Journal of International Money and Finance 152 (2025) 103281

Contents lists available at ScienceDirect

Journal of International Money and Finance

journal homepage: www.elsevier.com/locate/jimf

Climate change exposure and green bonds issuance

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ARTICLE INFO

Keywords:
Firm-level climate change exposure
Green bonds
CO_2 emissions
ESG scores

ABSTRACT

In this study, we examine the relationship between firm-level climate change exposure and green bond issuance. We find that firms exposed to climate change are more likely to issue green bonds. This relationship is primarily motivated by the firms' desire to hedge against physical and regulatory risks rather than to capitalize on new climate-related opportunities. Green bonds issued by climate-exposed firms have lower proceeds, higher coupon rates and larger maturities. The issuance of such bonds is associated with higher ESG scores but not with lower carbon emissions. Our findings survive a battery of robustness tests including endogeneity checks, and are important to issuers, asset managers and bond market regulators.

1. Introduction

Climate change poses significant risks to the global economy, with firms being increasingly exposed to climate-related financial risks. These risks can be categorized into two main types: physical risks, which include threats such as rising temperatures, extreme weather events, damages to infrastructure from sea level rise, productivity reduction, and elevated operational costs; and transition risks, which arise from the shift toward a low-carbon economy and include a broad range of potential shocks, including changes in climate policy, reputational impacts, evolving market preferences, and technological advancements (Bolton and Kacperczyk, 2023). These risks highlight the urgent need for comprehensive strategies to mitigate climate impacts and transition to sustainable economic models. As a result, both investors and regulators are placing growing emphasis on understanding firm-level climate risk exposure. The necessity to manage these risks has led markets to explore innovative financing mechanisms, such as green bonds. These instruments are designed to fund environmentally friendly projects, supporting investments in areas such as renewable energy, energy efficiency, green buildings, clean transportation, sustainable agriculture, and other clean, low-carbon technologies (Baker et al., 2022).

From a firm's perspective, issuing green bonds offers several advantages. First, green bonds provide firms with a reputational advantage, as they send a strong signal regarding the firms' commitment to sustainability (Flammer 2021; Sangiorgi and Schopohl, 2023; Dutordoir et al., 2024). This reputational benefit is particularly valuable for climate-exposed firms, which face significant criticism for their environmental impact as they often belong to brown industries. Second, green bonds provide a hedging advantage during periods of heightened climate uncertainty, because they are perceived as safe havens compared to conventional bonds (Cepni et al., 2022). Hence, for climate-exposed firms, which are more vulnerable to fluctuations in climate-related risks, green bond issuance presents a strategic financing option. Finally, green bonds are often associated with lower borrowing costs, as investors are willing to pay higher prices for bonds issued by firms with strong environmental performance (Huyhn and Xia, 2021). In support of these

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https://doi.org/10.1016/j.jimonfin.2025.103281

Available online 17 January 2025

arguments, Caramichael and Rapp (2024) find that green corporate bonds have lower yields at issuance relative to conventional bonds, underscoring the borrowing the cost advantage of green bonds, or 'greenium'.

Although a positive association between climate change exposure and green bond issuance seems intuitive, it is not theoretically guaranteed. Jiang et al. (2025) show that physical climate risk is negatively correlated with firms' debt levels, potentially because firms with higher climate exposure face challenges in securing bank loans or accessing bond markets (Painter, 2020; Huang et al., 2021; Berkman et al., 2024). This is especially true for companies in environmentally sensitive sectors, such as energy and agriculture, where the physical impacts of climate change are more severe (Monasterolo and De Angelis, 2020). While green bonds might seem to offer a more affordable financing alternative for climate-exposed firms, evidence suggests that the so-called 'greenium' – the cost advantage of green bonds – is negligible when compared to quasi-identical brown bonds from the same issuer (Larcker and Watts, 2020). Finally, green bonds come with additional administrative and compliance costs relative to traditional bonds (ElBannan and Löffler, 2024). Consequently, firms exposed to climate risks, even if inclined to issue green bonds, may face significant constraints due to their limited access to financing.

Motivated by the above discussion, the aim of this paper is to examine whether firms with higher exposure to climate risks are more or less likely to issue green bonds. To address our research question, we analyze a panel dataset of 14,629 firm-year observations, including 83 green bonds issuers (140 green bonds issues). We utilize the firm-level climate change exposure measure developed by Sautner et al. (2023a), which allows us to examine the relationship between climate change exposure and green bond issuance at a more granular level. This measure, derived from textual analysis of quarterly earnings call transcripts, captures dimensions of climate-related physical and regulatory risks as well as opportunities.

Although climate change is frequently regarded as an aggregate risk factor linked to global physical changes, its effects within sectors are far from uniform. Sautner et al. (2023a) demonstrate that between 70 % and 96 % of the variation in climate exposure measures, occurs at the firm-level, with firms within the same industry experiencing different degrees of climate-related exposure over time. Furthermore, the effects of climate change on individual firms are multifaceted and might stem from different sources (Giglio et al., 2021). For instance, while physical climate changes and regulatory efforts to mitigate global warming may impose costs on certain firms, they can simultaneously create important opportunities for others. Consequently, using a firm-specific measure of climate exposure offers a significant advantage over country-level metrics, as it enables a more precise identification of risks that directly influence firm-specific decisions, such as issuing green bonds.

Our baseline results indicate a positive association between firm-level climate change exposure and green bond issuance. In other words, firms exposed to climate risks are more likely to issue green bonds. A deeper examination of the components of the Sautner et al. (2023a) measure, reveals that this positive relationship is primarily driven by the need to hedge against physical and regulatory risks. By contrast, firms with greater climate-related opportunities, such as those operating in renewable energy or electric vehicle sectors, do not exhibit a higher propensity to issue green bonds, suggesting that the motivation to issue green bonds is more closely tied to risk mitigation than to capitalizing on emerging opportunities. Our baseline results survive a battery of robustness tests, including different model specifications and sample restrictions.

We recognize the potential for endogeneity to bias our findings. Managers have significant discretion in reporting their firms' climate change exposure, which suggests that variations in our climate exposure measure may not exogenously determined. To address this issue, we adopt the two-stage least squares instrumental variable approach proposed by Berkman et al. (2024). Additionally, our results may be influenced by a dynamic relationship between climate change exposure and green bond issuance. To account for this, we apply a dynamic Generalized Method of Moments (GMM) approach, as in Makrychoriti and Pyrgiotakis (2024). Finally, following Flammer (2021), we address the self-selection of green bond issuers by matching issuing firms with comparable non-issuers based on key firm characteristics, including their exposure to climate change. Our findings remain robust across all methodologies.

Next, we examine the relationship between green bond issuance and corporate environmental performance. Previous studies document mixed results on this issue. Flammer (2021) shows that carbon emissions decrease following green bond issuance. However, ElBannan and Löffler (2024) observe that this relationship weakens when additional factors, such as green bond issue volumes, are considered. Our analysis indicates that green bond issuance is associated with higher ESG scores during the issuance year, but this positive association dissipates in subsequent years. Furthermore, we find no significant association between green bond issuance and carbon emissions in any period up to three years after issuance. Importantly, we find similar results when we conduct a difference-in-differences analysis as in Flammer (2021). At the first glance, these findings suggest that green bonds may not provide significant environmental benefits. Nonetheless, we should acknowledge that green bond projects do not necessarily guarantee lower firm-level carbon emissions, as any emission reduction from green bond projects could be offset by an increase in emissions generated by other firm activities (Ehlers et al., 2020).

