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# The Effectiveness of Green Bonds in Reducing Carbon Risk

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**Title:** The Effectiveness of Green Bonds in Reducing Carbon Risk

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## **Abstract**

This study analyses the role of green bonds in mitigating carbon-related risks and supporting environmental growth in the European and US markets. Created approximately two decades ago, green bonds are used to finance environmentally friendly projects and to incentivize companies to adopt sustainable practices. This study uses a variety of models, including the CAPM, three-factor, and five-factor models, to investigate how green bonds affect the firms' cumulative abnormal returns (CARs) during carbon-related events using event studies and regression analysis.

The findings show that larger companies with strong ESG ratings better manage risks, while those with higher emissions are penalized by the market. Compared to the US, the European market reacts more strongly to carbon risks. While challenges like inconsistent regulations and greenwashing still exist, this thesis highlights the potential of green bonds to support sustainability.

By looking at both the benefits and drawbacks of green bonds, it offers practical insights for investors, policymakers, and businesses striving for a low-carbon future.

**Keywords:** Green Bonds, Carbon risk, ESG, American Market, European Market

**Título:** A Eficácia dos Obrigações Verdes na Redução do Risco de Carbono

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## Resumo

Este estudo analisa o papel das obrigações verdes na mitigação dos riscos relacionados com o carbono e no apoio ao crescimento ambiental nos mercados europeu e norte-americano. Criadas há cerca de duas décadas, as obrigações verdes são utilizadas para financiar projetos amigos do ambiente e para incentivar as empresas a adotarem práticas sustentáveis. Este estudo utiliza uma variedade de modelos, incluindo o CAPM, o modelo de três fatores e o modelo de cinco fatores, para investigar a forma como as obrigações verdes afetam as rendibilidades anormais acumuladas (CARs) das empresas durante eventos relacionados com o carbono, utilizando estudos de eventos e análises de regressão.

Os resultados mostram que as empresas de maior dimensão com fortes classificações ESG gerem melhor os riscos, ao passo que as empresas com emissões mais elevadas são penalizadas pelo mercado. Em comparação com os EUA, o mercado europeu reage mais fortemente aos riscos de carbono. Embora ainda existam desafios como regulamentações inconsistentes e greenwashing, esta tese destaca o potencial das obrigações verdes para apoiar a sustentabilidade.

Ao analisar tanto as vantagens como as desvantagens das obrigações verdes, esta tese oferece perspectivas práticas para investidores, decisores políticos e empresas que lutam por um futuro com baixas emissões de carbono.

**Palavras-chave:** Obrigações Verdes, Risco de Carbono, ESG, Mercado Americano, Mercado Europeu

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# 1. Introduction

With the increasing occurrence of climate challenges, the financial sector has become an important tool to support sustainability and mitigate environmental risks. In the early 2000s, green bonds were first issued in the market. Green bonds are a financial tool created to support environmentally friendly projects. It became an important way to raise money to aid the development of sustainable initiatives. This type of bond allows the investors to fund projects that aim to, for example, reduce their carbon emissions or to fight against climate change. Green bonds are essentially the same as regular loans with fixed payments but they have a purpose significantly more important than simply funding good environmental projects, they encourage all the other companies to adapt their way of investing and producing and to start having more green practices.

The relationship between green bonds and the mitigation of carbon risk is very important for policymakers, investors, and researchers. Carbon risk refers to the financial impact caused by carbon emissions and events related to climate change. Actually, for companies, this is a major challenge. They need to adapt to a new world that is becoming increasingly more regulated and that considers the environment as a major issue. Different studies highlight that green bonds can help firms lower their carbon emissions, improve their environmental efforts, and support sustainable economic growth. Nevertheless, the effectiveness of green bonds in achieving these goals is still not very clear.

This thesis will examine the role of green bonds in the mitigation of carbon risk, with a particular focus on the European and US markets between January 2008 and August 2024. For that, a robust methodological framework will be employed which includes both event studies and regression analyses. This study aims to analyze how the market reacts to carbon-related events with an examination of the cumulative abnormal returns (CARs) of companies. The analysis incorporates multiple asset pricing models, including the capital asset pricing model (CAPM), the three-factor model (3FF), and the five-factor model (5FF), to provide a comprehensive understanding of how green bonds influence firm resilience and market dynamics.

Furthermore, this research explores companies' firm-specific variables such as Total Assets, the Quick Ratio, debt-to-equity ratio, return on assets (ROA), Carbon Emissions, and ESG (environmental, social, and governance) performance, which collectively influence the

relationship between green bond issuance and carbon risk. By analysing different regions and factors specific to individual companies, the thesis aims to offer practical advice for investors, regulators, and businesses working to manage the challenges of carbon risk and sustainable finance.

## 2. Literature Review

### 2.1 Introduction to Green Bond and Carbon Risk

Climate change and the consumption of carbon started to be a big discussion a few decades ago. At the beginning of the 21st century, green bonds appeared in Europe with the objective of financing projects that respect the environment and the climate. According to Bachelet et al. (2019), a green bond is defined as “a ‘plain-vanilla’ fixed income product” that helps mitigate climate change and gives investors the chance to finance a green project.

With all the climate initiatives that have appeared, green bonds have gained a large interest from companies and investors because they help companies adapt to this new way of producing and consuming. Bachelet et al. (2019) further highlight that “green bonds were considered the main example of an innovative fixed-income investment product that could provide significant amounts of capital to finance the fight against climate change”. Over the years, the green bonds market has grown significantly, additionally, companies have begun to reduce their carbon footprint, which leads us to assume that they may also mitigate their risk linked to carbon events. While Bachelet et al. (2019) provide a broad understanding of green bonds as an instrument for climate financing, this thesis will examine if green bonds have an impact on the firms’ carbon risk reduction.

### 2.2 Green Bonds and Carbon Risk Reduction

Flammer (2021) finds that green bond issuers improve their environmental performance post-issuance. Particularly, concerning increases in companies’ environmental ratings and decreases in CO<sub>2</sub> emissions. Earlier literature, therefore, finds empirical support for the success of green bonds in fulfilling their main purpose of improving companies’ environmental purpose. The positive environmental outcomes associated with green bonds support the carbon footprint reduction of firms, which is a key aspect of mitigating the carbon risk. This thesis expands on previous research by analysing differences across regions to better understand how green bonds can affect carbon risk mitigation.

## 2.3 Role of certification and issuer characteristics

The reputation of the green bond market has vastly improved over time. In general, people associate green bonds with a safer investment. As the years have passed, some companies have started to profit from this belief. This, in turn, led to the appearance of “greenwashing” which has hurt the green bond market.

