change* (p. 268). Hoboken, N. J: John Wiley & Sons.

Le Quéré, C., Moriarty, R., Andrew, R. M., Peters, G. P., Ciais, P., Friedlingstein, P., … Zeng, N. (2015). Global carbon budget 2014. *Earth System Science Data*, *7*(1), 47–85. https://doi.org/10.5194/essd-7-47-2015

Leaton, J., Campanale, M., & Leggett, J. (2011). Unburnable carbon—Are the world's financial markets carrying a carbon bubble? *Carbon Initiative Tracker*, 1–36.

Lewandowski, S. (2017). Corporate carbon and financial performance: The role of emission reductions. *Business Strategy and the Environment*, *26*(8), 1196–1211. https://doi.org/10.1002/bse.1978

Matsumura, E. M., Prakash, R., & Vera-Muñoz, S. C. (2014). Firm-value effects of carbon emissions and carbon disclosures. *The Accounting Review*, *89*(2), 695–724. https://doi.org/10.2308/accr-50629

Misani, N., & Pogutz, S. (2015). Unraveling the effects of environmental outcomes and processes on financial performance: A non-linear approach. *Ecological Economics*, *109*, 150–160. https://doi.org/10.1016/j.ecolecon.2014.11.010

Nordhaus, W. D. (2017). Revisiting the social cost of carbon. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(7), 1518–1523. https://doi.org/10.1073/pnas.1609244114

OECD. (2014). *The size and sectoral distribution of SOEs in OECD and partner countries*. OECD. https://doi.org/10.1787/9789264215610-en

Oestreich, A. M., & Tsiakas, I. (2015). Carbon emissions and stock returns: Evidence from the EU Emissions Trading Scheme. *Journal of Banking & Finance*, *58*, 294–308. https://doi.org/10.1016/j.jbankfin.2015.05.005

Pan, X., Chen, X., Sinha, P., & Dong, N. (2020). Are firms with state ownership greener? An institutional complexity view. *Business Strategy and the Environment*, *29*(1), 197–211. https://doi.org/10.1002/bse.2358

PCI, 2020. Portfolio Carbon Initiative: Guidance for financial institutions to assess the climate impact from investing and lending activities. https://ghgprotocol.org/portfolio-carbon-initiative

PDC, 2020. The portfolio decarbonization coalition. Mobilizing financial markets to drive economic decarbonization. https://unepfi.org/pdc/. Accessed 30 May 2020.

Perdan, S., & Azapagic, A. (2011). Carbon trading: Current schemes and future developments. *Energy Policy*, *39*(10), 6040–6054. https://doi.org/10.1016/j.enpol.2011.07.003

PRI, 2020. Principles of responsible investment. https://www.unpri.org/. Accessed 15 June 2020.

Refinitiv, 2020. Thomson Reuters ESG scores methodology. https://www.refinitiv.com/content/dam/marketing/en_us/documents/methodology/esg-scores-methodology.pdf. Accessed 15 June 2020.

Riedl, A., & Smeets, P. (2017). Why do investors hold socially responsible mutual funds? *The Journal of Finance*, *72*(6), 2505–2550. https://doi.org/10.1111/jofi.12547

Ritchie, J., & Dowlatabadi, H. (2015). Divest from the carbon bubble? Reviewing the implications and limitations of fossil fuel divestment for institutional investors. *Review of Economics & Finance*, *5*(2), 59–80.

Saka, C., & Oshika, T. (2014). Disclosure effects, carbon emissions and corporate value. *Sustainability Accounting, Management and Policy Journal*, *5*(1), 22–45. https://doi.org/10.1108/SAMPJ-09-2012-0030

Sandberg, J. (2011). Socially responsible investment and fiduciary duty: Putting the Freshfields report into perspective. *Journal of Business Ethics*, *101*(1), 143–162. https://doi.org/10.1007/s10551-010-0714-8

Stern, N., & Stern, N. H. (2007). *The economics of climate change: The Stern review*. Cambridge University press.

TRBC, 2020. TRBC sector classification. https://www.refinitiv.com/en/financial-data/indices/trbc-business-classification. Accessed 15 June 2020.

Trumpp, C., & Guenther, T. (2017). Too little or too much? Exploring U-shaped relationships between corporate environmental performance and corporate financial performance. *Business Strategy and the Environment*, *26*(1), 49–68. https://doi.org/10.1002/bse.1900

Tuerk, A., Zelljadt, E., 2016. The global rise of emissions trading. Climate Policy Info Hub. http://climatepolicyinfohub.eu/global-rise-emissions-trading

Ulshöfer, G., & Bonnet, G. (2009). *Corporate social responsibility auf dem Finanzmarkt*. Wiesbaden: VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-91792-4

UNEP, 2020. Global trends in renewable energy investment. https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf. Accessed 15 June 2020.

UNFCCC, 2015. The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. Accessed 15 June 2020.

van Duuren, E., Plantinga, A., & Scholtens, B. (2016). ESG integration and the investment management process: Fundamental investing reinvented. *Journal of Business Ethics*, *138*(3), 525–533. https://doi.org/10.1007/s10551-015-2610-8

Wang, L., Li, S., & Gao, S. (2014). Do greenhouse gas emissions affect financial performance?—An empirical examination of Australian public firms. *Business Strategy and the Environment*, *23*(8), 505–519. https://doi.org/10.1002/bse.1790

White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica*, *48*(4), 817–838. https://doi.org/10.2307/1912934

Xue, B., Zhang, Z., & Li, P. (2019). Corporate environmental performance, environmental management and firm risk. *Business Strategy and the Environment*, *29*(3), 1074–1096. https://doi.org/10.1002/bse.2418

How to cite this article: Benz L, Paulus S, Scherer J, Syryca J, Trück S. Investors' carbon risk exposure and their potential for shareholder engagement. *Bus Strat Env*. 2021;30:282–301. https://doi.org/10.1002/bse.2621