We also examine the association between climate change exposure and green bond characteristics. We find that firms more exposed to climate risk tend to issue green bonds with smaller amounts, higher coupon rates, and longer maturities. This aligns with prior research showing that firms facing climate risk pay a premium when issuing bonds (Huang et al., 2018) and prefer longer maturities (Painter, 2020). This behaviour likely reflects a cautionary approach to financing, as these firms anticipate potential repayment challenges from financial losses caused by extreme weather events.

Thus far, most academic research on green bonds has concentrated on pricing (Lam and Wurgler, 2024). However, understanding the motivations behind firms issuing green bonds is crucial for expanding the green bond market. The literature exploring firms' motivations for green bond issuance is limited, potentially due data availability issues. Dutordoir et al. (2024) argue that until recently, there were not enough data on corporate green bond issuers to investigate this research question. Thus, our paper contributes to the sparse but growing body of literature examining the motivations for issuing green bonds (Flammer, 2021; Sangiorgi and Schopohl, 2023; Dutordoir et al., 2024). Specifically, we analyze how firm-level climate change exposure influences corporate green bond issuance. In this regard, our study is also related to the growing literature which examines the impact of climate change risks on corporate debt markets (Jiang et al., 2025; Benkraiem et al., 2025; Mertzanis et al. 2025).

The remainder of this study is structured as follows. Section 2 reviews the relevant literature. Section 3 details the data collection process and our methodology. Section 4 discusses the baseline results. Section 5 provides additional analyses and robustness checks, and Section 6 concludes the paper.

2. Literature review

2.1. Climate change risk & firms' behavior

Climate change risk poses fundamental challenges to macroeconomic conditions and financial stability (Hong et al., 2020). Climate risks are broadly categorized into physical risks—arising from events such as floods, droughts, and hurricanes—and transitional risks, which stem from policy, regulatory, and market shifts toward a low-carbon economy (Battiston et al., 2021). Both types of risk have significant financial implications for firms, and their ability to manage and disclose these risks is becoming increasingly important in corporate strategy. Stroebel and Wurgler (2021) survey 861 finance academics and practitioners regarding the severity of these risks. Respondents highlighted regulatory risk as the most significant in the short to medium term (up to five years), while identifying physical risk as the predominant concern over the long term (up to 30 years). As a matter of fact, Lamperti et al. (2021) and Battiston et al. (2021) argue that physical climate risks can undermine financial stability and trigger prolonged economic crises.

The intersection of climate risk and corporate finance has attracted growing academic interest, particularly regarding firm-level responses to climate change. A growing body of literature highlights the implications of climate risk exposure on firms' financial and operating performance (Bolton and Kacperczyk, 2021; Matsumura et al., 2014; Kruttli et al., 2019; Hsu et al., 2023; Pankratz et al., 2023). Studies reveal that, following the post-Paris Agreement period, climate risk correlates with lower levels of leverage (Ginglinger and Moreau, 2023), higher loan rates (Delis et al., 2024), and increased cost of capital (El Ghoul et al., 2018). Conversely, firms with stronger environmental commitments often secure more favourable credit terms (Degryse et al., 2023).

Another crucial determinant of firms' response to climate risk is investor behaviour, as it could impact firms' sustainability practices. Overall, the consensus in the literature is that investors do care about climate risk. Krueger et al. (2020) show that institutional investors are increasingly seeking to mitigate climate-related risks by integrating ESG into their investment decisions. Bolton and Kacperczyk (2021) find that investors are demanding a higher compensation for their carbon-related exposure. By contrast, they are more inclined to pay a premium for a firm's bonds if the firm demonstrates strong environmental performance in periods of intense climate risk (Huynh and Xia, 2021). Finally, recent studies exploring the effect of country-specific climate risk and uncertainty on firms' green innovation, provide mixed evidence (Bai et al., 2023; Huang, 2023; Sun et al., 2024), while others show that increased climate policy uncertainty and climate risk encourage the consumption of renewable energy and the adoption of more sustainable practices, thus leading to decreased CO_2 emissions (Guesmi et al., 2023).

2.2. Motivations for green bond issuance

Green bonds, introduced as a financial innovation to promote environmental sustainability, have emerged as a popular tool for firms to finance climate-friendly projects. Unlike traditional bonds, green bonds are specifically designed to fund projects with clear environmental benefits, including investments in renewable energy, improvements in energy efficiency, and initiatives for climate change adaptation (Tang and Zhang, 2020). Their issuance allows firms to access a growing pool of capital from investors who are increasingly seeking to align their portfolios with ESG principles (Baker et al., 2022).

The motivations behind green bond issuance are diverse, encompassing both financial and non-financial objectives. On the financial side, firms often issue green bonds for benefits such as reduced borrowing costs and access to a wider investor base (Caramichael and Rapp, 2024). Tang and Zhang (2020) highlight that beyond these financial advantages, green bonds also provide significant reputational benefits by strengthening a firm's ESG profile. Additionally, regulatory and policy frameworks, including the Paris Agreement and national carbon reduction targets, play a critical role in encouraging firms to issue green bonds (Batten et al., 2020; Karpf and Mandel, 2018).

Flammer (2021) groups the motivations behind green bond issuance into three main categories. First, aligning with the signalling argument, green bonds can serve as a credible signal of a company's commitment to sustainability. This is because green bonds often come with constraints which ensure that funds are directed toward sustainability projects. Second, firms may issue green bonds as a form of "greenwashing" to promote a misleading impression that the raised funds will be used in sustainable projects. Third, companies could secure cheaper financing through green bonds by taking advantage of investors' willingness to sacrifice higher returns in exchange for societal benefits. Flammer finds that green bond issuers improve their environmental performance relative to non-issuers, providing supporting evidence for the signalling hypothesis. The latter argument is in line with survey evidence presented by Sangiorgi and Schopohl (2023), which indicates that issuers are primarily motivated by a desire to combat climate change and the signalling benefits of green bonds. In a similar vein, Dutordoir et al. (2024) find that firms are more likely to issue green bonds over conventional bonds when they can enjoy strong reputational benefits for being green.

Despite these findings, the literature has yet to reach a consensus. Ehlers et al. (2020) find that green bond-funded projects do not always result in lower firm-level carbon emissions. A potential explanation for this inconsistency is that an emission reduction from green projects could be offset by an increase in CO_2 emissions generated by other firm activities. Additionally, Lam and Wurgler (2024) find that the proceeds of U.S. corporate and municipal green bonds are used to refinance existing debt, initiate new non-green projects, or support ongoing projects. Therefore, the results of these studies imply that green bonds could also be motivated by greenwashing or lower cost of borrowing,

The reasons behind firms issuing green bonds are still not fully understood. For firms highly exposed to climate risk, green bond issuance can serve both as a tool for financing climate-resilient projects but also as a signal to investors of the firm's commitment to environmental responsibility. Furthermore, since firms with higher exposure to climate change often struggle to secure traditional financing, green bonds may present a viable alternative for obtaining necessary capital.