In response to this, certification of green bonds has become essential to safeguard against greenwashing. Government or supranational institutions inspire trust more easily however private companies need a third-party certification to instill confidence. Once companies can prove their credibility, they are likely to have the opportunity to access more favorable financing conditions. This, in turn, can have a significant impact on green bond pricing. Baker et al. (2018) found that the premium on certified green bonds doubles or triples compared to those that are self-labeled. This shows that green bonds are usually seen as low-risk, attractive bonds for investors, which have a positive impact on the price and the demand. In this thesis we will not analyse whether different companies have received a third-party certification, instead, we will study each company’s carbon consumption and the risk they have linked to carbon which will allow us to better understand if the companies in question are attempting to profit from the green bond system.

## 2.4 Market Reaction to Green Bonds and low carbon investments

With all the major international agreements that have appeared in the last decade due to ongoing climate concerns, investors have become more attracted to both green bonds and other low-carbon investments. On the one hand, this allows investors to have a portfolio that is more in line with the new sustainable reality. On the other hand, this provides investors with a means to mitigate the risks they have linked to carbon. Matsumura et al. (2019) prove that, following the Paris Agreement, the weight of the low-carbon indices within optimal portfolios has increased significantly which suggests that stock market investors have started to consider low-carbon assets to be an appealing investment choice. This thesis aims to provide more information on the ability of green bonds to reduce carbon risk and the risk posed to assets.

## 2.5 Challenges in Green Bond Implementation

There are several problems involved in the implementation of green bonds despite the appeal in the market. Bachelet et al. (2019) show that only around 60% of green bonds are currently externally reviewed which means that not only is bond authenticity subject to major asymmetric information issues but that there is also a lack of consistency in external verification.

Without third-party verification and certification, as discussed earlier, it is somewhat complicated for investors to know whether or not green bonds invest in projects that truly benefit the environment or if it's merely "greenwashing". This can create a lack of confidence and have an overall negative impact on the green bond market. It is important to note that the risk is higher for private companies because governmental institutions are subject to stricter regulations. Because of this, it is more difficult for governmental institutions to engage in "greenwashing". In this thesis, I aim to provide insights into the prevalence of greenwashing in the European and American markets, which, while not yielding results for specific companies, can help investors understand whether this issue is significant. Furthermore, this thesis has the potential to offer valuable insights that can inform effective policy recommendations.

### 3. Data

To analyse the effectiveness of green bonds in reducing carbon risk, I collected diverse datasets from multiple sources to allow a comprehensive study of both market and firm-level responses to green bond issuance. All variables utilized in this study were downloaded specifically for Europe (STOXX Europe 600) and for America (S&P500).

Several firm-specific variables are included in the regression analysis namely Total Assets, Quick Ratio, debt-to-equity and ROA. These variables are included to account for firm-specific factors that may influence abnormal returns. Firm profitability is captured by ROA while firm size is proxied by the natural logarithm of Total Assets. The Quick Ratio represents the liquidity of the firm, the debt-to-equity ratio indicates the Leverage.

To account for firm emissions and sustainability practices, I include both ESG and Carbon Emissions data from Refinitiv. CO<sub>2</sub> equivalent emissions total is used to measure a firm's carbon footprint. Scope 1 to 3 emissions are also included to cover the direct, indirect and value chain emissions. The CO<sub>2</sub> equivalent emission total indicates, in tonnes, the emission of carbon dioxide and CO<sub>2</sub> equivalents, like methane, nitrous oxide, hydrofluorocarbons, perfluorinated compounds, sulfur hexafluoride, and nitrogen trifluoride. To obtain this value they sum Scope 1 and Scope 2 emissions. A greenhouse gas protocol is followed to classify the emissions by type. Concerning Scope 1, it was downloaded on Refinitiv the variable name is "CO<sub>2</sub> equivalent emission direct, Scope 1" which considers the same emissions as the CO<sub>2</sub> equivalent emission total and also follows a protocol to classify the emissions. The values represent the emissions

in tonnes. For Scope 2, I used the variable “CO2 equivalent emission indirect Scope 2” which is calculated in the same way as the two variables mentioned before but in this case, this gives the emission that comes from the consumption of purchased electricity, heat or steam which happen at the place where electricity, steam or heat is produced. Scope 3 follows the same rules but in this case, emissions from contractor-owned vehicles, employee business travel, waste disposal, outsourced work, customer use of products, making materials the company buys, and electricity bought to sell again are measured.

Moving to the ESG score serves as a comprehensive indicator of a company's environmental, social, and governance performance, combining scores from the three dimensions. Specifically, the environmental pillar score evaluates a company's impact on natural systems, including air, land, and water, reflecting its ability to mitigate environmental risks and Leverage opportunities for sustainable practices. The overall ESG combined score not only incorporates self-reported data from the various ESG pillars but also accounts for any ESG-related controversies, providing a more nuanced understanding of a company's commitment to creating long-term value for its shareholders while managing environmental responsibilities.

Figure 1 provides the summary statistics of all the variables mentioned above for Europe.

Variable	Obs	Mean	Std. dev.	Min	Max
Total Asset	12,311	10.1514	0.8650	6.9360	12.6138
Quick Ratio	13,200	0.7830	1.0094	-56.0372	28.6421
D/E Ratio	13,200	1.1496	12.2523	-0.0706	1355.0000
ROA	13,200	0.0504	0.0934	-0.6665	2.4932
Scope1	8,082	4.7806	1.3995	-1.5229	9.5587
Scope2	7,979	4.8157	1.0803	-0.3010	7.4496
Scope3	6,250	5.3906	1.5326	0.4771	9.2140
CO2 Equivalent Emission					
Total	8,900	5.2330	1.2039	0.4771	8.3784
ESG Score	13,200	48.7237	29.9781	0.0000	95.7398
ESG Combined Score	13,200	45.5891	28.0457	0.0000	95.0103
Environmental Pillar Score	13,200	48.6293	33.3828	0.0000	99.2016

Figure 1: Europe Data Summary Statistics

Figure 2 provides summary statistics of the variables for the United States.

Variable	Obs	Mean	Std. dev.	Min	Max
Total Asset	10,536	10.2042	0.6965	6.5218	12.5883
Quick Ratio	10,846	0.9238	1.1219	0.0000	16.3149
D/E Ratio	10,964	1.4802	8.9991	0.0000	422.1000
ROA	10,982	0.0682	0.0913	-5.0200	0.7625
Scope1	5,621	5.2803	1.3148	-0.3010	8.1944
Scope2	5,443	5.3734	0.8185	0.7160	7.8306
Scope3	3,865	5.8143	1.3028	1.4205	9.0682
CO2 Equivalent Emission					
Total	6,059	5.8176	1.0096	1.8865	8.3467
ESG Score	10,996	46.9393	26.2444	0.0000	95.1624
ESG Combined Score	10,996	43.1703	24.2449	0.0000	92.5424
Environmental Pillar Score	10,996	40.4705	31.2771	0.0000	98.5458

Figure 2: United States Data Summary Statistics

Since an event study requires identifying key events, I accessed the EM-DAT database to obtain a list of climatological and meteorological events that occurred over the past 20 years. This data allows me to select specific events to realize the event study. I chose the 5 events that caused the greatest financial damage in Europe and the 5 most damaging events in America.

