DOI: 10.1111/jiec.13574

RESEARCH ARTICLE

JOURNAL OF INDUSTRIAL ECOLOGY WILEY

Carbon disclosures and information asymmetry

Empirical evidence on the importance of text in understanding numerical emission allowance disclosures

Tobias Steindl[1] | **Florian Habermann**[2,3] | **Stephan Küster**[4]

[1]Institute of Business Administration, University of Regensburg, Regensburg, Germany

[2]Department of Accounting, HEC Lausanne – University of Lausanne, Lausanne, Switzerland

[3]Ingolstadt School of Management, Catholic University Eichstätt-Ingolstadt, Ingolstadt, Germany

[4]Department of Finance, Accounting and Taxation, Free University of Berlin, Berlin, Germany

Correspondence
Tobias Steindl, Professorship of Corporate Social Responsibility Control, Reporting and Governance, University of Regensburg, Universitätsstrasse 31, 93053 Regensburg, Germany.
Email: tobias.steindl@ur.de

Editor Managing Review: Junming Zhu

Abstract

Carbon disclosures are essential for investors to evaluate firms' efforts to combat climate change. In this study, we focus on a specific type of carbon disclosures—namely, emission allowance disclosures—that capture how firms implement emission reductions under the European Union emission trading system (EU ETS). Given the continuously changing institutional features of the EU ETS and the lack of authoritative guidance on how firms should account for emission allowances in their financial statements, it is exceedingly difficult for investors to understand *numerical* emission allowance disclosures and to compare them across—and even within—firms. Motivated by this criticism, we hypothesize and find that textual disclosures *complementing* numerical emission allowance disclosures are associated with lower information asymmetries between firms and their investors. Further analyses show that textual disclosures that: (i) describe the *accounting approach*, and (ii) contain *institutional information* on the EU ETS, respectively, are particularly important for improving the information environment of numerical emission allowance disclosures. Overall, our findings suggest that text can improve the understanding of numbers in a carbon disclosure context. Therefore, our study not only contributes to the (industrial ecology) literature but also has important implications for regulators, policymakers, investors, financial analysts, and firms.

KEYWORDS
carbon accounting, climate change, emission allowances, emissions trading system, industrial ecology, information asymmetry

1 | INTRODUCTION

Greenhouse gas emissions (emissions hereafter) must reach net-zero in the near term to limit global warming to 1.5°C above pre-industrial levels (IPCC, 2018; IPCC, 2023; Klaaßen & Stoll, 2021; Zaklan et al., 2021). To achieve that goal, carbon pricing programs have gained momentum worldwide, particularly in the form of emission trading system (ETS) (Zhu et al., 2019, 2022). Currently, 37 different ETS are in operation worldwide, with the ETS of the European Union (EU ETS) being the second largest (Dechezleprêtre et al., 2023; ICAP, 2023). Established in 2005, the EU ETS covers approximately 40% of the EU's emissions and is the cornerstone of the EU's climate policy (García et al., 2021; Känzig, 2023).

The EU ETS operates under a cap-and-trade principle, where a cap is set on the total amount of greenhouse gases that can be emitted. Every year, the cap is reduced, so total emissions decrease. To implement the cap, emission allowances are allocated among firms covered by the EU ETS.[1] *Each* allocated emission allowance gives a firm the right to emit 1 metric ton of greenhouse gases. If a firm reduces its emissions below the amount covered by the allocated allowances, it can either keep the spare allowances for future needs or sell them on the market. If a firm produces more emissions than covered by the allocated allowances, it must buy additional emission allowances on the market. The market establishes the price of emission allowances (European Commission, 2023; Känzig, 2023; Lazzini et al., 2021).

To understand the financial and regulatory consequences of firms' emissions, investors rely on emission allowance disclosures provided by firms in annual reports (Basse Mama & Mandaroux, 2022; Johnston et al., 2008). Emission allowances are generally disclosed *numerically* (Ertimur et al., 2020; Kim et al., 2023).[2] However, there is no authoritative guidance—for example, in the form of an accounting standard—on how emission allowances should be disclosed numerically in annual reports (Hombach & Sellhorn, 2022; IFRS Foundation, 2014; Lovell et al., 2013). This lack of authoritative guidance has resulted in up to 15 different accounting approaches, making it challenging for investors to compare numerical emission allowance disclosures across firms (Black, 2013; IFRS Foundation, 2014; PWC, 2007). Furthermore, the constantly changing institutional features of the EU ETS affect the measurement of numerical emission allowance disclosures, which, in turn, reduces their consistency. Context is often needed to fully understand the financial, regulatory, and strategic implications of numerical emission allowance disclosures. In a nutshell, the literature currently criticizes numerical emission (allowance) disclosures for lacking comparability, consistency, and understandability (Allini et al., 2018; Busch et al., 2022; Ertimur et al., 2020; Glenk, 2023; Haupt & Ismer, 2013; Kim et al., 2023; Klaaßen & Stoll, 2021; Luers et al., 2022). Motivated by this criticism, our study asks: Are *textual* disclosures that complement *numerical* emission allowance disclosures associated with lower information asymmetry between a firm and its investors?

To answer this question, we employ a vocabulary-based information retrieval algorithm to extract sentences from firms' annual reports that complement numerical emission allowance disclosures. Based on a sample of EU ETS firms between 2008 and 2020, we show that textual disclosures that complement numerical emission allowance disclosures are indeed associated with lower information asymmetry. Focusing on specific content, we find that the negative association is even stronger for textual disclosures that: (i) describe the *accounting approach*, and (ii) contain *institutional information* on the EU ETS, respectively. An instrumental variable (IV) approach indicates causality. Our auxiliary sentiment analysis shows that neither a positive nor negative tone is associated with lower information asymmetry. Rather, textual disclosures written in a neutral and fact-based manner are associated with lower information asymmetry. This supports our main findings that the *content* is important to investors. Last, our auxiliary media analysis extends the perspective from investors to another stakeholder group—namely, the general public—and reveals that (institutional) textual disclosures are associated with higher media coverage, indicating reduced information asymmetry between firms and the general public.

Our study contributes to the literature in several distinct ways. First, we contribute to the overarching literature in industrial ecology—and related fields—on the financial implications of carbon performance and disclosures (Alsafi et al., 2020; Bendig et al., 2023; Busch & Lewandowski, 2018). Specifically, we introduce an unexplored dimension to the stream of literature investigating the association between carbon disclosures and information asymmetry (Borghei et al., 2018; Schiemann & Sakhel, 2019): textual disclosures complementing numerical carbon disclosures. Thereby, we directly respond to calls for more nuanced research on the financial consequences of carbon disclosures (Velte et al., 2020). Second, we contribute to studies that evaluate different approaches to how firms should account for emission allowances in their financial statements (Ertimur et al., 2020; Giner, 2014; Haupt & Ismer, 2013). While these studies propose a specific accounting approach to regulators, our findings suggest that if authoritative guidance is missing, textual disclosures explaining the accounting approach should be required. Thus, we address a recent call for research on how the (unregulated) information environment of carbon disclosures can be improved (Borghei, 2021). Third, we contribute to the EU ETS literature by showing that it is important for investors to understand how the (continuously changing) institutional features of the EU ETS affect numerical emission allowance disclosures (Clarkson et al., 2015; García et al., 2021; Känzig, 2023). Fourth, our study contributes to the literature studying the relevance of sustainability disclosures to non-financial stakeholders, such as the general public (Axjonow et al., 2018). Fifth, we contribute to the carbon disclosure literature by using an IV approach to address causality. In doing so, we directly respond to Velte et al. (2020), who state that future carbon disclosure research should address causality issues by employing, for example, an IV approach.[3] Finally, our study informs the vigorous discourse in industrial ecology—and beyond—on how to improve the quality of carbon performance data (Busch et al., 2022; Luers et al., 2022; Sullivan & Gouldson, 2012).

2 | LITERATURE AND HYPOTHESES DEVELOPMENT

Agency theory suggests that information asymmetry exists between a firm's management with superior information and its information-disadvantaged investors (Barth et al., 2017; Jensen & Meckling, 1976). This can induce adverse selection, which, in turn, reduces liquidity and increases the return investors demand to compensate for risk (Amihud & Mendelson, 1986; Christensen et al., 2021; Constantinides, 1986). Prior analytical research shows that corporate disclosures are a mechanism managers can use to reduce information asymmetry (Diamond & Verrecchia, 1991; Verrecchia, 2001). Several empirical studies provide evidence that corporate *financial* as well as *sustainability* disclosures

are associated with lower information asymmetry (Barth et al., 2017; Cormier et al., 2011; Fuhrmann et al., 2017; Leuz & Verrecchia, 2000; Martínez-Ferrero et al., 2016; Romito & Vurro, 2021). Most closely related to our study, Borghei et al. (2018) show that *carbon disclosures* are associated with lower information asymmetry. Schiemann and Sakhel (2019) extend this study by focusing on specific carbon disclosures (i.e., climate change-related physical risk disclosures) and provide evidence that the association between these disclosures and information asymmetry is only negative for firms affected by the EU ETS.[4] In their systematic literature review, Velte et al. (2020) summarize a negative association between carbon disclosures and information asymmetry.