3. Data and methodology

3.1. Sample selection

We collect green bond data from Bloomberg database,[1] over the period 2015 to 2022.[2] Our focus in on corporate green bonds, therefore, we exclude government issues. This initial screening results in a sample of 4,254 green bonds (1,459 unique issuers from 67 countries). Then, we utilize the firm-level climate change exposure measure developed by Sautner et al. (2023a),[3] and collect accounting data from Compustat Global. We match data from the three databases using the firms' ticker symbols and the firms' Compustat GVKey (Global Company Key). This matching process yields a sample of 140 green bonds issued by 83 unique firms across 11 countries: Australia, Austria, Chile, Denmark, Finland, France, Germany, Italy, United Arab Emirates, United Kingdom, and United States. The reduction in sample size reflects the limited overlap in data coverage between the two databases and the initial green bond sample. For example, firm-level climate change exposure data are available for 14,269 firms worldwide, with 52 % headquartered in the United States. To construct a sample of non-issuers, we include firms with data available in both Compustat Global and the Sautner et al. (2023a) database, restricting the sample to non-green bond issuers headquartered in the same countries as the green bond issuers. Finally, the macro-indicators of our sample are sourced from World Development Indicators and Worldwide Governance Indicators (World Bank). Firm-level and country-specific data are matched based on the location of the firms' country of headquarters. Our final sample consists of 14,629 firm-year observations (4,799 unique firms, out of which 83 are green bond issuers). All variables are defined in the Appendix (Table A1).

3.2. Firm-level climate change exposure measures

As mentioned before, to proxy for climate change exposure, we use the firm-level measures developed by Sautner et al. (2023a). To construct the climate change exposure measures, Sautner et al. (2023a) utilize corporate quarterly earnings calls to assess firms' risks and opportunities related to climate change. They capture a firm's exposure to a topic by measuring the proportion of the conversation during earnings calls dedicated to that subject (Hassan et al., 2019; Hassan et al., 2021). Their measures reflect the market's perception of a firm's exposure to both positive and negative climate-related factors, including physical threats, regulatory changes, and technological opportunities. For the construction of the firm-level climate change exposure index and its components (Regulation interventions, Physical threats, and Technological opportunities) Sautner et al. (2023a) develop a new method that adapts a keyword discovery algorithm which identifies four different climate change-related bigrams sets. The first, captures general aspects of climate change, while the other three components focus on climate-related opportunities, physical shocks and regulatory shocks. Those four sets of bigrams are then used to create firm-level measures −which are equal to the frequency of climate change-related bigrams adjusted for the total number of bigrams in the conversation- and reflect the attention paid by participants to these topics during earnings calls. Climate related opportunities component captures the exposure of a firm to technological opportunities generated by climate change, especially for those operating in renewable energy, electric cars, or energy storage. Physical threats capture the exposure of a firm to physical threats and risks such as sea level rise, local heat waves or droughts, while regulation interventions reflect the exposure of a firm to regulatory risks like carbon taxes, cap and trade markets. We consider the use of a firm-specific measure of climate exposure as advantageous, when compared to a country-level one, since it allows for the identification of risks that are more likely to affect idiosyncratic outcomes and decisions, such as the green bond issuance (Hassan et al., 2019). The firm-level climate change exposure measures are defined in the Appendix (Table A1).

3.3. Control variables and model specification

We include a vector of firm-specific and country-specific characteristics as our baseline control variables. Following Flammer (2021), Tang and Zhang (2020) and Wang et al. (2023) among others, we use the following controls: the natural logarithm of firms' market value of equity as a proxy for firm size (*Size*), the ratio of the market value of total assets (equals the book value of total assets plus the market value of common stock minus the book value of common stock) to the book value of total assets (*Tobin's Q),* the ratio of total debt to total assets (*Leverage*), the return on assets (*ROA*), the ratio of cash holdings to the book value of total assets (*Cash*), capital

[1] Tang and Zhang (2020) mention that Climate Bond Initiative (CBI) together with Bloomberg are the most inclusive sources for green bond data.
[2] The sample period including one-lagged control variables spans from 2015 to 2022.
[3] The climate change exposure data are available at https://doi.org/10.17605/OSF.IO/FD6JQ.

expenditures divided by total assets *(Capital expenditure)* and the ratio of intangible assets to total assets *(Intangible assets)*.[4] These firm characteristics capture the capital structure, profitability, and investment opportunities, which could affect firm decisions such as sustainable and green projects adoption (Minton and Schrand 1999; Flammer, 2021; Tang and Zhang, 2020; Wang et al., 2023).

To capture the macro-environment we include two country-level control variables namely (i) the GDP per capita *(Ln (GDP per capita))* computed as the natural logarithm of GDP per country in a country and (ii) the rule-of-law index of La Porta et al. (2006) (*Rule of Law*) to control for the governance quality in a country. The index reflects the perceptions up to which agents have confidence in and abide by societal rules such as the quality of contract enforcement, property rights, the police, and the courts, and the likelihood of crime and violence. Both macro-indicators are downloaded from World Development Indicators and Worldwide Governance Indicators (World Bank). Detailed definitions of these variables can be found in Table A1 in the Appendix.

To address our main research question, we estimate the following logit model:

$$Logit(GreenBondIssuance)_{i,c,t} = a + \beta_1 \times ClimateExposure_{i,t-1} + \beta_2 \times X_{t-1} + IndustryFE + YearFE + \varepsilon_{i,c,t} \quad (1)$$

where *Green Bond Issuance* is a dummy variable that equals 1 if a firm *i* in country *c* at year *t* issues a green bond, and 0 otherwise, $Climate\ exposure_{i,t-1}$ is the firm's *i* climate change exposure at year/t, and X_{t-1} denotes a vector of our control variables at year/t. In all our model specifications, we control for country, industry fixed effects (using Fama-French 48 industry classification) and year fixed effects (Sautner et al., 2023b).[5] Standard errors are clustered at the firm level. To control for the presence of outliers, all continuous variables are winsorized at the 1 % and 99 % levels.

3.4. Summary statistics

Table 1 presents the distribution of the sampled green bonds by issuer's country. Specifically, column 1 demonstrates the issuer's country, column 2 the number of issuers per country, while column 3 reports the number of bonds issued by country. Columns 4, 5 and 6 present the green bond characteristics, namely the bond value, the bond coupon, and the bond maturity, respectively. The green bond value is expressed in $ millions and the maturity in years. Our initial sample includes 140 unique observations of green bond issuance globally from a total number of 83 issuers headquartered in 11 countries. US firms dominate the sample (79 % of unique issuers and 75 % of green bonds). This is justified not only by the fact that the US is the most active bond market, but also by the overrepresentation of US firms in the databases from which we retrieve data. Following the US, the countries that are next in terms of bond market activity are France, Germany and Denmark, with France leading our sample in terms of average amount issued ($1.774 billion). Finally, coupon bonds vary from 0.50 (United Kingdom) to 3.95 (United Arab Emirates), while bond maturity spans from 5.04 (Italy) to 18.05 (Germany) years.