In terms of robustness, I conducted event studies using three different models: CAPM, the three-factor model (3FF), and the five-factor model (5FF). I sourced all relevant financial data from the Kenneth R. French website to ensure a comprehensive analysis. The data downloaded from the Kenneth R. French website includes Fama/French 3 factors (daily), Fama/French 5 factors (daily), Fama/French European 3 factors (daily), and Fama/French European 5 factors (daily). The coefficients that come from these documents were used to calculate the expected returns of the companies to provide a solid foundation to evaluate their performance.

The inclusion of both firm-level and market data allows me to analyse the impact of each event on specific companies, distinguishing between those that have issued green bonds and those that have not. This differentiation allows for a comparative analysis of the events' impact on green bond-issuing companies versus non-green bond companies, providing knowledge of how green bonds may influence a firm's robustness to carbon risks. This approach supports an understanding of the effectiveness of green bonds across different firm types.

## 4. Methodology

### 4.1 Event Study Approach

Using my 10 selected events and individual stock price data, I conducted an event study. To add to the robustness of my analysis, I applied three different event studies for each region, utilizing the CAPM, 3FF, and 5FF. I employed varying time windows for each event, specifically a (-2,2) and a (-5,5) window, ensuring that the selected events were anticipated to have an immediate impact on the companies analysed. The (-2,2) window is classified as a short event window, while the (-5,5) window represents a long event window.

For the CAPM model, I first calculated returns based on daily stock price data using the following:

$$(1) R_i = (R_i - R_{i-1})/R_{i-1}$$

Where  $R_i$  is the return at day  $i$ . With these returns, I calculated the intercept and slope using Excel's formula functions. Using these values, I then determined the Expected Return using the following formula:

$$(2) ER_i = \alpha_i + \gamma_i \times R_i$$

Here  $ER$  represents the expected return, the  $\alpha$  refers to the intercept value, and the  $\gamma$  indicates the slope value. Finally, I calculated the Abnormal Return for each event using:

$$(3) AR_i = R_i - ER_i$$

Where the  $AR$  signifies the abnormal return.

For the 3FF and 5FF models, the process was slightly different. I used the same initial formula (reference equation (1)) to calculate returns and then applied the respective multi-factor models to calculate the individual factor coefficients. To calculate the coefficients needed for the expected return using the 3FF or 5FF models, I applied Excel's LINEST formula. In each calculation, I used one year of return data, excluding either the 2 days before the event date or 5 days before, depending on the event window. With the returns, I included the corresponding 3FF or 5FF factor values for the same dates. This approach allowed me to obtain the necessary coefficients for each factor in each of the 3FF and 5FF models, which were then used to estimate

the respective expected returns. As with the CAPM, I then calculated the Abnormal Return using the same approach as used for the CAPM version.

After calculating all abnormal returns, I proceeded to determine the cumulative abnormal return for each event. Depending on the event window, I calculated the CAR differently. For the long event window, I used this formula to calculate the cumulative abnormal returns:

$$(4) CAR_{(-5,5)} = \sum_{i=-5}^5 AR_i$$

Similarly, for the short event window, I compute:

$$(5) CAR_{(-2,2)} = \sum_{i=-2}^2 AR_i$$

Once completed, I compiled the results for each event date. To conclude the event-study approach, I conducted a t-test to evaluate whether the CARs are statistically different from zero. This test helps determine if the observed CAR values around the event dates significantly deviate from what would be expected in a normal market environment, where no abnormal returns are anticipated. To conduct the t-test, I tested the null hypothesis by doing:

$$(6) CAR = 0$$

I was able to assess the statistical significance of environmental events on firm returns through the event study. This analysis allows me to examine how firms respond to these environmental events and subsequently investigate the impact that green bond issuances have on these CARs, providing insight into the effectiveness of green bonds in influencing firm performance and market reactions.

## 4.2 Regression Analysis

Next, I combined the CAR results with firm-specific data in Excel. I created a dummy variable to indicate whether a company issued a green bond each year, assigning a value of 0 if no green bonds were issued that year or previously, and 1 if any green bond was issued in the relevant period. In the sample, 120 companies in Europe issued green bonds and 35 in the US.

I subsequently organized this data into six separate Excel files, each containing the CAR values alongside the corresponding firm-specific and green bond information. Following this, I

conducted a series of fixed-effects regressions in STATA to analyse the impact of green bond issuances on firm-specific CAR values. I employed a structured approach to progressively incorporate firm-specific variables, allowing for a better understanding of how different firm characteristics might influence the effect of green bond issuances on CARs. Each regression utilized a fixed-effects model to control for unobserved heterogeneity among firms and incorporated robust standard errors to address any potential heteroskedasticity in my model, thereby ensuring reliable and unbiased results.

$$(7) CAR_i = \alpha + \beta_1 GBDummy_i + \sum \beta_k Controls_i + FirmFE + \epsilon_i$$

Where  $\beta_1$  is the coefficient of the dummy variable, *GBDummy* represents the dummy variable it indicates 1 if the company issued green bonds and 0 if not.  $\beta_k$  is the coefficient for each control variable *k*, *Controls* indicates all my control variables listed in the data part above, *FirmFE* expresses the firm fixed effect, and the  $\epsilon$  symbolize the error term.

## 5. Results

The following section discusses the results of the event study. First, we will comment the cumulative average abnormal returns (CAAR). Next, we will turn to the t-test of the means of the CAARs. The results will be demonstrated for both the long and short event windows. After that, the results from the regressions computed with the control variables will be discussed.