Most prior empirical research on corporate disclosures does *not* distinguish between numerical and textual disclosures (Borghei et al., 2018; Dhaliwal et al., 2012; Doan & Sassen, 2020; Goettsche et al., 2016; Muslu et al., 2019; Schiemann & Sakhel, 2019), and if they do, they focus *either* on numerical *or* textual ones (Du & Yu, 2021; Griffin et al., 2017; Lang & Stice-Lawrence, 2015; Zhou et al., 2024). Only recently, scholars have begun to examine the *interrelation* between numerical and textual disclosures. Ahn et al. (2022) and Siano and Wysocki (2018) examine the prevalence of numbers within textual disclosure, while Allee et al. (2023) and Kim and Nikolaev (2024) focus on the narrative context around numbers. Furthermore, Burd et al. (2024) examine the textual discussion of numbers in financial statements. These studies provide evidence that the interrelation between numerical and textual *financial* disclosures (e.g., tax disclosures) is associated with an improved information environment.

Drawing on the literature discussed, we argue that textual disclosures are beneficial in understanding firms' numerical *emission allowance* disclosures.[5] First, textual disclosures that supplement numerical ones can provide clarity and context, which cannot be directly inferred from numerical disclosures alone (Burd et al., 2024; Li, 2008). Since emission allowances are a highly technical and complex metric for investors to understand (Depoers et al., 2016; Ertimur et al., 2020; Kim et al., 2023), providing insightful context to disclosed numbers can be highly beneficial. Second, textual disclosures can facilitate the comparability of numerical disclosures across firms. Given that comparability has been identified as one of the key concerns of sustainability disclosures (Amel-Zadeh & Serafeim, 2018; Busch et al., 2022; European Commission, 2020; Glenk, 2023), textual disclosures can allow investors to identify similarities or differences between firms' numerical emission allowance disclosures (PWC, 2007). Third, the consistency of numerical emission allowance disclosures over time is another major concern (PWC, 2007). By documenting *changes* in methods, the data (generating process), or any other relevant factors in the time series, textual disclosures can contribute to a better understanding of numerical disclosures within the same firm over time (Glenk, 2023). Fourth, whether firms increase or decrease emissions can be derived from numerical emission disclosures (Griffin et al., 2017; Matsumura et al., 2014), but additional textual disclosures are needed to allow investors to understand a firm's emission reduction *strategy*, such as whether the firm holds emission allowances for compliance purposes, or whether it reduces emissions and sells excess allowances. Consequently, we formally state our first hypothesis (H1) as follows.

H1: Textual disclosures related to firms' numerical emission allowance disclosures are associated with lower information asymmetry.

Next, we focus on *specific content* within the textual disclosures—namely, textual disclosures describing the *accounting approach* underlying the numerical emission allowance disclosure. We argue that describing the accounting approach is particularly important in reducing information asymmetry since neither the International Accounting Standards Board (IASB) nor the Financial Accounting Standards Board (FASB) provide authoritative guidance on how firms shall account for emission allowances in their financial statements (Black, 2013; IFRS Foundation, 2014; Lovell et al., 2013).[6] This lack of authoritative guidance—for example, in the form of an accounting standard—has forced firms to develop their own solutions, which has resulted in a high degree of latitude in accounting approaches (Allini et al., 2018; Black, 2013; Warwick & Ng, 2012). In fact, firms have applied as many as 15 different accounting approaches, making it very difficult for investors to compare emission allowances across firms without textual disclosures explaining the accounting approach applied (IFRS Foundation, 2014; PWC, 2007). Therefore, practitioners have called for textual disclosures that describe the accounting approach. Specifically, textual disclosures should draw together the key accounting line items that are affected by emission allowances, so investors can understand the financial impact on the firm (PWC, 2007). In a nutshell, textual disclosures describing the accounting approach might increase the relevance, comparability, and transparency of the numerical emission allowance disclosures, thereby increasing their usefulness to investors. This leads us to our second hypothesis (H2), which formally reads as follows.

H2: Textual disclosures describing the *accounting approach* underlying the numerical emission allowance disclosures are associated with lower information asymmetry.

Another specific type of content we focus on is *institutional information*—that is, how the firm is affected by the regulations, policies, and institutional features of the EU ETS. Given the learning-by-doing approach of the EU ETS, firms have had to adapt very quickly to its continuously changing regulations, policies, and institutional features. In fact, 126 regulatory updates—mainly concerning the supply of emission allowances—were issued between 2005 and 2019 (Känzig, 2023). These regulatory changes may influence the measurement of emission allowances, and, thereby, affect numerical emission allowance disclosures. Hence, explaining how a regulatory update affects numerical emission allowance disclosures should be important for investors to appropriately compare the disclosed numbers *within the same firm over time*. Furthermore, textually disclosing how a firm deals with such regulatory updates should be relevant to investors because deficient allowances to cover emissions are enforced heavily with fines (Känzig, 2023). In addition, EU ETS regulations, policies, and institutional features might affect a firm's risk profile, competitiveness, and

allowance trading strategy, which, in turn, are essential aspects of investment (risk) decisions (Hoffmann, 2007; Sprengel & Busch, 2011; Vespermann & Wittmer, 2011). Survey evidence shows that 33% of EU firms regard the transition to stricter climate regulations as a risk, while 29% see it as an opportunity to improve their competitiveness (European Investment Bank, 2023). Since information on risks, competitiveness, and allowance trading strategies cannot be inferred from numerical disclosures (alone), additional textual disclosures on these matters should benefit investors. Based on these grounds, we formally propose our third hypothesis (H3) as follows.

H3: Textual disclosures containing *institutional information* related to firms' numerical emission allowance disclosures are associated with lower information asymmetry.

3 | DATA AND METHODOLOGY

3.1 | Sample and data

Our sample focuses on firms listed on the STOXX Europe 600 index. For the years 2005 (i.e., the launch of the EU ETS) to 2020, we collect EU ETS data from the EU Transaction Log (EUTL) and euets.info.[7] Using a multi-level matching approach, we aggregate verified emissions, allocated emission allowances, and surrendered emission allowances from the installation level to the (STOXX Europe 600) firm level. Data for our outcome variable and control variables are collected from Refinitiv Eikon. We exclude STOXX Europe 600 firms: (i) that are not parent firms, (ii) with no information on emission allowances, and (iii) operating in the aviation industry.[8] For the resulting 158 STOXX Europe firms, we observe 2528 observations (i.e., firm-years). Excluding firm-years (i) from financial institutions,[9] (ii) with missing data on firm-level variables, and (iii) for years before 2008[10] yields a *baseline* sample of 1255 firm-years. Supporting Information S1 describes the sample selection process in detail.

Using firms' annual reports, we identify firm-years with *numerical* emission allowance disclosures under the EU ETS. This yields 967 firm-years in our disclosure sample (i.e., *main* sample). To identify firm-years with *textual* disclosures related to firms' numerical emission allowance disclosures, we apply a vocabulary-based approach that identifies sentences with narrative information related to firms' numerical emission allowance disclosures; 542 firm-years provide such textual disclosures. Our vocabulary-based approach is outlined in Supporting Information S2.

3.2 | Measures

3.2.1 | Outcome variable

To measure firm-level information asymmetry, we follow prior literature and use the bid-ask spread, which represents the difference between the highest price a buyer is willing to pay (bid) and the lowest price a seller is willing to accept (ask) for a particular share (Leuz & Verrecchia, 2000; Schiemann & Sakhel, 2019). The bid-ask spread serves as a proxy for information asymmetry because wider spreads typically indicate greater uncertainties or disparities in the information of buyers and sellers regarding the value of a firm's share. Conceptually, the bid-ask spread is smaller when the adverse selection component of the cost of capital is smaller (Glosten & Milgrom, 1985; Schiemann & Sakhel, 2019). We define INFOASY as the natural logarithm of firm *i*'s median daily relative bid-ask spread over the 365-day period following the firm *i*'s earnings announcement date of financial year *t*. A higher value indicates higher information asymmetry.

3.2.2 | Test variables

We utilize a vocabulary-based approach specifically designed to identify and extract sentences from annual reports related to numerical emission allowance disclosures under the EU ETS.[11] Supporting Information S2 describes this vocabulary-based approach in detail. Based on the sentences retrieved, we construct our test variables.