Table 2 presents the summary statistics for our sample. Panel A presents the summary statistics of the firm-specific and country-specific characteristics for the whole sample, while Panel B only for the green bond issuers. For the whole universe of firms (Panel A) the mean value of firm-level climate change exposure is 1.54, while the standard deviation is 2.80. For the green bond issuer firms (Panel B), both the mean value and standard deviation of firm-level climate change exposure appear to be higher and equal to 6.98 and 6.42, respectively. The summary statistics for our control variables closely resemble those reported in prior green bond studies (Tang and Zhang, 2020; Wang et al., 2023).

We report the Pearson correlations between the variables of the whole sample in Table 3. We observe a positive correlation between the firm-level climate change exposure and both the issuance and number of green bonds, equal to 0.15 and 0.13, respectively, providing some preliminary evidence that firms exposed to climate change are more likely to issue green bonds. For our control variables, we observe a very weak degree of collinearity, with the highest correlation coefficients being equal to −0.39, between *Cash* and *Size*. Moreover, the Variance Inflation Factors (VIFs) are below 10 in all cases, limiting the concern of multicollinearity.

4. Main empirical findings

4.1. Baseline results

We move to our multivariate regression analysis, where we investigate the relationship, if any, between firm-level climate risk exposure and green bond issuance. Table 4 reports the results of this analysis. Column 1 presents the results of a logit regression (model 1), where the dependent variable is a dummy, which equals 1 if the firm has announced a green bond issue in year t, and 0 otherwise. In column 2, the dependent variable is the number of green bonds a firm issued in year t (model 2), which equals 0 for non-issuers.

In both models, the results for our variables of interest, namely the *Green bond issuance* and *Number of Green bonds,* indicate that firms exposed to climate change are more likely to issue green bonds. More specifically, in model 1, the coefficient of *Green bond issuance* is statistically significant at the 1 % level and equal to 0.278, while in model 2 the coefficient of *Number of Green bonds* is

[4] Tangibility (and subsequently *Intangible assets)* is able to affect green bond initiatives, as firms' asset structures may drive their choices for long-term green projects.

[5] We do not include firm fixed in our logistic regressions effects as their inclusion will drop all firms with no variation in the dependent variable. However, in our panel regressions where the dependent variable is the number of issues, we replace country and industry fixed effects with firm fixed effects, and we obtain similar results.

Table 1
Green bond characteristics by country This table presents the distribution of the sampled green bonds by issuer's country. Green bond data are extracted from Bloomberg over the period 2015 to 2022. *Value* is expressed in $ millions and *Maturity* in years.

Country	*#issuers*	*# bonds*	*Value*	*Coupon*	*Maturity*
Australia	1	1	431.25	2.50	5.07
Austria	1	1	118.14	0.85	15.05
Chile	1	2	600.00	3.15	10.29
Denmark	3	11	380.71	1.43	10.06
Finland	1	5	213.90	2.49	5.71
France	4	6	1774.15	1.72	8.38
Germany	3	6	620.09	2.41	18.05
Italy	1	1	400.00	0.90	5.04
United Arab Emirates	1	1	450.00	3.95	10.04
United Kingdom	1	1	460.00	0.50	7.05
United States	66	105	682.21	2.54	11.12
Total/Average	83	140	696.36	2.42	9.62

Table 2
Summary statistics This table presents the summary statistics of our sample. Panel A presents the summary statistics for the whole sample 14,629 observations. Panel B reports the summary statistics for the 83 green bond issuers. All variables are defined in the Appendix.

Panel A: All firms (N = 14,629)	Mean	Std. dev	25th	Median	75th
Climate exposure	1.54	2.80	0.17	0.47	1.44
Size	7.68	2.02	6.36	7.70	8.97
Tobin's Q	2.15	2.19	1.09	1.45	2.26
Leverage	0.28	0.22	0.10	0.25	0.41
ROA	0.08	0.14	0.05	0.10	0.14
Cash	0.12	0.13	0.03	0.08	0.17
Capital expenditures	0.04	0.05	0.01	0.03	0.05
Intangible assets	0.21	0.21	0.02	0.13	0.35
Ln (GDP per capita)	10.96	0.18	10.82	10.95	11.09
Rule of Law	1.48	0.18	1.39	1.53	1.57
Panel B: Issuers (N = 83)					
Climate exposure	6.98	6.42	0.75	4.41	15.33
Size	10.71	1.69	9.27	10.57	12.67
Tobin's Q	1.94	2.24	1.03	1.26	1.96
Leverage	0.33	0.16	0.21	0.35	0.46
ROA	0.08	0.06	0.05	0.07	0.12
Cash	0.06	0.08	0.01	0.04	0.08
Capital expenditures	0.05	0.04	0.02	0.05	0.07
Intangible assets	0.13	0.18	0.01	0.04	0.15
Ln (GDP per capita)	11.03	0.22	11.07	11.09	11.17
Rule of Law	1.40	0.20	1.34	1.39	1.42

Table 3
Correlation matrix This table presents pairwise correlations between the variables of the whole sample (14,629 observations). All variables are defined in the Appendix. The symbols c, b, and a denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Green bond issuance (1)	1.00											
Number of green bonds (2)	0.81^{a}	1.00										
Climate exposure (3)	0.15^{a}	0.13^{a}	1.00									
Size (4)	0.11^{a}	0.09^{a}	0.10^{a}	1.00								
Tobin's Q (5)	−0.01	−0.00	-0.02^{c}	-0.15^{a}	1.00							
Leverage (6)	0.02^{c}	0.02^{c}	0.03^{a}	0.20^{a}	-0.09^{a}	1.00						
ROA (7)	0.00	0.00	-0.06^{a}	0.27^{a}	0.01	0.00	1.00					
Cash (8)	-0.04^{a}	-0.03^{a}	-0.05^{a}	-0.39^{a}	0.29^{a}	-0.29^{a}	-0.19^{a}	1.00				
Capital expenditures (9)	0.01	0.02	0.07^{a}	0.04^{a}	-0.02^{b}	0.12^{a}	0.05^{a}	-0.14^{a}	1.00			
Intangible assets (10)	-0.03^{a}	-0.02^{c}	-0.15^{a}	0.04^{a}	0.00	0.12^{a}	0.12^{a}	-0.14^{a}	-0.31^{a}	1.00		
Ln (GDP per capita) (11)	0.03^{a}	0.03^{a}	-0.03^{b}	-0.05^{a}	0.01	0.09^{a}	-0.10^{a}	0.03^{a}	-0.06^{a}	−0.00	1.00	
Rule of Law (12)	-0.04^{a}	-0.02^{c}	-0.09^{a}	-0.09^{a}	-0.04^{a}	-0.12^{a}	0.06^{a}	−0.01	0.08^{a}	−0.00	-0.12^{a}	1.00

statistically significant also at the 1 % level and equal to 0.008. When it comes to our control variables, firm size, leverage, and capital expenditure, appear to have significant positive associations with green bond issuance, indicating that larger, high-levered firms with increased capital expenditures tend to issue green bonds. The rest of our control variables do not demonstrate significant effects on the green bond issuance, which may be partially attributed to the complexity of the green financing decision-making process.