# 5.1 Long Event Window

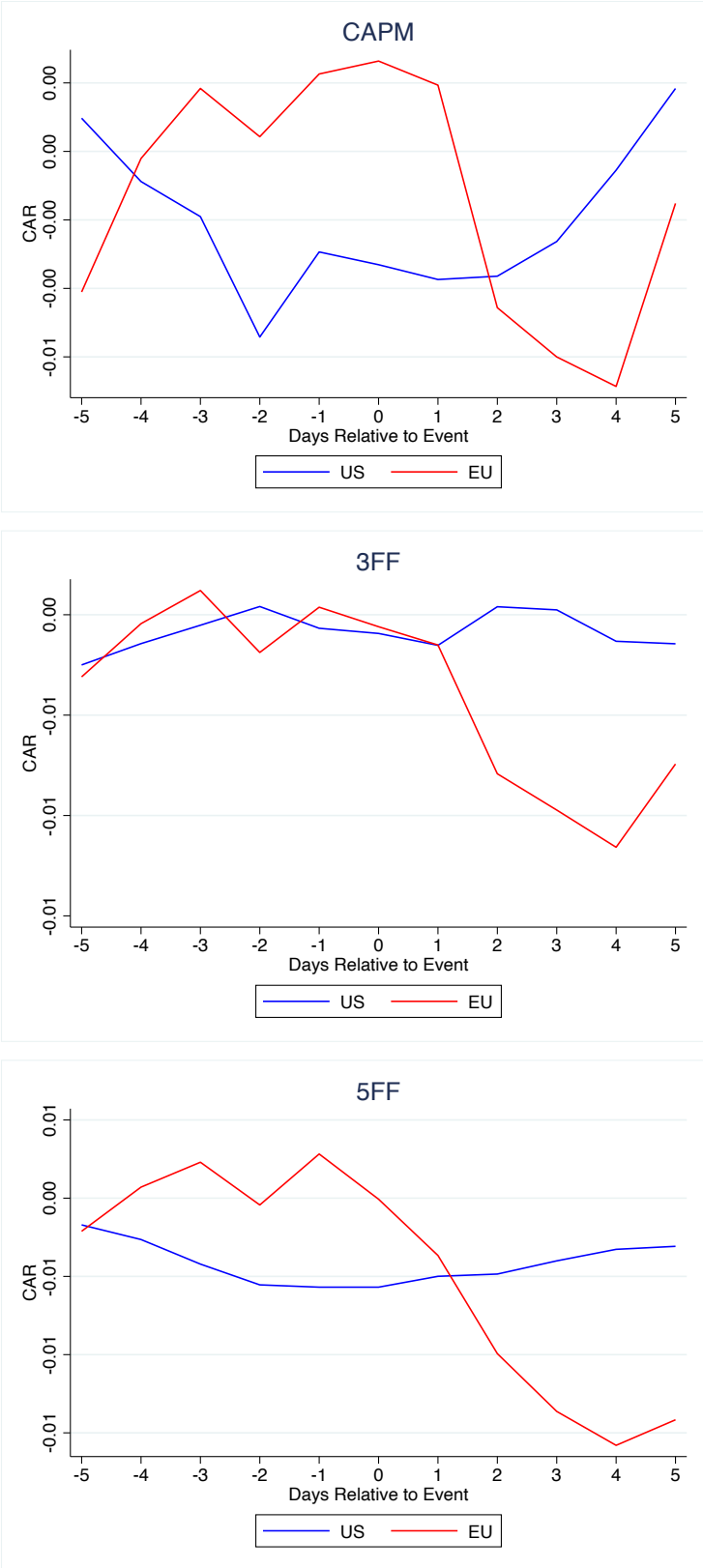


Figure 3: Cumulative Abnormal Return (CAR)

The long event window is a (-5,5) window that captures a broader range of market reactions. This will allow us to have a more comprehensive analysis because it will contain both anticipation effects as well as delayed market responses.

The CAR’s analysis reveals distinct differences between European and US markets, as well as in the different asset pricing models. Europe demonstrates more significant and immediate reactions to the events compared to the United States market. This indicates that Europe seems to have a higher sensitivity to carbon-related risks. In the three models, the European CARs drop from the day after the event until the fourth day. After that, we can observe an increase in the results. The model's effectiveness increases with fewer factors, and the increase from the fourth to the fifth day is significant.

For the United States market, we can observe smoother movements, particularly in the 3FF and 5FF where we don’t observe any impact due to the event. However, for the CAPM model, we can observe a positive impact after the event but before the event, the results were declining.

Model-wise, the 3FF and 5FF models provide smoother trends at least for the US market, while the CAPM model captures greater variability in CAR. This highlights the importance of additional risk factors, such as size, value, profitability, and investment. European markets tend to show stronger responses to these factors, while US markets remain more stable overall.

Region	Model	Obs	Mean	Std. err.	Std. dev.	[95% conf. interval]		t
EU	CAPM	3005	0.0026337	0.0012007	0.0658203	0.0002794	0.004988	2.1935**
EU	3FF	3005	-0.0005953	0.0011114	0.0609249	-0.0027745	0.0015839	-0.5356
EU	5FF	3005	-0.0000655	0.0011263	0.0617407	-0.0022739	0.0021428	-0.0582
US	CAPM	2505	-0.0040534	0.0009861	0.049353	-0.005987	-0.0021198	-4.1106*
US	3FF	2505	-0.0007661	0.0009577	0.0479318	-0.002644	0.0011119	-0.7999
US	5FF	2505	-0.0059041	0.000836	0.0418405	-0.0075434	-0.0042649	-7.0626*

Figure 4: T-test

Regarding the European results, the CAPM model shows a significant positive t-value which means that the CARs are statistically different from zero and it supports the idea that green bonds have a positive impact on carbon risk reduction. However, the other models are not significant which can indicate that the green bonds impact on the carbon risk is small or that the multifactor models are not capturing the correct relationship.

Concerning the US, the results are negative which shows that carbon events harm the market. This supports the idea that carbon risks are material for US firms. Moreover, two models are

significant which reinforces the opinion that green bonds are not helping to reduce the carbon risk. Taking into consideration that there are only 35 companies in the United States that have issued green bonds the results of these companies do not have a lot of impact on the market trend compared to Europe where there are 120 companies that issued green bonds.

Next, we analyse a series of regressions performed based on each model. First, we will start with the European market:

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	-0.0392*** (0.007)	-0.0397*** (0.007)	-0.0397*** (0.007)	-0.0390*** (0.007)	-0.0266*** (0.010)	-0.0252** (0.010)	-0.0258** (0.010)	-0.0109 (0.013)	-0.0329*** (0.007)	-0.0329*** (0.007)	-0.0329*** (0.007)
Quick Ratio		0.0024 (0.003)	0.0024 (0.003)	0.0025 (0.003)	0.0199* (0.006)	0.0220* (0.006)	0.0208*** (0.006)	0.0105 (0.011)	0.0024 (0.003)	0.0025 (0.003)	0.0025 (0.003)
Debt-to-equity ratio			-0.0001 (0.000)	-0.0001 (0.000)	0.0014 (0.001)	0.0014 (0.000)	0.0010 (0.000)	0.0016 (0.003)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)
ROA				-0.0464*** (0.018)	-0.0862* (0.051)	-0.0952* (0.054)	-0.0937* (0.054)	-0.0379 (0.070)	-0.0436** (0.017)	-0.0436** (0.017)	-0.0437** (0.017)
CO <sub>2</sub> equivalent emissions total					-0.0170** (0.007)	-0.0198* (0.011)	-0.0173 (0.019)	-0.0229 (0.021)			
Scope 1						0.0047 (0.010)	0.0038 (0.012)	0.0052 (0.013)			
Scope 2							-0.0043 (0.009)	-0.0004 (0.010)			
Scope 3								-0.0047 (0.003)			
ESG Score									-0.0001 (0.000)	0.0002 (0.000)	0.0002 (0.000)
ESG Combined Score										-0.0003 (0.000)	-0.0003 (0.000)
Environmental Pillar Score											0.0000 (0.000)
Constant	0.3990*** (0.066)	0.4018*** (0.067)	0.4022*** (0.068)	0.3968*** (0.067)	0.3520*** (0.109)	0.3284*** (0.112)	0.3477*** (0.112)	0.2280 (0.143)	0.3422*** (0.073)	0.3416*** (0.073)	0.3413*** (0.073)
Observations	2788	2788	2788	2788	2035	1853	1812	1362	2788	2788	2788
R-squared	0.0237	0.0241	0.0241	0.0266	0.0404	0.0442	0.0447	0.0334	0.0274	0.0282	0.0283
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 5: Regressions for Europe CAPM