Our first test variable TEXT captures the number of sentences in an annual report containing *any* narrative information related to firms' *numerical* emission allowance disclosures.[12] Our second test variable TEXT_ACC is a subset of TEXT and focuses on the number of sentences that describe the *accounting approach* (e.g., measurement, recognition, treatment) underlying the numerical emission allowance disclosures.[13] Our third test variable TEXT_INST is also a subset of TEXT and focuses on the number of sentences that contain *institutional* information related to firms' numerical emission allowance disclosures, such as: (i) how the firm is affected by (updated) regulations of the EU ETS, (ii) how the firm is responding to (continuously changing) institutional features of the EU ETS, (iii) how the firm monitors its emissions to ensure that all emissions are covered by allowances, or (iv) how the firm deals with specific risks (or opportunities) emanating from the EU ETS.[14]

3.2.3 | Control variables

We control for a series of observable firm characteristics with potential influence on information asymmetry and emission allowance disclosures: firms' share price (PRICE), firms' share turnover (SHARETURN), market capitalization (SIZE), emission score (EMISSIONSCORE), disclosure policy index (DISCLPOL), market-to-book ratio (MTB), analyst coverage (ANALYST), debt-to-equity ratio (LEVERAGE), negative income (LOSS), number of operating segments (COMPLEXITY), and the variability of share return (VOLATILITY). These control variables are derived from prior studies investigating information asymmetry (Barth et al., 2017; Muller et al., 2011; Schiemann & Sakhel, 2019). Table 1 defines the control variables.

3.3 | Model specification

To test our hypotheses, we estimate the following regression model:

$$\text{INFOASY}_{\text{ijct}} = \beta_1(\text{TEXT or TEXT\_ACC or TEXT\_INST})_{\text{ijct}} + \beta_2' \mathbf{X}_{\text{ijct}} + \gamma_j + \varphi_c + \omega_t + \varepsilon_{\text{ijct}}, \quad (1)$$

where *i* indexes firms, *j* indexes industries, *c* indexes countries, and *t* indexes years. INFOASY is the outcome variable, denoting information asymmetry. The test variable is either TEXT, TEXT_ACC, or TEXT_INST, denoting the extent (of the different content) of textual disclosures, respectively. $\boldsymbol{X}$ is a vector of firm-level control variables. γ are industry fixed effects. φ are country fixed effects. ω are year fixed effects. ε is the error term. Standard errors are robust standard errors adjusted for clustering at the firm and year level (Gow et al., 2010).

4 | RESULTS

4.1 | Descriptive statistics

Table 2 reports the descriptive statistics. Our first test variable TEXT has a mean of approximately 4 sentences, a maximum of 35 sentences, and a minimum of 0 sentences. Our second test variable TEXT_ACC has a mean of approximately 2 sentences, a maximum of 23 sentences, and a minimum of 0 sentences. Our third test variable TEXT_INST has a mean of approximately 1 sentence, a maximum of 12 sentences, and a minimum of 0 sentences. Given the relatively moderate number of sentences covered by our test variables, we conclude that an *overload* of textual information appears not to be the case, and, hence, is not given any further attention.

Table 3 shows the correlation matrix. The pairwise correlation coefficients among the control variables do not exceed |0.50|, except for the pairs SHARETURN and PRICE ($\rho = -0.511$), and SHARETURN and SIZE ($\rho = -0.607$), respectively. Removing SHARETURN does not change the direction and significance of our main findings. Furthermore, the variance inflation factors reported in Table 4 are well below the critical threshold of 10. We conclude that our specified model is unlikely to be subject to multicollinearity.

4.2 | Main results

Table 4 presents our main findings. Column (1) shows that *textual* disclosures related to firms' numerical emission allowance disclosures are associated with lower information asymmetry. The negative coefficient of TEXT is statistically significant at the 1% level and economically sizable. Specifically, the disclosure of every additional sentence (ΔTEXT = 1) is associated with a 1% decrease (= [exp(−0.010)−1] × 100) of the bid-ask spread (INFOASY), ceteris paribus. This finding supports our first hypothesis (H1).

Turning to column (2), we find that textual disclosures describing the *accounting approach* underlying the numerical emission allowance disclosures are associated with lower information asymmetry. The negative coefficient of TEXT_ACC is statistically significant at the 1% level and economically stronger than the coefficient of TEXT. In particular, the disclosure of every additional accounting-related sentence (ΔTEXT_ACC = 1) is associated with a 1.88% decrease (= [exp(−0.019)−1] × 100) of the bid-ask spread (INFOASY), ceteris paribus. This finding supports our second hypothesis (H2) and indicates that textual disclosures describing the *accounting approach* are more relevant than textual disclosures containing *any type of information* related to firms' numerical emission allowance disclosures.

Looking at column (3), we find that textual disclosures containing *institutional information* related to firms' numerical emission allowance disclosures are associated with lower information asymmetry. The negative coefficient of TEXT_INST is statistically significant at the 5% level and economically stronger than the coefficient of TEXT_ACC. Specifically, the disclosure of every additional sentence that contains institutional information (ΔTEXT_INST = 1) is associated with a 2.27% decrease (= [exp(−0.023)−1] × 100) of the bid-ask spread (INFOASY), ceteris paribus. This

TABLE 1 Variable descriptions.

Variable	Description	Data source
Outcome variable		
INFOASY	Natural logarithm of the median daily bid-ask spread, computed as the closing bid price minus the closing ask price divided by the average of the closing bid and ask price and multiplied by 100. Measurement period: 365 days period following the firm's earnings announcement date of financial year *t*.	Refinitiv Eikon
Test variables		
TEXT	The number of sentences in the firm's annual report in year *t* that is related to numerical emission allowance disclosures.	Hand-collected and calculated
TEXT_ACC	The number of sentences in the firm's annual report in year *t* that describes the accounting approach underlying the numerical emission allowance disclosures.	Hand-collected and calculated
TEXT_INST	The number of sentences in the firms' annual report in year *t* that contains institutional information related to the numerical emission allowance disclosures.	Hand-collected and calculated
Control variables		
PRICE	The firm's share price measured as the annual median of the logarithm of the daily share price. Measurement period: 365 days period following the firm's earnings announcement date of financial year *t*−1.	Refinitiv Eikon
SHARETURN	The firm's share turnover measured as the logarithm of the annual trading volume in US dollars divided by the market value of common equity. Measurement period: 365 days period following the firm earnings announcement date of financial year *t*−1.	Refinitiv Eikon
MTB	Natural logarithm of the firm's market capitalization divided by its total book value.	Refinitiv Eikon
SIZE	Natural logarithm of the firm's market capitalization.	Refinitiv Eikon
COMPLEXITY	Number of operating segments in which a company reports revenues according to IFRS 8.	Refinitiv Eikon
ANALYST	The average number of analysts providing earnings per share (EPS) forecasts for year *t* during the 180-day period following the previous financial year's earnings announcement.	Refinitiv Eikon
DISCLPOL	We construct a disclosure policy index based on earnings quality, the change in EPS, and a corporate governance score. We measure earnings quality with discretionary accruals based on the modified Jones (1991) model by Dechow et al. (1995). The change in EPS is calculated as the difference in EPS from year *t*−1 to year *t*. Finally, the corporate governance score is obtained from the Refinitiv Eikon database. We rank the three variables into deciles with the most transparent firms taking a value of 10 and the most opaque a value of 1. The rankings are then summed and divided by 30 to obtain an index that ranges from 0.1 to 1.0.	Refinitiv Eikon and calculated
EMISSIONSCORE	Emission category score measures the firm's commitment and effectiveness toward reducing emissions in the production and operational processes.	Refinitiv Eikon
LEVERAGE	Debt-to-equity ratio.	Refinitiv Eikon
LOSS	An indicator variable that equals 1 if the firm reports negative income in year *t*, and 0 otherwise.	Refinitiv Eikon
VOLATILITY	The variability of share return measured as the standard deviation of daily share returns over the past year.	Refinitiv Eikon
Variables for robustness tests		
ALLOC	Natural logarithm of one plus the allocated emission allowances in millions.	EUTL and euets.info
DISCL	An indicator variable that equals 1 if the firm provides numerical emission allowance disclosures in year *t*, and 0 otherwise.	Refinitiv Eikon and hand-collected
MILLS	Inverse Mills ratio calculated from the first-stage regression estimates of the Heckman self-selection model.	Calculated
PEER_TEXT	Country-industry mean (excluding the focal firm) of the variable TEXT.	Calculated
PEER_TEXT_ACC	Country-industry mean (excluding the focal firm) of the variable TEXT_ACC.	Calculated
PEER_TEXT_INST	Country-industry mean (excluding the focal firm) of the variable TEXT_INST.	Calculated
Variables for auxiliary analyses		
TEXT_POSITIVE	The percentage of sentences (identified for the variable TEXT) that have a positive tone. The sentence classification is performed with the pre-trained FinBERT language model.	Hand-collected and calculated

(Continues)

TABLE 1 (Continued)

Variable	Description	Data source
TEXT_NEUTRAL	The percentage of sentences (identified for the variable TEXT) that have a neutral tone. The sentence classification is performed with the pre-trained FinBERT language model.	Hand-collected and calculated
TEXT_NEGATIVE	The percentage of sentences (identified for the variable TEXT) that have a negative tone. The sentence classification is performed with the pre-trained FinBERT language model.	Hand-collected and calculated
MEDIA	Natural logarithm of one plus the number of media items (e.g., newspaper articles) mentioning the name of the firm *and* at least one of the following search strings: "emission right," "eu ets," "trading scheme," "emission trading," "carbon accounting," "ifric 3," "emission allowance," "CO_2 allowance," "carbon allowance," "pollution pricing," and "pollutant pricing mechanism." Measurement period: 365 days period following the firm's earnings announcement date of financial year *t*.	Nexis and Refinitiv Eikon

Note: All variables with no natural upper and lower bounds are winsorized at extreme percentiles.