Table 4

Baseline regressions: Climate exposure and green bond issuance This table presents our baseline results. Colum 1 presents the results of a logit regression, where the dependent variable is a dummy which equals 1 if the firm has announced a green bond issue in year *t*, and 0 otherwise. In column 2, the dependent variable is the number of green bonds a firm issued in year *t* (0 for non-issuers). All variables are defined in the Appendix. All continuous variables are winsorized at 1% and 99% level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	Green bond issuance	Number of Green bonds
Variables	(1)	(2)
Climate exposure	0.278***	0.008***
	(7.33)	(2.71)
Size	0.822***	0.006***
	(8.14)	(4.78)
Tobin's Q	0.079	0.000
	(1.28)	(0.48)
Leverage	1.194*	−0.004
	(1.71)	(−0.63)
ROA	1.347	−0.005
	(0.68)	(−0.98)
Cash	−0.968	0.001
	(−0.44)	(0.14)
Capital expenditures	7.022	0.060*
	(1.53)	(1.89)
Intangible assets	−0.706	−0.002
	(−0.59)	(−0.29)
Ln (GDP per capita)	1.686	0.028
	(1.38)	(1.00)
Rule of Law	−1.434	−0.028
	(−1.53)	(−0.89)
Constant	−28.243**	−0.317
	(−2.27)	(−1.20)
Country FE	Yes	Yes
Industry FE	Yes	Yes
Year FE	Yes	Yes
N	14,629	14,629
Pseudo R^2/ Adjusted R^2	0.381	0.030

Next, we re-run our baseline analysis, by replacing *Climate exposure* with its components, namely, i) Regulation interventions, ii) Physical threats, and iii) Technological opportunities. Regulation interventions capture the exposure of a firm to regulatory risks like carbon taxes, cap and trade markets, physical threats capture the exposure of a firm to physical threats and risks such as sea level rise, local heat waves or droughts, while climate related opportunities reflect the exposure of a firm to technological opportunities generated by climate change, especially for those operating in renewable energy, electric cars, or energy storage. The components are discussed in detail in Section 3.2 and in the Appendix (Table A1).

Table 5 presents the results of this analysis. The model specifications remain the same as in models 1 and 2 of Table 4. Columns 1 to 3 present the results of logistic regressions, where the dependent variable is *Green bond issuance*, while columns 4 to 6 present the results of panel regressions, where the dependent variable is *Number of Green bonds*. The results from this analysis show, that there is a strong and positive association between *Regulation interventions*, and *Physical threats* with green bond issuance. Specifically, when the dependent variable is *Green bond issuance, Regulation interventions* is positive and statistically significant at the 5 % level, and *Physical threats* is positive and statistically significant at the 1 % level. When the dependent variable is *Number* of *Green bonds,* the coefficient of *Regulation interventions* is positive and statistically significant at the 1 % level, and the coefficient of *Physical threats* is positive and statistically significant at the 5 % level. On the contrary, *Technological opportunities* is statistically insignificant in both models. These findings suggest that firms primarily issue green bonds to cover costs associated with physical threats and regulatory compliance, rather than to pursue investments in green technological opportunities.

4.2. Addressing endogeneity

Before extending our analysis on the underlying mechanisms of firm-level climate exposure effect on green financing, we should address endogeneity concerns regarding our baseline results. So far, to account for omitted variable bias and unobserved heterogeneity in our regressions, we have included a vector of control variables, alongside country, industry and year fixed effects. To further address endogeneity concerns, we employ a two-stage least squares instrumental variable regression (2SLS IV) approach and a dynamic Generalized Method of Moments (GMM) approach as in Makrychoriti and Pyrgiotakis (2024).

The primary challenge of the 2SLS IV approach is identifying a valid instrument that satisfies both the relevance and exclusion restrictions. This means finding an instrument that is strongly correlated with the endogenous variable (e.g., climate exposure) but uncorrelated with the error term. For the selection of our instrumental variable, we follow Berkman et al. (2024), and use the average

Table 5
Components of climate exposure This table presents the baseline estimates of Eq. (1) by replacing *Climate exposure* with its components, namely, *Regulation interventions*, *Physical threats*, and *Technological opportunities*. Columns 1 to 3 present the results of logistic regressions, where the dependent variable is a dummy which equals 1 if the firm has announced a green bond issue in year *t*, and 0 otherwise. Columns 4 to 6 present the results of panel regressions, where the dependent variable is the number of green bonds a firm issued in year *t* (0 for non-issuers). All variables are defined in the Appendix. All continuous variables are winsorized at 1% and 99% level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	Green bond issuance			Number of Green bonds		
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Regulation interventions	1.023**			0.045***		
	(2.24)			(2.84)		
Physical threats		5.446***			0.196**	
		(4.04)			(2.52)	
Technological opportunities			0.116			0.002
			(1.21)			(0.75)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	14,629	14,629	13,442	13,442	13,442	13,442
Pseudo R^2/ Adjusted R^2	0.327	0.331	0.330	0.019	0.020	0.016

climate exposure within the firm's industry (*CC_Ind*). We expect *CC_Ind* to satisfy the relevance criterion, as greater industry average climate exposure can positively affect firm-specific climate exposure, while at the same time, it is unlikely to have a direct impact on green firm-level bond issuance. Consequently, we believe that *CC_Ind* also satisfies the exclusion criterion.

Panel A in Table 6 reports the results of the 2SLS IV analysis. Column 1 reports the result of the first-stage regression, using *CC_Ind* as the instrument. Consistent with Berkman et al. (2024), the coefficient of *CC_Ind* is positive and statistically significant at the 1 % level, providing support for the instrument validity. In addition, our instrument passes both the weak identification (Kleibergen-Paap Wald F statistic) and the under-identification tests (Kleibergen-Paap rk LM statistic). Columns 2 and 3 present the results of the second-stage regressions, where the dependent variable is *Green bond issuance* (Column 2) and *Number of Green bonds* (Column 3). The instrumented variables of interest are positive and statistically significant at the 5 % level, or better.

While the 2SLS IV analysis increases our confidence in the baseline results, our estimates could still be biased if past values of the dependent variable are correlated with the current independent variables of interest (Wintoki et al., 2012). This concern is particularly relevant for firms that issued multiple green bonds during our examination period. To address this issue, we implement a Generalized Method of Moments (GMM) approach, which mitigates potential bias by utilizing past values of both the dependent and independent variables as 'internal' instruments.

Panel B of Table 6 presents the results of the dynamic GMM approach.[6] Columns 1 and 2 present the results where the dependent variable is *Green bond issuance* and *Number of Green bonds*, respectively. The coefficient of *Climate exposure* in both model specifications is positive and statistically significant at least at the 5 % level. We assess the validity of overidentifying restrictions using the Hansen J test. Additionally, we test second-order serial correlation in the error terms using the AR (2) test from Arellano and Bond (1991). In both models, these tests suggest that the GMM estimator is valid. Thus, the results of this analysis indicate that the positive relationship between *Climate exposure* and *Green bond issuance* persists even after accounting for any dynamic relationship between past green bond issuances and current firm-level climate change exposure.