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	-0.0110** (0.005)	-0.0116** (0.006)	-0.0116** (0.006)	-0.0110** (0.006)	-0.0090 (0.009)	-0.0056 (0.009)	-0.0065 (0.009)	0.0098 (0.012)	-0.0069 (0.006)	-0.0069 (0.006)	-0.0069 (0.006)
Quick Ratio		0.0032 (0.002)	0.0032 (0.002)	0.0033 (0.002)	0.0082 (0.007)	0.0096 (0.007)	0.0087 (0.008)	-0.0004 (0.009)	0.0032 (0.002)	0.0032 (0.002)	0.0032 (0.002)
Debt-to-equity ratio			0.0001 (0.002)	0.0001 (0.002)	0.0007 (0.001)	0.0007 (0.001)	-0.0002 (0.001)	0.0003 (0.003)	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.000)
ROA				-0.0325 (0.020)	-0.0699 (0.053)	-0.0734 (0.056)	-0.0698 (0.056)	-0.0330 (0.070)	-0.0306 (0.019)	-0.0306 (0.020)	-0.0306 (0.020)
CO <sub>2</sub> equivalent emissions total					-0.0030 (0.005)	-0.0046 (0.010)	-0.0058 (0.019)	-0.0195 (0.019)			
Scope 1						0.0025 (0.009)	0.0035 (0.013)	0.0084 (0.013)			
Scope 2							-0.0014 (0.010)	0.0084 (0.008)			
Scope 3								-0.0027 (0.003)			
ESG Score									-0.0001 (0.000)	0.0000 (0.000)	0.0000 (0.000)
ESG Combined Score										0.0000 (0.000)	0.0000 (0.000)
Environmental Pillar Score											0.0000 (0.000)
Constant	0.1110** (0.054)	0.1147** (0.055)	0.1140** (0.056)	0.1101** (0.055)	0.1027 (0.097)	0.0627 (0.097)	0.0826 (0.098)	-0.0686 (0.127)	0.0732 (0.063)	0.0731 (0.063)	0.0731 (0.063)
Observations	2788	2788	2788	2788	2035	1853	1812	1362	2788	2788	2788
R-squared	0.002	0.0029	0.003	0.0044	0.006	0.0063	0.0061	0.0039	0.0048	0.0049	0.0049
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 6: Regressions for Europe 3FF

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	-0.0081 (0.006)	-0.0086 (0.006)	-0.0085 (0.006)	-0.0079 (0.006)	-0.0088 (0.009)	-0.0050 (0.009)	-0.0052 (0.009)	0.0106 (0.012)	-0.0035 (0.007)	-0.0035 (0.007)	-0.0035 (0.007)
Quick Ratio		0.0024 (0.002)	0.0025 (0.002)	0.0026 (0.002)	0.0127*** (0.007)	0.0136*** (0.007)	0.0124*** (0.008)	0.0003 (0.010)	0.0025 (0.003)	0.002501 (0.003)	0.0025 (0.003)
Debt-to-equity ratio			0.0001 (0.000)	0.0001 (0.000)	0.0011 (0.001)	0.0010 (0.001)	0.0002 (0.000)	0.0006 (0.002)	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.000)
ROA				-0.0396** (0.017)	-0.1032** (0.052)	-0.1188** (0.056)	-0.1131** (0.055)	-0.0851 (0.065)	-0.0376** (0.017)	-0.0376** (0.017)	-0.0380** (0.017)
CO <sub>2</sub> equivalent emissions total					-0.0086 (0.006)	-0.0058 (0.010)	-0.0221 (0.017)	-0.0254 (0.020)			
Scope 1						-0.0021 (0.010)	0.0030 (0.012)	0.0039 (0.013)			
Scope 2							0.0103 (0.007)	0.0129 (0.009)			
Scope 3								-0.0054** (0.003)			
ESG Score									-0.0001 (0.000)	0.0000 (0.000)	-0.0002 (0.000)
ESG Combined Score										-0.0001 (0.000)	-0.0001 (0.000)
Environmental Pillar Score											0.0002 (0.000)
Constant	0.0825 (0.057)	0.0853 (0.057)	0.0845 (0.057)	0.0798 (0.058)	0.1285 (0.098)	0.0836 (0.101)	0.0994 (0.100)	-0.0281 (0.125)	0.0401 (0.066)	0.0399 (0.066)	0.0385 (0.066)
Observations	2788	2788	2788	2788	2035	1853	1812	1362	2788	2788	2788
R-squared	0.0024	0.0029	0.0029	0.0049	0.0149	0.0159	0.0165	0.0165	0.0054	0.0055	0.0061
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 7: Regressions for Europe 5FF

In the regressions, several variables were found to be significant and highlight important trends in market reactions. First, Total Assets show a negative and significant coefficient in the CAPM and 3FF model, indicating that firms experience lower CARs. This may reflect an increase in the evaluation made by investors. Second, the Quick Ratio, with positive and significant coefficients in some regressions of the CAPM and 5FF model, suggests that firms with higher liquidity are better protected against negative market reactions, likely due to their short-term financial resilience. Additionally, CO2 equivalent emissions total show negative and significant coefficients, which indicates that firms with higher emissions are penalized by the market, because investors perceive greater risks associated with higher carbon exposure. Lastly, return on assets has negative and significant coefficients, suggesting that more profitable firms experience lower CARs.