TABLE 2 Descriptive statistics.

Variable	*N*	Mean	SD	MIN	MAX
INFOASY	967	−3.069	0.718	−4.319	−1.516
TEXT	967	3.854	5.206	0.000	35.000
TEXT_ACC	967	2.053	3.097	0.000	23.000
TEXT_INST	967	1.123	1.828	0.000	12.000
PRICE	967	2.885	1.159	0.861	4.856
SHARETURN	967	1.206	0.118	1.012	1.433
SIZE	967	16.677	1.182	14.614	18.720
EMISSIONSCORE	967	82.739	15.584	15.000	99.760
DISCLPOL	967	0.572	0.161	0.100	1.000
MTB	967	2.015	1.285	0.660	6.870
ANALYST	967	21.437	7.115	9.000	33.000
LEVERAGE	967	94.666	69.940	14.550	284.070
LOSS	967	0.040	0.197	0.000	1.000
COMPLEXITY	967	4.882	1.758	1.000	8.000
VOLATILITY	967	0.019	0.008	0.007	0.063

Note: This table reports the number of firm-years (*N*), mean, standard deviation (SD), minimum, and maximum for each variable in our main sample (i.e., disclosure sample). Please see Table 1 for variable definitions.

finding supports our third hypothesis (H3) and suggests that *institutional-oriented* textual disclosures are even more relevant than *accounting-related* textual disclosures.

5 | ROBUSTNESS

In this section, we conduct several robustness tests that address the following endogeneity concerns: omitted variables, self-selection, and causality.

5.1 | Omitted variables

To assess the robustness of our findings to an omitted variable bias, we implement the bounding methodology proposed by Oster (2019). This methodology allows us to estimate how large the impact of unobservables (i.e., omitted variables) relative to observables (i.e., the included control variables and fixed effects)—denoted as δ—needs to be to drive the coefficients of our test variables to zero ($\beta_1 = 0$). We find that it is unlikely that the coefficient estimates of our test variables are driven by omitted variables, as the untabulated δ for all models is well above the threshold of 1 as recommended by Oster (2019). To be more precise, unobservables would need to be more than three times ($\delta = 3.16$) as important as the included observables to produce an effect of zero for our test variable TEXT.

TABLE 3 Correlation matrix.

#	Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1)	INFOASY														
(2)	TEXT	**−0.059**													
(3)	TEXT_ACC	**−0.056**	**0.858**												
(4)	TEXT_INST	**−0.064**	**0.797**	**0.550**											
(5)	PRICE	**−0.136**	−0.017	**0.055**	−0.037										
(6)	SHARETURN	**−0.212**	**0.068**	0.035	**0.087**	**−0.511**									
(7)	SIZE	**−0.085**	−0.022	−0.043	−0.013	0.031	**−0.607**								
(8)	EMISSIONSCORE	**−0.119**	−0.037	−0.047	−0.044	−0.002	**−0.110**	0.296							
(9)	DISCLPOL	**−0.082**	**0.170**	**0.153**	**0.111**	**−0.076**	−0.033	**0.208**	**0.181**						
(10)	MTB	0.004	**−0.177**	**−0.139**	**−0.156**	**0.108**	**−0.196**	**0.18**	0.039	**−0.099**					
(11)	ANALYST	0.024	−0.042	−0.050	−0.006	−0.014	**−0.356**	**0.478**	**0.188**	0.045	0.041				
(12)	LEVERAGE	0.007	−0.049	−0.050	**−0.064**	**0.097**	**0.062**	**−0.123**	0.015	**−0.094**	**0.176**	−0.003			
(13)	LOSS	−0.020	**0.144**	0.025	**0.130**	0.004	**0.066**	**−0.099**	**−0.067**	**−0.080**	**−0.098**	0.007	0.031		
(14)	COMPLEXITY	0.041	**0.099**	**0.100**	**0.057**	0.044	**−0.122**	**0.098**	**0.069**	0.052	**−0.130**	**0.103**	**0.165**	**0.068**	
(15)	VOLATILITY	**0.061**	0.019	0.024	0.024	0.005	**0.228**	**−0.355**	**−0.180**	**−0.212**	**−0.298**	**−0.136**	**0.075**	**0.146**	0.052

Note: This table reports the Pearson correlation coefficients (ρ). The number of firm-years (N) is 967. Please see Table 1 for variable definitions. Values in boldface denote statistical significance at the 5% level.

To further mitigate concerns of an omitted variable bias, we rerun Equation (1) with firm fixed effects instead of country and industry fixed effects. In doing so, we account for unobserved, time-invariant differences across firms. It is important to note that—given the size of our main sample—the introduction of firm fixed effects risks overspecifying our model. Table 5 shows the estimates of the firm fixed effects regressions. The coefficients of our test variables are similar to those reported in Table 4.

5.2 | Self-selection

The disclosure sample (i.e., our main sample) is not randomly selected because firms themselves decide (i.e., self-selection decision) whether to provide numerical emission allowance disclosures. This endogenous sampling raises the concern of a self-selection bias. The standard approach to address such a bias is to perform a two-stage Heckman (1979) self-selection model. In the first stage probit regression, we estimate the probability of firms' self-selection into the disclosure sample (i.e., DISCL = 1) using an instrument. Specifically, we choose ALLOC as our selection IV, defined as the natural logarithm of one plus the number of EU ETS emission allowances allocated to firm *i* in year *t*. In Supporting Information S3, we demonstrate that ALLOC is a valid instrument since it fulfills both the relevance and exclusion conditions. With respect to the exclusion condition, we acknowledge that ALLOC is potentially only *partially* exogenous, as it may be determined not only by exogenous factors (e.g., regulatory shocks) but also by endogenous firm characteristics (e.g., firms' prior emission levels).[15] Supporting Information S3 also provides the estimates of the first-stage regression.

Based on the first-stage regression estimates, we calculate the inverse Mills ratio (MILLS) and include it in the second-stage (outcome) regressions. In doing so, we control for a potential self-selection bias. Table 6 reports the estimates of the second-stage regressions. The coefficients for MILLS are statistically significant at the 1% level in all three outcome regressions, indicating the presence of a self-selection bias. However, the coefficients of our test variables have the same signs and significance levels as in Table 4. In addition, the coefficient magnitudes are very similar to those reported in Table 4. Hence, we conclude that our main findings are robust to a Heckman self-selection model.

5.3 | Causality

Our main findings do not allow for a causal interpretation. This is because disclosing (different content of) textual information is an endogenous decision and, thereby, not random. To circumvent this endogeneity issue, we employ a two-stage IV approach. In the first stage, we instrument our test variables using two instruments—namely, ALLOC and PEER. The definition of ALLOC is the same as in Section 5.2.[16] PEER is defined as the country-industry mean (excluding the focal firm) of the respective test variable *to be* instrumented (i.e., TEXT, TEXT_ACC, and TEXT_INST).

TABLE 4 Main results.

	(1) INFOASY	(2) INFOASY	(3) INFOASY
TEXT	−0.010***		
	(0.004)		
TEXT_ACC		−0.019***	
		(0.006)	
TEXT_INST			−0.023**
			(0.011)
PRICE	−0.380***	−0.375***	−0.380***
	(0.022)	(0.022)	(0.022)
SHARETURN	−5.112***	−5.093***	−5.118***
	(0.303)	(0.303)	(0.304)
SIZE	−0.310***	−0.308***	−0.312***
	(0.036)	(0.036)	(0.035)
EMISSIONSCORE	−0.004***	−0.004***	−0.004***
	(0.001)	(0.001)	(0.001)
DISCLPOL	0.054	0.054	0.039
	(0.129)	(0.129)	(0.129)
MTB	0.005	0.005	0.006
	(0.018)	(0.018)	(0.018)
ANALYST	−0.001	0.000	−0.001
	(0.004)	(0.004)	(0.004)
LEVERAGE	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
LOSS	0.032	0.004	0.016
	(0.107)	(0.109)	(0.106)
COMPLEXITY	0.010	0.011	0.010
	(0.011)	(0.011)	(0.011)
VOLATILITY	11.563***	11.482***	11.806***
	(4.106)	(4.101)	(4.109)
Country fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.44	0.44	0.44
Highest VIF	2.75	2.75	2.76
N	967	967	967

Note: This table reports coefficients and standard errors (in parentheses) from ordinary least squares (OLS) regressions. Fixed effects are included as indicated. Standard errors are robust standard errors adjusted for clustering at the firm and year levels. Please see Table 1 for variable definitions.
Abbreviation: VIF, variance inflation factor.
Statistical significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

In Supporting Information S3, we demonstrate the validity and discuss the limitations of our chosen IVs. Furthermore, Supporting Information S3 provides the estimates of the first-stage regressions.