4.3. Climate exposure, green bonds and environmental performance

So far, we have established a positive relationship between firm-level climate change exposure and green financing. On the one hand, this finding could be interpreted as evidence of firms' proactiveness in addressing environmental risks. On the other hand, it might be also possible that the motives behind green bond issuance are less environmentally driven, potentially reflecting a strategic response to regulatory or market pressures rather than a genuine commitment to sustainability. In fact, there is growing scepticism about the true intentions behind green bond issuance. For example, Lam and Wurgler (2024) find that only 2 % of proceeds from corporate and municipal green bonds finance new green projects. This raises questions about the actual impact of green bonds issued by firms with high climate change exposure. Do these bonds contribute to improvements in corporate sustainability, or are they a tool for signalling environmental responsibility without substantive action?

To address these questions, we investigate whether green bonds' issuance is associated with an increase in firms' *ESG score* and/or a decrease in *CO_2 emissions*. We collect data on ESG scores and CO_2 emissions (Greenhouse gas, GHG) emissions from Refinitiv (ASSET

[6] We implement the dynamic GMM approach as in Makrychoriti and Pyrgiotakis (2024). For this approach, we use the xtabond2 command in Stata 17 using the options "lag (2 4)" to indicate the most recent and the most distance lag, respectively, and "collapse" to avoid instrument proliferation. Furthermore, we assume firm size, Tobin's q, the two country-level controls, and country, year and industry dummies to be strictly exogenous using the option "iv".

Table 6
2SLS IV and GMM This table presents the results of our 2SLS IV regressions (Panel A) or dynamic GMM regressions (Panel B). In Panel A, column 1 reports the result of the first-stage regression, using *CC_Ind* as the instrument. *CC_Ind* is the annual average climate exposure within the firm's industry. Columns 2 and 3 present the results of the second-stage regressions, where the dependent variable is *Green bond issuance* (Column 2) and *Number of Green bonds* (Column 3). All continuous variables are winsorized at 1% and 99% level. *T*-statistics (in parentheses) are based on standard errors clustered at the firm and year levels. The symbols *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	Climate exposure	Green bond issuance	Number of Green bonds
Panel A: 2SLS IV	(1)	(2)	(3)
CC_Ind	0.970***		
	(8.29)		
Climate exposure (Instrumented)		0.008**	0.015***
		(2.36)	(2.64)
Baseline controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	14,629	14,629	14,629
Adjusted R^2	0.305	0.006	0.007
Underidentification test (Kleibergen-Paap rk LM statistic)	63.506		
Weak identification test (Kleibergen-Paap Wald F statistic)	68.655		
	Green bond issuance		Number of Green bonds
Panel B: GMM	(1)		(2)
Climate exposure	0.001***		0.002**
	(3.21)		(2.17)
Baseline controls	Yes		Yes
Country FE	Yes		Yes
Industry FE	Yes		Yes
Year FE	Yes		Yes
N	14,629		14,629
AR (1) test (*p*-value)	0.001		0.227
AR (2) test (*p*-value)	0.484		0.579
Hansen test of overidentifying restrictions (*p*-value)	0.704		0.595

4). GHG emissions are measured as the sum of the direct (Scope 1) and indirect (Scope 2) carbon dioxide (CO_2) emissions and CO_2 equivalents (Refinitiv item: ENERDP023). Our dependent variable is then estimated as the natural logarithm of the CO_2 emissions scaled by the book value of assets.[7] The analysis is repeated in the year end of the bond issue, as well as in years + 1 and + 2 after the issue.[8]

Table 7 presents the results from panel regressions where the dependent variable is either the firms' *ESG score* (model 1 to 3), or the *CO_2 emissions* (model 4 to 6). Overall, *Green bond issuance* is not statistically significant in any of the models, except for Model 1, where it is positive and marginally significant. Conversely, *Climate exposure* in positive and statistically significant at the 1 % level in model 1 and at the 10 % level in model 2, while it is also positive and highly statistically significant in models 4 to 6. For the *ESG* regressions, these results suggest that in the year *t*, firms with high climate change exposure achieve higher ESG scores, potentially due to their greater tendency to issue green bonds. However, this effect diminishes in later years. For the *CO_2 emissions* regressions, the results align with expectations, as firms with greater climate exposure are typically associated with brown industries (Sautner et al., 2023a).

Altogether, our findings suggest that green bond issuance does not necessarily lead to an improvement in corporate environmental performance and/or a reduction in carbon emissions. However, the lack of statistical significance should be interpreted with caution, as it does not provide conclusive evidence of greenwashing. For instance, it is possible that CO_2 emission reductions achieved through green bond-funded projects are offset by increased emissions from other firm activities (Ehlers et al., 2020).

4.4. Psm-matching and difference-in-differences specification

One potential issue in our empirical analysis is the presence of systematic differences between green bond issuers and non-issuers. To address this concern, we have included a set of control variables in our model specifications. However, limited distributional overlap in characteristics among firms could still bias our regression estimates (Heckman et al., 1998). To mitigate this problem, we employ a propensity score matching (PSM) approach to match green bond issuers with comparable non-issuers.

On the matching approach is inspired by Flammer et al. (2021). More precisely, for each country, year, and Fama-French industry group, green bond issuers are matched with non-issuers on the basis of *Climate exposure, Size, Tobin's Q, Leverage*, and *ROA*. *Size, ROA, Tobin's Q*, and *Leverage* are commonly used in the literature to construct a set of comparable firms (e.g., Almeida et al., 2009; Frésard and Valta, 2016; Flammer, 2021). We also include *Climate exposure* to ensure that firms being compared have similar exposures to

[7] Scaling CO_2 with total assets ensures cross-sectional comparability and bypasses potential heterogeneity issues among different units.
[8] Results do not change if we extend the analysis to +3 years after the issue.

Table 7
Climate exposure, green bonds and environmental performance This table presents panel regressions results where the dependent variable is either the firms' ESG score, or the *CO_2 emissions*, measured as the natural logarithm of the CO_2 emissions scaled by the book value of assets (in $ dollars). The analysis is repeated in the year end of the bond issue, as well as in years + 1 and + 2 after the issue. All variables are defined in the Appendix. All continuous variables are winsorized at 1 % and 99 % level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10 %, 5 % and 1 % levels, respectively, using a 2-tail test.

	ESG			CO_2 emissions		
	Year t	Year $t+1$	Year $t+2$	Year t	Year $t+1$	Year $t+2$
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Green bond issuance	2.840*	3.030	1.222	0.116	0.008	0.132
	(1.68)	(1.28)	(0.44)	(0.49)	(0.03)	(0.42)
Climate exposure	0.234***	0.172*	0.096	0.072***	0.078***	0.083***
	(3.99)	(1.66)	(0.84)	(5.46)	(5.23)	(5.20)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	10,313	5,511	3,838	5,846	3,362	2,269
Adjusted R^2	0.494	0.495	0.492	0.543	0.530	0.551

climate risks. By matching on this dimension, we mitigate the concern of unobservable characteristics creating a spurious correlation between climate exposure and green bond issuance. Additionally, matching firms based on country, industry, and year ensures that treated and matched control firms operate under similar business conditions, including economic, regulatory, and other external factors (Flammer, 2021).