The R-squared values are low, which indicates that these models explain only a small proportion of the variance in CARs, a common occurrence in event studies where external factors heavily influence market reactions.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	-0.0041 (0.007)	-0.0033 (0.007)	-0.0033 (0.007)	-0.0001 (0.006)	0.0025 (0.013)	0.0066 (0.015)	0.0106 (0.015)	0.0117 (0.019)	0.0081 (0.008)	0.0074 (0.008)	0.0080 (0.008)
Quick Ratio		0.0034 (0.002)	0.0035 (0.002)	0.0038 (0.002)	0.0018 (0.003)	0.0033 (0.003)	0.0032 (0.003)	0.0053 (0.003)	0.0038 (0.002)	0.0037 (0.002)	0.0037 (0.002)
Debt-to-equity ratio			0.0001 (0.000)	0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	0.0000 (0.000)	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.000)
ROA				-0.0741** (0.031)	-0.0370 (0.044)	-0.0161 (0.046)	-0.0115 (0.046)	0.0233 (0.057)	-0.0675** (0.032)	-0.0642** (0.032)	-0.0652** (0.031)
CO <sub>2</sub> equivalent emissions total					0.0184** (0.009)	0.0341** (0.017)	0.0348 (0.023)	0.0044 (0.035)			
Scope 1						-0.0217 (0.015)	-0.0257* (0.015)	-0.0251 (0.019)			
Scope 2							-0.0035 (0.009)	-0.0104 (0.024)			
Scope 3								-0.0017 (0.002)			
ESG Score									-0.0002** (0.000)	0.0002 (0.000)	0.0003 (0.000)
ESG Combined Score										-0.0005*** (0.000)	-0.0005*** (0.000)
Environmental Pillar Score											-0.0001 (0.000)
Constant	0.0386 (0.068)	0.0272 (0.069)	0.0268 (0.069)	-0.0013 (0.066)	-0.1355 (0.161)	-0.1584 (0.167)	-0.1662 (0.172)	-0.1920 (0.219)	-0.0732 (0.075)	-0.0664 (0.075)	-0.0724 (0.075)
Observations	2457	2457	2457	2457	1749	1658	1628	1181	2457	2457	2457
R-squared	0.0007	0.0021	0.0025	0.0075	0.0061	0.01	0.0092	0.0141	0.0104	0.0146	0.0152
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 8: Regressions for US CAPM

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	0.0065 (0.007)	0.0063 (0.007)	0.0063 (0.007)	0.0071 (0.006)	-0.0100 (0.011)	-0.0184 (0.011)	-0.0159 (0.011)	-0.0132 (0.013)	-0.0046 (0.008)	-0.0044 (0.008)	-0.0040 (0.008)
Quick Ratio		-0.0010 (0.003)	-0.0010 (0.003)	-0.0009 (0.003)	-0.0016 (0.003)	-0.0019 (0.003)	-0.0024059 (0.003)	0.0021 (0.003)	-0.0008 (0.003)	-0.0008 (0.003)	-0.0008 (0.003)
Debt-to-equity ratio			0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0005 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)
ROA				-0.0185 (0.039)	-0.0574 (0.047)	-0.0543 (0.049)	-0.0570835 (0.049)	-0.0990* (0.059)	-0.0280 (0.039)	-0.0288 (0.039)	-0.0297 (0.039)
CO <sub>2</sub> equivalent emissions total					0.0026 (0.007)	-0.0015 (0.009)	-0.0147 (0.018)	-0.0066 (0.028)			
Scope 1						0.0099 (0.009)	0.0118662 (0.009)	0.0087 (0.012)			
Scope 2							0.0085557 (0.012)	0.0036 (0.020)			
Scope 3								0.0028 (0.002)			
ESG Score									0.0003*** (0.000)	0.0002 (0.000)	0.0003 (0.000)
ESG Combined Score										0.0001 (0.000)	0.0001 (0.000)
Environmental Pillar Score											-0.0001 (0.000)
Constant	-0.0674 (0.070)	-0.0641 (0.074)	-0.0641 (0.074)	-0.0711 (0.068)	0.0981 (0.116)	0.1576 (-0.119)	0.1518536 (0.118)	0.1020 (0.126)	0.0321 (0.078)	0.0304 (0.078)	0.0254 (0.078)
Observations	2457	2457	2457	2457	1749	1658	1628	1181	2457	2457	2457
R-squared	0.0078	0.0079	0.0079	0.0082	0.0066	0.009	0.0092	0.0111	0.0146	0.0149	0.0153
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 9: Regressions for US 3FF

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	-0.0063 (0.006)	-0.0059 (0.002)	-0.0059 (0.006)	-0.0024 (0.006)	0.0022 (0.012)	0.0034 (0.013)	0.0072 (0.013)	0.0065 (0.016)	0.0055 (0.006)	0.0051 (0.006)	0.0053 (0.006)
Quick Ratio		0.0017 (0.002)	0.0017 (0.002)	0.0020 (0.002)	0.0023 (0.002)	0.0032 (0.003)	0.0032 (0.003)	0.0046 (0.003)	0.0020 (0.002)	0.0020 (0.002)	0.0019 (0.002)
Debt-to-equity ratio			-0.0001 (0.000)	-0.0001 (0.000)	-0.0003** (0.000)	-0.0003** (0.000)	-0.0003** (0.000)	-0.0003** (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)
ROA				-0.0811* (0.026)	-0.0806* (0.041)	-0.0693 (0.045)	-0.0650 (0.045)	-0.0578 (0.057)	-0.0748* (0.026)	-0.0730*** (0.026)	-0.0733* (0.026)
CO <sub>2</sub> equivalent emissions total					0.0139*** (0.007)	0.0297** (0.014)	0.0227 (0.019)	0.0349 (0.028)			
Scope 1						-0.0219*** (0.013)	-0.0243*** (0.013)	-0.0261 (0.016)			
Scope 2							0.0025 (0.008)	-0.0030 (0.018)			
Scope 3								-0.0035** (0.002)			
ESG Score									-0.0002** (0.000)	0.0000 (0.000)	0.0001 (0.000)
ESG Combined Score										-0.0003*** (0.000)	-0.0003*** (0.000)
Environmental Pillar Score											0.0000 (0.000)
Constant	0.0594 (0.057)	0.0537 (0.058)	0.0539 (0.058)	0.0232 (0.057)	-0.1045 (0.140)	-0.0958 (0.145)	-0.0964 (0.150)	-0.1037 (0.186)	-0.0459 (0.063)	-0.0423 (0.063)	-0.0437 (0.062)
Observations	2457	2457	2457	2457	1749	1658	1628	1181	2457	2457	2457
R-squared	0.0021	0.0026	0.0028	0.0108	0.0123	0.0173	0.0173	0.0271	0.0144	0.016	0.016
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 10: Regressions for US 5FF

In the United States market, we can observe the same trend as in Europe concerning the ROA which indicates that higher profitability is associated with lower CARs. This might show that investors expect profitable firms to handle well climate risks, and that provokes negative reactions in the market when the companies fail to meet the expectations. The ESG score is also relevant in all the models, which shows that the market harms the companies that have bad ESG scores, which means companies that have high emissions. This argument is also proven in the CAPM and 5FF model, with significant coefficients for the CO2 equivalent emissions total, Scope 1, and ESG combined score.

To conclude, the R-squared values are as low as for Europe, and this is normal for event studies since several external factors exist that may influence market reactions.