We include the predicted values from the first stage (i.e., $\widehat{\text{TEXT}}$, $\widehat{\text{TEXT\_ACC}}$, and $\widehat{\text{TEXT\_INST}}$) in our second-stage regressions. Table 7 shows the estimates of the second-stage regressions. The coefficients of our test variables have the same signs as in Table 4 and remain statistically significant at conventional levels. The coefficient magnitudes are considerably larger than those reported in Table 4, indicating that our main results are rather conservative. Overall, the estimates of our IV approach suggest a causal link between our test variables and INFOASY, respectively.

TABLE 5 Robustness: Firm fixed effects.

	(1) INFOASY	(2) INFOASY	(3) INFOASY
TEXT	−0.009**		
	(0.004)		
TEXT_ACC		−0.017***	
		(0.006)	
TEXT_INST			−0.022**
			(0.011)
Control variables	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.65	0.65	0.65
N	967	967	967

Note: This table reports coefficients and standard errors (in parentheses) from ordinary least squares (OLS) regressions. Fixed effects are included as indicated. Standard errors are robust standard errors adjusted for clustering at the firm and year levels. Please see Table 1 for variable definitions. Statistical significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

6 | AUXILIARY ANALYSES

6.1 | Sentiment analysis

So far, we have provided evidence that the *content* of textual disclosures is associated with lower information asymmetry. Now, we examine whether the *sentiment* of these disclosures also matters. Sentiment refers to the tone of a text—that is, positive, negative, or neutral—which reveals *how* specific content is being disclosed. Since measuring sentiment requires a more contextualized and complex understanding of language, we rely on a deep learning model for natural language processing, called FinBERT (Huang et al., 2023). FinBERT is particularly well suited for this type of analysis since it outperforms dictionary-based methods and other machine learning algorithms in its sentiment classification (Huang et al., 2023).[17] We apply the already pre-trained model for the sentiment task and classify our retrieved sentences into sentences with a positive, negative, and neutral tone.[18]

Panel A of Table 8 shows the results of our sentiment analysis. Looking at columns (1) and (2), we find that neither a positive nor negative tone is associated with information asymmetry. Turning to column (3), we find that a neutral tone is associated with lower information asymmetry. Collectively, these auxiliary findings support our main results that the *content*—presented in a neutral and fact-based manner—is important.[19]

6.2 | Media analysis

Next, we expand our perspective from investors to another stakeholder group: the *general public*. In particular, we examine whether and how textual disclosures related to firms' numerical emission allowance disclosures are associated with media coverage. A positive association would suggest that the information included in firms' textual emission allowance disclosures is picked up by the media and disseminated among the general public, reducing information asymmetry between firms and the general public.

We measure media coverage (MEDIA) as the natural logarithm of one plus the number of media items—such as newspaper articles or newswires—mentioning the name of the firm *and* at least one of the following search strings:[20] "emission right," "eu ets," "trading scheme," "emission trading," "carbon accounting," "ifric 3," "emission allowance," "CO_2 allowance," "carbon allowance," "pollution pricing," and "pollutant pricing mechanism." Identical to our main outcome variable INFOASY, the measurement period for MEDIA covers the 365 days following the firm's earnings announcement date of financial year *t*.

Panel B of Table 8 provides the results of our auxiliary media analysis. Column (1) shows that textual disclosures related to firms' numerical emission allowance disclosures are associated with higher media coverage. Turning to column (2), we find that textual disclosures that describe the *accounting approach* are not associated with media coverage. Instead, column (3) shows that textual disclosures that contain *institutional information* on the EU ETS are associated with higher media coverage. This suggests that institutional information included in firms' textual emission allowance disclosures is picked up by the media and included, for example, in newspaper articles, which, in turn, reduces information asymmetry between firms

TABLE 6 Robustness: Heckman self-selection model.

	(1) INFOASY	(2) INFOASY	(3) INFOASY
TEXT	−0.010***		
	(0.004)		
TEXT_ACC		−0.018***	
		(0.006)	
TEXT_INST			−0.025**
			(0.011)
MILLS	0.195***	0.191***	0.200***
	(0.045)	(0.045)	(0.045)
Control variables	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.45	0.45	0.45
Highest VIF	2.78	2.77	2.79
N (selected)	967	967	967
N (non-selected)	288	288	288
N	1255	1255	1255

Note: This table reports coefficients and standard errors (in parentheses) from second-stage Heckman self-selection regressions. The first stage is not shown but is provided in Supporting Information S3. The control variables are the same as in Table 3. Fixed effects are included as indicated. Standard errors are robust standard errors adjusted for clustering at the firm and year levels. The first stage is based on our baseline sample. Please see Table 1 for variable definitions.
Abbreviation: VIF, variance inflation factor.
Statistical significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

TABLE 7 Robustness: Instrumental variable (IV) model.

	(1) INFOASY	(2) INFOASY	(3) INFOASY
$\widehat{TEXT}$	−0.026***		
	(0.009)		
$\widehat{TEXT\_ACC}$		−0.028**	
		(0.013)	
$\widehat{TEXT\_INST}$			−0.129***
			(0.030)
Control variables	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.43	0.44	0.39
N	967	967	967

Note: This table reports coefficients and standard errors (in parentheses) from second-stage instrumental variable (IV) regressions. The first stage is not shown but is provided in Supporting Information S3. The control variables are the same as in Table 3. Fixed effects are included as indicated. Standard errors are robust standard errors adjusted for clustering at the firm and year levels. Please see Table 1 for variable definitions.
Statistical significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

TABLE 8 Auxiliary analyses.

Panel A: Sentiment analysis			
	(1)	**(2)**	**(3)**
	INFOASY	**INFOASY**	**INFOASY**
TEXT_POSITIVE	−0.001		
	(0.023)		
TEXT_NEGATIVE		−0.023	
		(0.025)	
TEXT_NEUTRAL			−0.013***
			(0.004)
Control variables	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.44	0.44	0.44
N	967	967	967
Panel B: Media analysis			
	(1)	**(2)**	**(3)**
	MEDIA	**MEDIA**	**MEDIA**
TEXT	0.026***		
	(0.009)		
TEXT_ACC		0.012	
		(0.015)	
TEXT_INST			0.077***
			(0.027)
Control variables	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.48	0.47	0.48
N	967	967	967

Note: This table reports coefficients and standard errors (in parentheses) from ordinary least squares (OLS) regressions. The control variables are the same as in Table 3. Fixed effects are included as indicated. Standard errors are robust standard errors adjusted for clustering at the firm and year levels. Please see Table 1 for variable definitions.
Statistical significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

and the general public. In essence, our auxiliary media analysis reveals that (institutional) textual disclosures related to firms' numerical emission allowance disclosures matter not only to investors but also to another stakeholder group: the general public.

7 | DISCUSSION

Our main findings suggest that textual disclosure can improve the information environment of numerical emission allowance disclosures under the EU ETS. Given the heterogeneity in ETS designs globally, we start by discussing our findings in the light of different regulatory environments. ETSs operate across varying levels of government (i.e., from the city level to the supranational level), cover more or fewer industries, and apply different allocation methodologies. In addition, the average price of emission allowances varies substantially—ranging from 1 USD per metric ton in the Kazakhstan ETS to 93 USD per metric ton in the UK ETS in 2022 (ICAP, 2023). We argue that our findings are more pronounced under stricter ETSs due to the financial materiality of emission allowances. Furthermore, we conjecture that our findings on textual *institutional* disclosures are more pronounced if an ETS is characterized by continuously changing regulations, policies, and institutional features. In a similar vein, we argue

that our results on textual *accounting* disclosures are more pronounced if no (specific) accounting standard is available. Given the high number of regulatory changes in almost every ETS and the absence of specific accounting standards for emission allowances around the world, our findings are extremely timely and have important practical implications. Nonetheless, we encourage future research to investigate non-EU carbon pricing programs with distinct institutional features.

Our findings have important implications for regulators, policymakers, investors, financial analysts, and firms. First, our results suggest that if financial reporting *regulators*—such as the IASB—are not providing specific authoritative guidance on how firms should account for emission allowances in their financial statements, they should (at least) require them to provide textual disclosures that describe the accounting approach underlying the numerical emission allowance disclosures. Such an (interim) solution is particularly pressing since the IASB has deferred its standard-setting project on pollutant pricing mechanisms until at least 2027 (IFRS Foundation, 2022). Thus, our findings also respond to the IASB's call that it "would benefit from research that is more focused on issues relevant to forthcoming IASB decisions" (Teixeira, 2014, p. 9). Second, the European Financial Reporting Advisory Group (EFRAG) might consider our findings in further developing the European Sustainability Reporting Standards (ESRS). Concerning ESRS E1-9, the EFRAG might contemplate requiring not only the mere number of emission allowances but also textual disclosures on the financial implications. Third, our findings support the European Securities and Markets Authority's (ESMA) current enforcement priorities, which include firms' (textual) disclosures explaining the accounting policies underlying the recognition, measurement, and presentation of emission allowances (ESMA, 2023). Fourth, our results imply that *policymakers* of carbon pricing programs can use firms' textual disclosures that contain institutional information to evaluate how policy changes affect, for example, the financial risk profile of firms. Policymakers may also use textual emission allowance disclosures to assess and better understand (the effectiveness of) certain policy changes. Fifth, our findings imply that *investors* and *financial analysts* should not only include numerical emission allowance information in their models—for example, to compute earnings forecasts—but also adjust these numbers by using textual accounting and institutional information. Finally, our study has implications for *firms and their managers*. To reduce information asymmetries with investors, managers should make sure that textual disclosures: (i) describe the accounting approach underlying the numerical emission allowance disclosures, (ii) include information on how institutional features affect numerical emission allowance disclosures, and (iii) are written in a neutral and fact-based manner. Moreover, managers can increase their efforts to reduce information asymmetry with the general public by providing textual disclosures containing institutional information, since this type of information is often picked up by the media.