As a next step, we estimate a logistic regression, where the dependent variable equals 1 if the firm has issued a green bond in year *t*, and 0 otherwise. After calculating each firm's propensity score, we employ the nearest-neighbour matching method (with replacement) to pair firms accordingly. Columns 4 and 5 in Table 8 replicate the baseline regressions of Table 4, for the PSM-matched sample. *Climate exposure* continues to be positive and statistically significant at the 5 % level, or better, suggesting that our findings remain qualitatively the same even when we account for systematic differences between issuers and non-issuers.[9]

Thus far, our results do not support the idea that green bond issuance is associated with improvements in environmental performance. However, in the absence of an exogenous shock, these results are far from causal. Hence, to establish causality, we estimate a difference-in-differences (Did) model as in Flammer (2021). Specifically, the following regression is estimated:

$$ESG|CO2emissions_{i,t} = a_i + a_c \times a_t + a_s \times a_t + \beta \times GreenBondIssuance_{\iota,t} + \varepsilon_{i,t} \quad (2)$$

ESG scores or *CO_2 emissions is* the outcome variable of interest, i denotes firms, t years, c countries, and s Fama-French industries; a_i are firm fixed effects, $a_c \times a_t$ are country by year fixed effects, $a_s \times a_t$ are industry by year fixed effects, Green bond issuance is a dummy variable ("treatment dummy") that equals 1 if firm i has issued a green bond by year t and 0 otherwise, and ε is the error term.

Random assignment of the treatment is a crucial assumption for the validity of the DiD estimator. However, the issuance of green bonds is not randomly assigned; it is a highly endogenous decision made by firms. Additionally, identifying a quasi-natural experiment in which firms become issuers in a quasi-random manner is challenging. For this reason, we rely on the matching approach of Flammer (2021) who uses the PSM-matches as the plausible counterfactual. In this context, the PSM-matched non-issuing firms are expected to evolve similarly to the issuing firms in the absence of treatment. Consequently, the DiD analysis focuses exclusively on green bond issuers (treated firms) and their PSM-matched counterparts (control firms).

Columns 3 and 4 of Table 8 present the results of the DiD analysis. Overall, the results are similar with what reported in Table 7. Specifically, the DiD estimator is positive and statistically significant at the 5 % level when *ESG* is the dependent variable but loses any significance when *CO_2 emissions* is the dependent variable. Yet again, we do not find any evidence that green bond issuance leads to lower carbon emissions. This result is supportive of recent findings which suggest that green bonds do not lead to measurable environmental benefits (ElBannan and Löffler, 2024).

5. Additional analysis

5.1. Climate exposure and green bond characteristics

In the section, we examine the relationship between firm-level climate change exposure and green bond characteristics; specifically, the funds raised from the green bond issuance, the green bond coupon rate and the green bond time to maturity. In our model specifications we include the same baseline controls and control for country, industry and year fixed effects.

Table 9 presents the results of this analysis. The dependent variable in model 1 is the natural logarithm of funds raised from the

[9] Untabulated analysis indicates that there are no significant differences in observable characteristics between issuers and non-issuers in the propensity score matched sample.

Table 8
PSM-matching and difference-in-differences This table presents results on the PSM-matched sample. For each country, year, and Fama-French industry group, green bond issuers are matched with non-issuers on the basis of *Climate exposure*, *Size*, *Tobin's Q*, *Leverage*, and *ROA*. The matching is conducted using the nearest-neighbor approach (with replacement). Columns 1 and 2 replicate the baseline models of Table 4. Columns 3 and 4 present the results of the difference-in-differences regressions. All variables are defined in the Appendix. All continuous variables are winsorized at 1% and 99% level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	Baseline estimates		DiD model	
	Green bond issuance	Number of Green bonds	ESG	CO_2 emissions
Variables	(1)	(2)	(3)	(4)
Green bond issuance			1.379**	0.029
			(2.47)	(0.63)
Climate exposure	0.312***	0.033**		
	(2.59)	(5.09)		
Baseline controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	No	No
Industry FE	Yes	Yes	No	No
Year FE	Yes	Yes	No	No
Country × Year FE	No	No	Yes	Yes
Industry × Year FE	No	No	Yes	Yes
Firm FE	No	No	Yes	Yes
N	650	650	960	831
Pseudo R^2/ Adjusted R^2	0.514	0.139	0.919	0.968

Table 9
Climate exposure and green bond characteristics This table presents panel regression results on the green bond sample. The dependent variable is the natural logarithm of funds raised from the issue (*Amount in $)* in model 1, the coupon rate (*Coupon rate*) in model 2, and the natural logarithm of the number of days between maturity and issue (*Time to maturity*) in model 3. All variables are defined in the Appendix. All continuous variables are winsorized at 1% and 99% level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	Amount ($)	Coupon rate	Time to maturity
Variables	(1)	(2)	(3)
Climate exposure	−0.146***	0.092***	0.064***
	(−7.71)	(32.78)	(8.77)
Baseline controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	161	161	161
Adjusted R^2	0.760	0.783	0.630

issue (*Amount in $*), in model 2 the coupon rate (*Coupon rate*), and in model 3 the natural logarithm of the number of days between maturity and issue (*Time to maturity*). We observe a negative relationship between *Climate exposure* and the green bond proceeds. Conversely, coupon yield and the time to maturity are higher for highly exposed issuers. More specifically, in model 1 the coefficient of *Climate exposure* appears to be negative and equal to − 0.146, while in model 2 and model 3 the coefficients are positive and equal to 0.092 and 0.064, respectively. Notably, all three coefficients are statistically significant at the 1 % level.

Our findings indicate that firms facing greater exposure to climate change tend to issue green bonds with lower amounts, higher coupon rates, and longer maturities. This aligns with existing research suggesting that firms subject to climate risk pay a premium when issuing bonds (Huang et al., 2018) and are more likely to issue bonds with extended maturities (Painter, 2020). A plausible explanation for this behavior is that managers of firms exposed to climate risk adopt a more cautionary approach to short-term financing, as they may be concerned about potential difficulties in repaying debt should extreme weather events lead to significant financial losses.

5.2. *Further robustness checks*

Finally, we implement several robustness tests to ensure the stability of our baseline results. So far, we have not tested for the potential impact of aggregate risk measures in our results. For instance, Huang et al. (2018) show that Climate Risk (*CRI*) can affect the financing choices of a firm, while Ozkan et al. (2023) demonstrate that firms located in countries with intense climate risk, tend to engage more in corporate, social and responsible (CSR) activities. To alleviate this concern, we re-run our baseline regressions by including the Climate Risk index in our baseline specifications. We download Climate risk for each country of our sample from Germanwatch.[10] This index reflects the degree to which countries and regions experience losses (fatalities and economic losses) from natural disasters and extreme weather events (Chang et al., 2024; Ozkan et al., 2023). Columns 1 and 2 in Table 10 report our baseline estimates with the inclusion of county-level climate risk index (CRI). In line with our expectations, we observe that *Climate exposure* remains positive and statistically significant at the 1 % level, in both model specifications, suggesting that our results remain robust even after accounting for aggregate climate risk. As further robustness test, we replace country and industry fixed effects with firm fixed effects. To allow for the inclusion of fixed effects, we estimate a linear probability model instead of a logistic regression in column 3. Columns 3 and 4 of Table 10, report our baseline estimates with the inclusion of firm fixed effects. Finally, to ensure that our results do not simply reflect a US effect, we re-run our baseline regressions by excluding US firms from the sample. Our results hold.[11]

6. Conclusion

Climate change poses significant risks to the global economy, with firms being increasingly exposed to climate-related financial risks. These risks, include physical threats such extreme weather events and transition risks associated with shifting toward a low-carbon economy. Addressing these challenges necessitates urgent and comprehensive strategies to mitigate climate impacts and foster sustainable economic practices. For firms highly exposed to climate risk, green bond issuance can serve both as a tool for financing climate-resilient projects, but also as a signal to investors of the firm's commitment to environmental responsibility. At the same time, these firms may encounter greater difficulties in issuing green bonds, as investors often demand a premium for climate risks.