## 5.2 Short Event Window

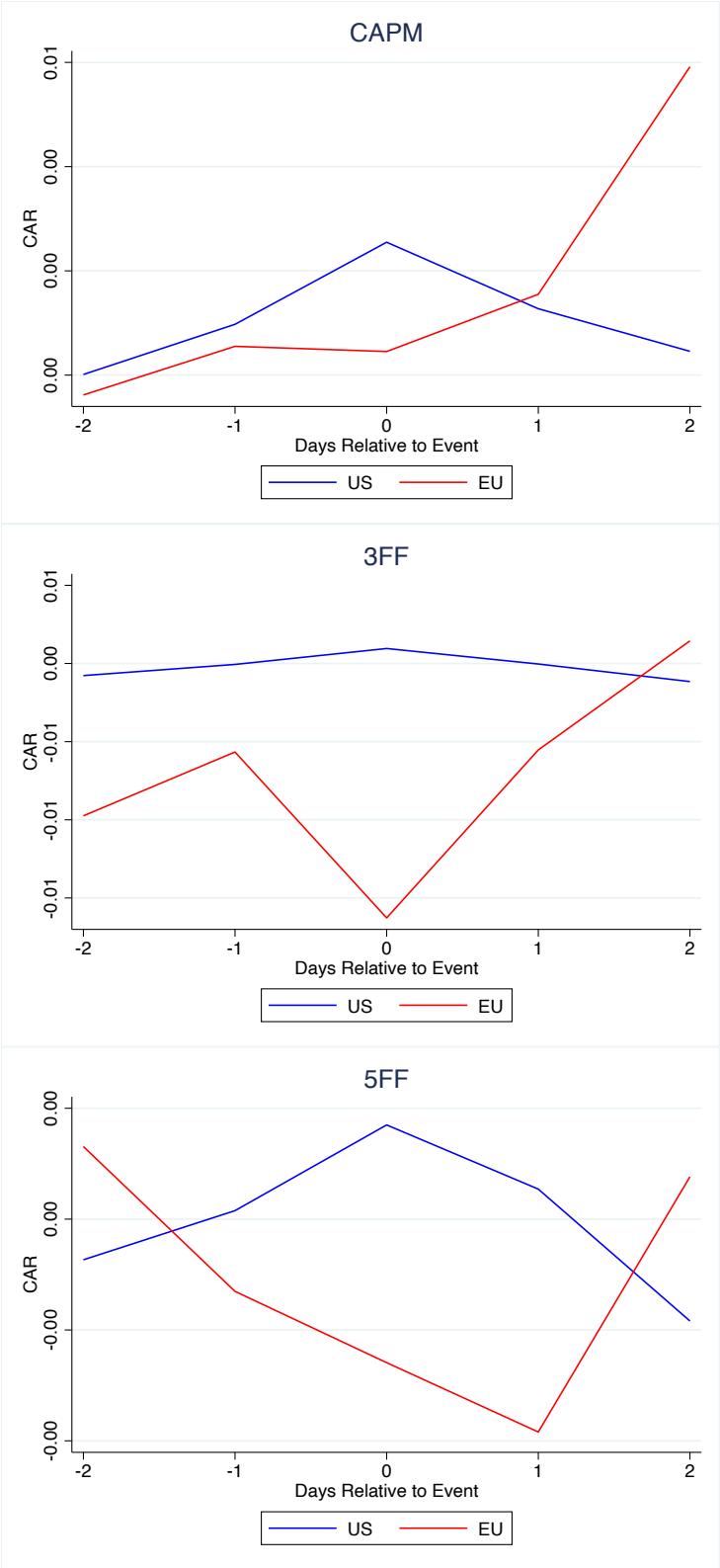


Figure 11: Cumulative Abnormal Return

The short-term event window represents the (-2,2) window. This window captures all the immediate reactions in the market.

Unlike in the long event window, we can observe that the US market is more reactive. In the 3 models, a decline in abnormal returns can be identified after the day of the event. The CAPM and the 5FF models have a higher contrast compared to the 3FF where the US market has a smoother reaction. This can be explained by the fact that the CAPM model oversimplifies the market reactions and for the 5FF the additional factors amplify the reactions of the market. Oppositely, for the European market, we can always observe a positive impact after the event date. But as in the long event window, the European market has more pronounced reactions and is always positive. In Europe, the more factors the model has, the smoother the reaction becomes.

Region	Model	Obs	Mean	Std. err.	Std. dev.	[95% conf. interval]		t
Europe	CAPM	3005	0.0004516	0.007878	0.043186	-0.0010931	0.0019963	0.5732
Europe	3FF	3005	-0.0162487	0.0010491	0.0575079	-0.0183056	-0.0141917	-15.4886*
Europe	5FF	3005	-0.0012929	0.0007651	0.0419392	-0.002793	0.0002072	-1.69***
America	CAPM	2505	0.0025617	0.0006323	0.0316441	0.0013219	0.0038015	4.0517*
America	3FF	2505	0.0009661	0.0005743	0.0287417	-0.00016	0.0020922	1.6824***
America	5FF	2505	0.0008623	0.0005779	0.0289242	-0.0002709	0.0019956	1.4922

Figure 12: T-test

The results observed in the Figure above are the opposite of the results in Figure 2. In this case, the significant models in the European market are the 3FF and particularly the 5FF. In the 3FF we have very high results that show that the companies are badly impacted by the carbon events. However, adding profitability and investment factors, reduces the strength of the market reaction. But we can still observe a negative impact. But in a sample of 600 companies only 120 companies are issuing green bonds, the markets don't necessarily represent the companies that issue green bonds.

For the US the results are much better in this short event window. This result suggested that the market may view carbon-related events as less destructive or potentially even favorable for American firms. CAPM and 3FF models are significant. However, the lack of significance in the 5FF model can indicate that adding factors dilutes the impact of the green bonds.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	-0.0033 (0.004)	-0.0036 (0.004)	-0.0035 (0.004)	-0.0032 (0.004)	0.0029 (0.006)	0.0027 (0.006)	0.0013 (0.006)	-0.0028 (0.009)	-0.0034 (0.005)	-0.0034 (0.005)	-0.0034 (0.005)
Quick Ratio		0.0016 (0.002)	0.0016 (0.002)	0.0017 (0.002)	0.0057 (0.006)	0.0076 (0.006)	0.0069 (0.006)	-0.0011 (0.003)	0.0017 (0.002)	0.0017 (0.002)	0.0016 (0.002)
Debt-to-equity ratio			0.0001 (0.000)	0.0001 (0.000)	0.0008 (0.001)	0.0008 (0.001)	0.0004 (0.001)	0.0023 (0.002)	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.000)
ROA				-0.0220** (0.009)	-0.0192 (0.041)	-0.0269 (0.042)	-0.0338 (0.043)	0.0022 (0.051)	-0.0221** (0.009)	-0.0221** (0.009)	-0.0217** (0.009)
CO <sub>2</sub> equivalent emissions total					-0.0015 (0.004)	-0.0066 (0.008)	-0.0050 (0.014)	-0.0006 (0.013)			
Scope 1						0.0053 (0.008)	0.0055 (0.010)	0.0049 (0.009)			
Scope 2							-0.0039 (0.006)	-0.0040 (0.007)			
Scope 3								0.0043 (0.002)			
ESG Score									0.0000 (0.000)	0.0001 (0.000)	0.0002 (0.000)
ESG Combined Score										-0.0001 (0.000)	0.0000 (0.000)
Environmental Pillar Score											-0.0001 (0.000)
Constant	0.0331 (0.038)	0.0349 (0.038)	0.0341 (0.038217)	0.0315 (0.038)	-0.0273 (0.067)	-0.0246 (0.068)	0.0017 (0.069)	0.0035 (0.089)	0.0337 (0.044)	0.0336 (0.044)	0.0347 (0.044)
Observations	2788	2788	2788	2788	2035	1853	1812	1362	2788	2788	2788
R-squared	0.0044	0.0048	0.0049	0.0061	0.0106	0.0141	0.0148	0.0192	0.0061	0.0062	0.0069
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 13: Regressions for Europe CAPM