8 | CONCLUSION

The literature has criticized *numerical* emission (allowance) disclosures for lacking comparability, consistency, and understandability. Motivated by this criticism, our study is the first to examine whether textual disclosures that complement numerical emission allowance disclosures are associated with lower information asymmetry. Consistent with our conjecture that text can provide clarity and context to numbers, we find that textual disclosures complementing numerical emission allowance disclosures are associated with lower information asymmetry. An IV approach even indicates causality. Focusing on specific content, we find that the negative association is even stronger for textual disclosures that: (i) describe the *accounting approach*, and (ii) contain *institutional information* on the EU ETS, respectively. Our auxiliary *sentiment* analysis suggests that textual disclosures are most effective in lowering information asymmetry when written in a neutral and fact-based manner, rather than with a positive or negative tone. Finally, our auxiliary *media* analysis extends the perspective from investors to another stakeholder group—namely, the general public—and reveals that (institutional) textual disclosures are associated with higher media coverage, indicating reduced information asymmetry between firms and the general public.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are subject to third-party restrictions. Data are available from the sources cited in the manuscript.

ORCID

Tobias Steindl https://orcid.org/0000-0003-0767-6970
Florian Habermann https://orcid.org/0000-0003-1982-6796
Stephan Küster https://orcid.org/0000-0002-5858-2221

ENDNOTES

[1] Specifically, emission allowances are either allocated for free or auctioned off (European Commission, 2023).
[2] We use the term numerical disclosures as an umbrella term for transactions recognized in the financial statements or reported numerically in the notes.

[3] In a similar vein, Zhu (2020) calls for the application of IV approaches in the industrial ecology literature since they have been considered helpful for advancing conventional methods.

[4] For firms not affected by the EU ETS, climate change-related physical risk disclosures are associated with higher information asymmetry (Schiemann & Sakhel, 2019). This finding is consistent with a less prevalent stream of literature, which argues that—under certain circumstances—corporate disclosures can induce more uncertainty about a firm's performance and, thereby, increase information asymmetry (Kothari et al., 2009; Ng et al., 2009). Since we are focusing on firms affected by the EU ETS, we put less weight on this stream of literature.

[5] Although the literature most closely related to our study points toward a negative effect of textual disclosures (complementing numerical disclosures) on information asymmetry, we acknowledge that such textual disclosures might not be beneficial if they obfuscate numerical disclosures, provide little new information (e.g., because of boilerplate language), or are a form of "cheap talk" communication (Burd et al., 2024; Hope et al., 2016; Li, 2008; Schons & Steinmeier, 2016).

[6] In December 2004, the IASB issued IFRIC 3 *Emission Rights* to provide authoritative guidance on how to account for emission allowances in financial statements. However, it was heavily criticized—mainly for accounting mismatches in treatments—and as a consequence, withdrawn only 6 months after its issuance. Since then, the IASB has been working on a solution, but without success.

[7] Abrell et al. (2022) made their EU ETS data publicly available under euets.info, given certain drawbacks of the EUTL database (e.g., download limit to 3000 rows).

[8] Firms operating in the aviation industry (i.e., aircraft operators) are excluded because of their unique position within the EU ETS.

[9] Financial institutions are excluded because of the different structures of their financial statements.

[10] Our sample period starts in 2008 because the first phase of the EU ETS (i.e., 2005 to 2007) was considered a "trial phase" (García et al., 2021).

[11] For our research setting, we use a vocabulary-based approach for information retrieval instead of a supervised machine learning or topic modeling approach for the following two reasons. First, we have a limited dataset, making the training of a machine learning model for information retrieval not feasible. Second, using a pre-trained model (e.g., ClimateBERT) is not suitable, since the classifications are not specific enough.

[12] Supporting Information S2 provides examples of these textual disclosures.

[13] For example: "As there are no specific rules under IFRS dealing with the accounting treatment of GHG emissions allowances, the group decided to apply the following principles: emission rights are classified as inventories, as they are consumed in the production process; emission rights purchased on the market are recognized at acquisition cost; emission rights granted free of charge are recorded in the statement of financial position at a value of nil" (GDF SUEZ, 2014, p. 211).

[14] For example: "ArcelorMittal's most substantial climate-related policy risk is the EU Emissions Trading scheme ("ETS"), which applies to all its European plants. The risk concerns the Company's primary steelmaking plants which are exposed to this regulation and yet unprotected against competition from imported steel" (ArcelorMittal, 2020, p. 247).

[15] In Supporting Information S3, we perform tests to isolate the exogenous part of ALLOC. In addition, we provide indirect evidence—to the extent possible—that ALLOC is largely determined by exogenous factors (e.g., regulatory shocks), rather than endogenous firm characteristics.

[16] Please note that ALLOC is subject to the same limitations discussed in Section 5.2 and Supporting Information S3 (Section 1).

[17] "[…] FinBERT excels in identifying the positive or negative sentiment of sentences that other algorithms mislabel as neutral […]" (Huang et al., 2023, p. 806).

[18] In particular, we apply the "yiyanghkust/finbert-tone" model from the transformers huggingface library.

[19] It is important to note that these findings are not comparable to—but complement—studies examining more extensive textual disclosures (e.g., entire sustainability reports covering a wide range of topics) or less technical textual disclosures (Du & Yu, 2021; Mittelbach-Hörmanseder et al., 2021; Muslu et al., 2019).

[20] The search strings are the same as the ones used to identify sentences in annual reports that capture information on emission allowances.

REFERENCES

Abrell, J., Cludius, J., Lehmann, S., Schleich, J., & Betz, R. (2022). Corporate emissions-trading behaviour during the first decade of the EU ETS. *Environmental and Resource Economics*, *83*(1), 47–83. https://doi.org/10.1007/s10640-021-00593-7

Ahn, J., Hoitash, R., & Hoitash, U. (2022). *Are words beneficial to the consumption of numbers in financial reports?* https://doi.org/10.2139/ssrn.3582662

Allee, K. D., Do, C., & Do, H. (2023). *Contextualization of numbers in earnings conference calls.* https://doi.org/10.2139/ssrn.3867023

Allini, A., Giner, B., & Caldarelli, A. (2018). Opening the black box of accounting for greenhouse gas emissions: The different views of institutional bodies and firms. *Journal of Cleaner Production*, *172*, 2195–2205. https://doi.org/10.1016/j.jclepro.2017.11.194

Alsafi, K., Elnahass, M., & Salama, A. (2020). Market responses to firms' voluntary carbon disclosure: Empirical evidence from the United Kingdom. *Journal of Cleaner Production*, *262*, 121377. https://doi.org/10.1016/j.jclepro.2020.121377

Amel-Zadeh, A., & Serafeim, G. (2018). Why and how investors use ESG information: Evidence from a global survey. *Financial Analysts Journal*, *74*(3), 87–103. https://doi.org/10.2469/faj.v74.n3.2

Amihud, Y., & Mendelson, H. (1986). Asset pricing and the bid-ask spread. *Journal of Financial Economics*, *17*(2), 223–249. https://doi.org/10.1016/0304-405X(86)90065-6

ArcelorMittal. (2020). Annual report. https://corporate-media.arcelormittal.com/media/qecb1avu/arcelor-mittal-annual-report-2020.pdf

Axjonow, A., Ernstberger, J., & Pott, C. (2018). The impact of corporate social responsibility disclosure on corporate reputation: A non-professional stakeholder perspective. *Journal of Business Ethics*, *151*(2), 429–450. https://doi.org/10.1007/s10551-016-3225-4

Barth, M. E., Cahan, S. F., Chen, L., & Venter, E. R. (2017). The economic consequences associated with integrated report quality: Capital market and real effects. *Accounting, Organizations and Society*, *62*, 43–64. https://doi.org/10.1016/j.aos.2017.08.005

Basse Mama, H., & Mandaroux, R. (2022). Do investors care about carbon emissions under the European Environmental Policy? *Business Strategy and the Environment*, *31*(1), 268–283. https://doi.org/10.1002/bse.2886

Bendig, D., Wagner, A., & Lau, K. (2023). Does it pay to be science-based green? The impact of science-based emission-reduction targets on corporate financial performance. *Journal of Industrial Ecology*, *27*(1), 125–140. https://doi.org/10.1111/jiec.13341