In this study, we examine the relationship between firm-level climate risk exposure and green bond issuance. Our baseline results reveal a positive relationship, suggesting that firms exposed to climate change are more likely to issue green bonds. Furthermore, we show that this relationship is primarily driven by the need to hedge against physical and regulatory risks, rather than capitalizing on emerging technological opportunities. In terms of environmental benefits, our evidence is mixed. On the one hand, issuers achieve higher ESG scores compared to non-issuers with similar characteristics and climate change exposure. On the other hand, this improvement in ESG scores is not accompanied by a decrease in CO_2 emissions. Finally, in terms of green bond characteristics, firms highly exposed to climate change raise fewer funds and issue bonds with higher coupon rates and longer maturities. Our findings are important to policymakers and regulators, as they add to the thin but growing literature which examines determinants of green bond issuance and their impact on corporate sustainability.

Future research could expand dataset coverage by incorporating additional geographical regions as more data on green bonds becomes available. Moreover, a key yet challenging consideration involves evaluating the efficiency of the governance framework within the green bond market, which predominantly operates under a private governance model. An optimal governance structure might benefit from alternative approaches, such as a hybrid model combining private and public governance (Flammer, 2021). Finally, ensuring broad access to detailed information on the use of proceeds and the impact reporting of green projects funded by green bonds could enhance market transparency and credibility.

We thank Prof. Fotios Pasiouras (Montpellier Business School (France), Prof. Spyros Spyrou (Athens University of Economics and Business, Greece) and Prof. George Leledakis (Athens University of Economics and Business, Greece) for their valuable comments on earlier versions of the paper.

CRediT authorship contribution statement

Khaled Guesmi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation. **Panagiota Makrychoriti:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Emmanouil G. Pyrgiotakis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[10] A detailed description of the Climate risk index (CRI) can be found in: https://www.germanwatch.org/en/cri.

[11] In further robustness checks, we have re-run our baseline models by including the Geopolitical risk index of Caldara and Iacoviello (2022). Previous studies document a positive association between geopolitical risk and green bond issuance (Mertzanis and Tebourbi, 2024). We also include two additional country-level controls obtained from World Bank, namely, Income inequality (as measured by the Gini coefficient) and Population growth. Our results remain (see Table A2 in the Appendix).

Table 10
Further robustness checks This table presents additional robustness checks. Columns 1 and 2 report our baseline estimates with the inclusion of county-level climate risk index (CRI). Columns 3 and 4 report our baseline estimates with the inclusion of firm fixed effects. In column 3, we estimate a linear probability model instead of a logistic regression. Columns 5 and 6 report our baseline estimates by excluding US firms from the sample. All variables are defined in the Appendix. All continuous variables are winsorized at 1% and 99% level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively, using a 2-tail test.

	CRI		Firm FE		Excl. US firms	
	Green bond issuance	Number of green bonds	Green bond issuance	Number of green bonds	Green bond issuance	Number of green bonds
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Climate exposure	0.275***	0.008***	0.004**	0.007*	0.265***	0.212***
	(7.32)	(2.67)	(2.31)	(1.86)	(3.16)	(3.86)
CRI	0.000	0.000				
	(0.03)	(0.64)				
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	No	No	Yes	Yes
Industry FE	Yes	Yes	No	No	Yes	Yes
Firm FE	No	No	Yes	Yes	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	18,140	14,629	13,465	13,465	1,167	1,167
Pseudo R^2/ Adjusted R^2	0.368	0.027	0.181	0.188	0.446	0.090

Appendix

Table A1
Description of variables.

Variable	Description
Green bond issuance	Dummy variable which equals 1 if the firm was issued a green bond in year *t*, and 0 otherwise.
Number of green bonds	Number of green bonds issued by the firm in year *t*.
Climate exposure	Firm-level climate exposure as measured by Sautner et al. (2023a).
Size	The natural logarithm of the firm's market value of equity (Compustat Global).
Tobin's Q	The ratio of the firms' market value of assets to book value of assets (Compustat Global).
Leverage	The ratio of the firms' book value of debt to the book value of assets (Compustat Global).
ROA	The ratio of the firms' net income to the book value of assets (Compustat Global).
Cash	The ratio of the firms' cash and cash equivalents to the book value of assets (Compustat Global).
Capital expenditures	The ratio of the firms' capital expenditures to the book value of assets (Compustat Global).
Intangibles	The ratio of the firms' intangible assets to the book value of assets (Compustat Global).
ESG	The firms' ESG score (ASSET 4).
CO_2 emissions	The natural logarithm of the ratio between total emissions (Tonnes) and total assets (Refinitiv) Direct (Scope 1) and indirect (Scope 2) carbon dioxide (CO_2) emissions and CO_2 equivalents in tonnes (Refinitiv item: ENERDP023)
% GDP growth	The annual (%) change in countries' GDP (World Bank).
Rule of law	The countries' rule of law score, developed by LaPorta et al. (1998).

Table A2
Additional controls This table presents the baseline regressions of Table 4 with the inclusion of additional controls. Columns 1 and 2 report our baseline estimates with the inclusion of Geopolitical risk index of Caldara and Iacoviello (2022). Columns 3 and 4 report our baseline estimates with the inclusion of two additional country-level controls, namely Income inequality and Population growth. Both variables are obtained from the World Bank database. All variables are defined in the Appendix. All continuous variables are winsorized at 1 % and 99 % level. Robust standard errors, clustered at the firm level, are reported in the parentheses. The symbols *, **, and *** denote statistical significance at the 10 %, 5 % and 1 % levels, respectively, using a 2-tail test.

	Green bond issuance	Number of green bonds	Green bond issuance	Number of green bonds
Variables	(1)	(2)	(3)	(4)
Climate exposure	0.305***	0.011**	0.292***	0.007**
	(6.58)	(2.26)	(6.14)	(2.35)
Income inequality	−0.057	0.007**		
	(−0.09)	(2.09)		
Population growth	1.195	0.011		
	(1.36)	(0.16)		

(*continued on next page*)

Table A2 (*continued*)

Variables	Green bond issuance (1)	Number of green bonds (2)	Green bond issuance (3)	Number of green bonds (4)
Geopolitical risk			0.156***	0.001**
			(3.33)	(2.62)
Baseline controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	No	No
N	14,629	14,629	14,629	14,629
Pseudo R^2/ Adjusted R^2	0.356	0.075	0.382	0.046

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