Black, C. M. (2013). Accounting for carbon emission allowances in the European Union: In search of consistency. *Accounting in Europe*, *10*(2), 223–239. https://doi.org/10.1080/17449480.2013.834730

Borghei, Z. (2021). Carbon disclosure: A systematic literature review. *Accounting & Finance*, *61*(4), 5255–5280. https://doi.org/10.1111/acfi.12757
Borghei, Z., Leung, P., & Guthrie, J. (2018). Does voluntary greenhouse gas emissions disclosure reduce information asymmetry? Australian evidence. *Afro-Asian Journal of Finance and Accounting*, *8*(2), 123–147. https://doi.org/10.1504/AAJFA.2018.091055
Burd, C., Casi-Eberhard, E., Grossetti, F., & Lisowsky, P. (2024). *Does the story matter? Putting financial statement numbers into context using XBRL data*. https://doi.org/10.2139/ssrn.4070703
Busch, T., Johnson, M., & Pioch, T. (2022). Corporate carbon performance data: Quo vadis? *Journal of Industrial Ecology*, *26*(1), 350–363. https://doi.org/10.1111/jiec.13008
Busch, T., & Lewandowski, S. (2018). Corporate carbon and financial performance: A meta-analysis. *Journal of Industrial Ecology*, *22*(4), 745–759. https://doi.org/10.1111/jiec.12591
Christensen, H. B., Hail, L., & Leuz, C. (2021). Mandatory CSR and sustainability reporting: Economic analysis and literature review. *Review of Accounting Studies*, *26*(3), 1176–1248. https://doi.org/10.1007/s11142-021-09609-5
Clarkson, P. M., Li, Y., Pinnuck, M., & Richardson, G. D. (2015). The valuation relevance of greenhouse gas emissions under the European Union carbon emissions trading scheme. *European Accounting Review*, *24*(3), 551–580. https://doi.org/10.1080/09638180.2014.927782
Constantinides, G. M. (1986). Capital market equilibrium with transaction costs. *Journal of Political Economy*, *94*(4), 842–862. https://doi.org/10.1086/261410
Cormier, D., Ledoux, M.-J., & Magnan, M. (2011). The informational contribution of social and environmental disclosures for investors. *Management Decision*, *49*(8), 1276–1304. https://doi.org/10.1108/00251741111163124
Dechezleprêtre, A., Nachtigall, D., & Venmans, F. (2023). The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *Journal of Environmental Economics and Management*, *118*, 102758. https://doi.org/10.1016/j.jeem.2022.102758
Dechow, P. M., Sloan, R. G., & Sweeney, A. P. (1995). Detecting earnings management. *The Accounting Review*, *70*(2), 193–225. http://www.jstor.org/stable/248303
Depoers, F., Jeanjean, T., & Jérôme, T. (2016). Voluntary disclosure of greenhouse gas emissions: Contrasting the carbon disclosure project and corporate reports. *Journal of Business Ethics*, *134*(3), 445–461. https://doi.org/10.1007/s10551-014-2432-0
Dhaliwal, D. S., Radhakrishnan, S., Tsang, A., & Yang, Y. G. (2012). Nonfinancial disclosure and analyst forecast accuracy: International evidence on corporate social responsibility disclosure. *The Accounting Review*, *87*(3), 723–759. https://doi.org/10.2308/accr-10218
Diamond, D. W., & Verrecchia, R. E. (1991). Disclosure, liquidity, and the cost of capital. *The Journal of Finance*, *46*(4), 1325–1359. https://doi.org/10.1111/j.1540-6261.1991.tb04620.x
Doan, M. H., & Sassen, R. (2020). The relationship between environmental performance and environmental disclosure: A meta-analysis. *Journal of Industrial Ecology*, *24*(5), 1140–1157. https://doi.org/10.1111/jiec.13002
Du, S., & Yu, K. (2021). Do corporate social responsibility reports convey value relevant information? Evidence from report readability and tone. *Journal of Business Ethics*, *172*(2), 253–274. https://doi.org/10.1007/s10551-020-04496-3
Ertimur, Y., Francis, J., Gonzales, A., & Schipper, K. (2020). Financial reporting for pollution reduction programs. *Management Science*, *66*(12), 6015–6041. https://doi.org/10.1287/mnsc.2019.3416
ESMA. (2023). *Public statement—European common enforcement priorities for 2023 annual financial reports*. https://www.esma.europa.eu/sites/default/files/2023-10/ESMA32-193237008-1793_2023_ECEP_Statement.pdf
European Commission. (2020). *Summary report of the public consultation on the review of the non-financial reporting directive*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=PI_COM:Ares(2020)3997889
European Commission. (2023). *EU Emissions Trading System (EU ETS)*. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
European Investment Bank. (2023). *EIB investment survey: European Union overview*. https://www.eib.org/attachments/lucalli/20230285_econ_eibis_2023_eu_en.pdf
Fuhrmann, S., Ott, C., Looks, E., & Guenther, T. W. (2017). The contents of assurance statements for sustainability reports and information asymmetry. *Accounting and Business Research*, *47*(4), 369–400. https://doi.org/10.1080/00014788.2016.1263550
García, A., García-Álvarez, M. T., & Moreno, B. (2021). The impact of EU allowance prices on the stock market indices of the European power industries: Evidence from the ongoing EU ETS Phase III. *Organization & Environment*, *34*(3), 459–478. https://doi.org/10.1177/1086026620924820
GDF SUEZ. (2014). *Registration document 2014*. https://www.engie.com/sites/default/files/assets/documents/2021-03/registration-document-2014_0.pdf
Giner, B. (2014). Accounting for emission trading schemes: A still open debate. *Social and Environmental Accountability Journal*, *34*(1), 45–51. https://doi.org/10.1080/0969160X.2014.885670
Glenk, G. (2023). *Toward decision-useful carbon information*. https://doi.org/10.2139/ssrn.4444037
Glosten, L. R., & Milgrom, P. R. (1985). Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics*, *14*(1), 71–100. https://doi.org/10.1016/0304-405X(85)90044-3
Goettsche, M., Steindl, T., & Gietl, S. (2016). Do customers affect the value relevance of sustainability reporting? Empirical evidence on stakeholder interdependence. *Business Strategy and the Environment*, *25*(3), 149–164. https://doi.org/10.1002/bse.1856
Gow, I. D., Ormazabal, G., & Taylor, D. J. (2010). Correcting for cross-sectional and time-series dependence in accounting research. *The Accounting Review*, *85*(2), 483–512. https://doi.org/10.2308/accr.2010.85.2.483
Griffin, P. A., Lont, D. H., & Sun, E. Y. (2017). The relevance to investors of greenhouse gas emission disclosures. *Contemporary Accounting Research*, *34*(2), 1265–1297. https://doi.org/10.1111/1911-3846.12298
Haupt, M., & Ismer, R. (2013). The EU Emissions Trading System under IFRS—Towards a 'true and fair view.' *Accounting in Europe*, *10*(1), 71–97. https://doi.org/10.1080/17449480.2013.772726
Heckman, J. J. (1979). Sample selection bias as a specification error. *Econometrica*, *47*(1), 153. https://doi.org/10.2307/1912352
Hoffmann, V. H. (2007). EU ETS and investment decisions. *European Management Journal*, *25*(6), 464–474. https://doi.org/10.1016/j.emj.2007.07.008
Hombach, K., & Sellhorn, T. (2022). Does every accounting issue need a solution? *Accounting and Business Research*, *52*(5), 540–561. https://doi.org/10.1080/00014788.2022.2079736
Hope, O.-K., Hu, D., & Lu, H. (2016). The benefits of specific risk-factor disclosures. *Review of Accounting Studies*, *21*(4), 1005–1045. https://doi.org/10.1007/s11142-016-9371-1
Huang, A. H., Wang, H., & Yang, Y. (2023). Finbert: A large language model for extracting information from financial text. *Contemporary Accounting Research*, *40*(2), 806–841. https://doi.org/10.1111/1911-3846.12832

ICAP. (2023). *Emissions trading worldwide: 2023 ICAP status report*. https://icapcarbonaction.com/en/publications/emissions-trading-worldwide-2023-icap-status-report

IFRS Foundation. (2014). *AP6B: Summary of accounting issues*. https://www.ifrs.org/content/dam/ifrs/meetings/2014/november/iasb/pollutant-pricing-mechanisms/ap06b-emissions-trading-schemes.pdf

IFRS Foundation. (2022). *Third agenda consultation*. https://www.ifrs.org/content/dam/ifrs/project/third-agenda-consultation/thirdagenda-feedbackstatement-july2022.pdf

IPCC. (2018). *Global warming of 1.5°C*. https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Full_Report_HR.pdf

IPCC. (2023). *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H.Lee and J.Romero (eds.)]*. IPCC, Geneva, Switzerland. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf https://doi.org/10.59327/IPCC/AR6-9789291691647

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, *3*(4), 305–360. https://doi.org/10.1016/0304-405X(76)90026-X

Johnston, D. M., Sefcik, S. E., & Soderstrom, N. S. (2008). The value relevance of greenhouse gas emissions allowances: An exploratory study in the related United States SO_2 market. *European Accounting Review*, *17*(4), 747–764. https://doi.org/10.1080/09638180802481615

Jones, J. J. (1991). Earnings management during import relief investigations. *Journal of Accounting Research*, *29*(2), 193. https://doi.org/10.2307/2491047

Känzig, D. (2023). The unequal economic consequences of carbon pricing. *National Bureau of Economic Research*, Advance online publication. https://doi.org/10.3386/w31221

Kim, A., & Nikolaev, V. V. (2024). *Context-based interpretation of financial information*. https://doi.org/10.2139/ssrn.4317208

Kim, T. H., Lee, S. H., & Vourvachis, P. (2023). Accounting standard-setting for an emission trading scheme: The Korean case. *Journal of Business Ethics*, *182*(4), 1003–1024. https://doi.org/10.1007/s10551-022-05290-z

Klaaßen, L., & Stoll, C. (2021). Harmonizing corporate carbon footprints. *Nature Communications*, *12*(1), 6149. https://doi.org/10.1038/s41467-021-26349-x

Kothari, S. P., Li, X., & Short, J. E. (2009). The effect of disclosures by management, analysts, and business press on cost of capital, return volatility, and analyst forecasts: A study using content analysis. *The Accounting Review*, *84*(5), 1639–1670. https://doi.org/10.2308/accr.2009.84.5.1639

Lang, M., & Stice-Lawrence, L. (2015). Textual analysis and international financial reporting: Large sample evidence. *Journal of Accounting and Economics*, *60*(2-3), 110–135. https://doi.org/10.1016/j.jacceco.2015.09.002

Lazzini, S., Occhipinti, Z., Parenti, A., & Verona, R. (2021). Disentangling economic crisis effects from environmental regulation effects: Implications for sustainable development. *Business Strategy and the Environment*, *30*(5), 2332–2353. https://doi.org/10.1002/bse.2749

Leuz, C., & Verrecchia, R. E. (2000). The economic consequences of increased disclosure. *Journal of Accounting Research*, *38*, 91. https://doi.org/10.2307/2672910

Li, F. (2008). Annual report readability, current earnings, and earnings persistence. *Journal of Accounting and Economics*, *45*(2-3), 221–247. https://doi.org/10.1016/j.jacceco.2008.02.003

Lovell, H., Bebbington, J., Larrinaga, C., & de Aguiar, T. R. S. (2013). Putting carbon markets into practice: A case study of financial accounting in Europe. *Environment and Planning C: Government and Policy*, *31*(4), 741–757. https://doi.org/10.1068/c1275

Luers, A., Yona, L., Field, C. B., Jackson, R. B., Mach, K. J., Cashore, B. W., Elliott, C., Gifford, L., Honigsberg, C., Klaassen, L., Matthews, H. D., Peng, A., Stoll, C., van Pelt, M., Virginia, R. A., & Joppa, L. (2022). Make greenhouse-gas accounting reliable—Build interoperable systems. *Nature*, *607*(7920), 653–656. https://doi.org/10.1038/d41586-022-02033-y

Martínez-Ferrero, J., Ruiz-Cano, D., & García-Sánchez, I.-M. (2016). The causal link between sustainable disclosure and information asymmetry: The moderating role of the stakeholder protection context. *Corporate Social Responsibility and Environmental Management*, *23*(5), 319–332. https://doi.org/10.1002/csr.1379

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

Mittelbach-Hörmanseder, S., Hummel, K., & Rammerstorfer, M. (2021). The information content of corporate social responsibility disclosure in Europe: An institutional perspective. *European Accounting Review*, *30*(2), 309–348. https://doi.org/10.1080/09638180.2020.1763818

Muller, K. A., Riedl, E. J., & Sellhorn, T. (2011). Mandatory fair value accounting and information asymmetry: Evidence from the European real estate industry. *Management Science*, *57*(6), 1138–1153. https://doi.org/10.1287/mnsc.1110.1339

Muslu, V., Mutlu, S., Radhakrishnan, S., & Tsang, A. (2019). Corporate social responsibility report narratives and analyst forecast accuracy. *Journal of Business Ethics*, *154*(4), 1119–1142. https://doi.org/10.1007/s10551-016-3429-7

Ng, J., Verrecchia, R. E., & Weber, J. P. (2009). *Firm performance measures and adverse selection*. https://doi.org/10.2139/ssrn.1324874

Oster, E. (2019). Unobservable selection and coefficient stability: Theory and evidence. *Journal of Business & Economic Statistics*, *37*(2), 187–204. https://doi.org/10.1080/07350015.2016.1227711

PWC. (2007). Trouble-entry accounting—Revisited https://www.drsc.de/app/uploads/2017/03/150_06f_Survey_EU_ETS_Zusatzinfo.pdf

Romito, S., & Vurro, C. (2021). Non-financial disclosure and information asymmetry: A stakeholder view on US listed firms. *Corporate Social Responsibility and Environmental Management*, *28*(2), 595–605. https://doi.org/10.1002/csr.2071

Schiemann, F., & Sakhel, A. (2019). Carbon disclosure, contextual factors, and information asymmetry: The case of physical risk reporting. *European Accounting Review*, *28*(4), 791–818. https://doi.org/10.1080/09638180.2018.1534600

Schons, L., & Steinmeier, M. (2016). Walk the talk? How symbolic and substantive CSR actions affect firm performance depending on stakeholder proximity. *Corporate Social Responsibility and Environmental Management*, *23*(6), 358–372. https://doi.org/10.1002/csr.1381

Siano, F., & Wysocki, P. D. (2018). *The primacy of numbers in financial and accounting disclosures: Implications for textual analysis research*. https://doi.org/10.2139/ssrn.3223757

Sprengel, D. C., & Busch, T. (2011). Stakeholder engagement and environmental strategy—The case of climate change. *Business Strategy and the Environment*, *20*(6), 351–364. https://doi.org/10.1002/bse.684

Sullivan, R., & Gouldson, A. (2012). Does voluntary carbon reporting meet investors' needs? *Journal of Cleaner Production*, *36*, 60–67. https://doi.org/10.1016/j.jclepro.2012.02.020

Teixeira, A. (2014). The International Accounting Standards Board and evidence-informed standard-setting. *Accounting in Europe*, *11*(1), 5–12. https://doi.org/10.1080/17449480.2014.900269

Velte, P., Stawinoga, M., & Lueg, R. (2020). Carbon performance and disclosure: A systematic review of governance-related determinants and financial consequences. *Journal of Cleaner Production*, *254*, 120063. https://doi.org/10.1016/j.jclepro.2020.120063

Verrecchia, R. E. (2001). Essays on disclosure. *Journal of Accounting and Economics*, *32*(1-3), 97–180. https://doi.org/10.1016/S0165-4101(01)00025-8

Vespermann, J., & Wittmer, A. (2011). Financial, ecological and managerial impacts of emission trading schemes: The case of Lufthansa. *Business Strategy and the Environment*, *20*(3), 174–191. https://doi.org/10.1002/bse.683

Warwick, P., & Ng, C. (2012). The 'cost' of climate change: How carbon emissions allowances are accounted for amongst European Union companies. *Australian Accounting Review*, *22*(1), 54–67. https://doi.org/10.1111/j.1835-2561.2011.00158.x

Zaklan, A., Wachsmuth, J., & Duscha, V. (2021). The EU ETS to 2030 and beyond: Adjusting the cap in light of the 1.5°C target and current energy policies. *Climate Policy*, *21*(6), 778–791. https://doi.org/10.1080/14693062.2021.1878999

Zhou, K., Jin, X., Li, X., & Tao, Y. (2024). Enhancing sustainable development through effective disclosure: Corporate environmental performance and readability. *Corporate Social Responsibility and Environmental Management*, *31*(1), 274–291. https://doi.org/10.1002/csr.2569

Zhu, J. (2020). Suggested use? On evidence-based decision-making in industrial ecology and beyond. *Journal of Industrial Ecology*, *24*(5), 943–950. https://doi.org/10.1111/jiec.13009

Zhu, J., Fan, Y., Deng, X., & Xue, L. (2019). Low-carbon innovation induced by emissions trading in China. *Nature Communications*, *10*(1), 4088. https://doi.org/10.1038/s41467-019-12213-6

Zhu, J., Ge, Z., Wang, J., Li, X., & Wang, C. (2022). Evaluating regional carbon emissions trading in China: Effects, pathways, co-benefits, spillovers, and prospects. *Climate Policy*, *22*(7), 918–934. https://doi.org/10.1080/14693062.2022.2054765

SUPPORTING INFORMATION

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

How to cite this article: Steindl, T., Habermann, F., & Küster, S. (2024). Carbon disclosures and information asymmetry: Empirical evidence on the importance of text in understanding numerical emission allowance disclosures. *Journal of Industrial Ecology*, *28*, 1883–1899. https://doi.org/10.1111/jiec.13574