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	0.0817*** (0.006)	0.0814*** (0.007)	0.0815*** (0.007)	0.0812*** (0.006)	0.1037*** (0.009)	0.0983*** (0.009)	0.0963*** (0.009)	0.0724*** (0.013)	0.0589*** (0.008)	0.0589*** (0.008)	0.0588*** (0.008)
Quick Ratio		0.0014 (0.002)	0.0014 (0.002)	0.0014 (0.002)	-0.0013 (0.007)	0.0006 (0.007)	-0.0002 (0.008)	-0.0044 (0.004)	0.0018 (0.002)	0.0018 (0.002)	0.0017 (0.002)
Debt-to-equity ratio			0.0001 (0.000)	0.0001 (0.000)	-0.0023** (0.001)	-0.0020** (0.001)	-0.0022** (0.001)	-0.0039 (0.003)	0.0002 (0.001)	0.0002 (0.000)	0.0001 (0.000)
ROA				0.0151 (0.026)	0.1228** (0.055)	0.0882 (0.055)	0.0765 (0.055)	0.0796 (0.059)	0.0048 (0.023)	0.0048 (0.023)	0.0055 (0.023)
CO <sub>2</sub> equivalent emissions total					-0.0210*** (0.005)	-0.0235** (0.011)	-0.0263 (0.019)	-0.0182 (0.016)			
Scope 1						0.0011 (0.011)	0.0037 (0.013)	-0.0019 (0.011)			
Scope 2							-0.0024 (0.008)	-0.0045 (0.007)			
Scope 3								0.0128*** (0.002)			
ESG Score									0.0005*** (0.000)	0.0007*** (0.000)	0.0010*** (0.000)
ESG Combined Score										-0.0003 (0.000)	-0.0003 (0.000)
Environmental Pillar Score											-0.0003** (0.000)
Constant	-0.8465*** (0.065)	-0.8449*** (0.066)	-0.8457*** (0.066)	-0.8439*** (0.066)	-0.9792*** (0.096)	-0.9142*** (0.099)	-0.8784*** (0.098)	-0.7056*** (0.134)	-0.6419*** (0.074)	-0.6423*** (0.074)	-0.6400*** (0.074)
Observations	2788	2788	2788	2788	2035	1853	1812	1362	2788	2788	2788
R-squared	0.01256	0.1258	0.1258	0.1261	0.127	0.1232	0.1247	0.1428	0.1399	0.1407	0.1423
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 14: Regressions for Europe 3FF

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	0.0081** (0.003)	0.0077** (0.004)	0.0078** (0.004)	0.0081** (0.004)	0.0095 (0.006)	0.0109* (0.006)	0.0094 (0.006)	0.0078 (0.008)	0.0063 (0.004)	0.0063 (0.004)	0.0063 (0.004)
Quick Ratio		0.0022 (0.002)	0.0022 (0.002)	0.0023 (0.002)	0.0051 (0.006)	0.0065 (0.006)	0.0055 (0.007)	-0.0024 (0.003)	0.0023 (0.002)	0.0023 (0.002)	0.0023 (0.002)
Debt-to-equity ratio			0.0002 (0.000)	0.0002 (0.000)	0.0007 (0.001)	0.0072 (0.001)	0.0002 (0.001)	0.0018 (0.002)	0.0002 (0.000)	0.0002 (0.000)	0.0002 (0.000)
ROA				-0.0166* (0.010)	-0.0157 (0.041)	-0.0316 (0.042)	-0.0366 (0.043)	-0.0073 (0.050)	-0.0174* (0.009)	-0.0174* (0.010)	-0.0172* (0.009)
CO <sub>2</sub> equivalent emissions total					-0.0001 (0.004)	-0.0015 (0.008)	-0.0016 (0.014)	0.0032 (0.013)			
Scope 1						0.0007 (0.008)	0.0013 (0.011)	0.0004 (0.009)			
Scope 2							-0.0022 (0.006)	-0.0016 (0.006)			
Scope 3								0.0040** (0.002)			
ESG Score									0.0000 (0.000)	0.0000 (0.000)	0.0001 (0.000)
ESG Combined Score										0.0000 (0.000)	0.0000 (0.000)
Environmental Pillar Score											-0.0001 (0.000)
Constant	-0.0838** (0.035)	-0.0813** (0.035)	-0.0825** (0.036)	-0.0845** (0.036)	-0.1038 (0.064)	-0.1146* (0.064)	-0.0880 (0.064)	-0.1164 (0.083)	-0.0684* (0.041)	-0.0684* (0.041)	-0.0678* (0.041)
Observations	2788	2788	2788	2788	2035	1853	1812	1362	2788	2788	2788
R-squared	0.0026	0.0035	0.0036	0.0044	0.005	0.0074	0.0065	0.0142	0.0046	0.046	0.0048
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 15: Regressions for Europe 5FF

In the short event window, ROA continues to be a significant and negative coefficient. This continues to suggest that more profitable firms have lower CARs. The coefficient on Total Assets is positive and significant in the 3FF and 5FF model, which indicates that larger firms have higher CARs. As with the Total Assets, Scope 3 can also be observed as significant and positive in the different models. This contradicts other significant coefficients, such as total CO2 equivalent emissions, ESG combined score, and environmental pillar score, which show that firms with better scores and lower Scope 3 emissions experience higher cumulative abnormal returns (CARs). In contrast, the positive relationship indicates that higher indirect emissions correlate with increased CAR. Additionally, the debt-to-equity ratio shows negative and significant coefficients in certain models suggesting that higher Leverage is associated with lower CARs, likely due to perceived financial risk.

The R-squared values indicate that these models explain only a small portion of the variance in CARs, which remains consistent with the findings from the long event window regressions.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	0.0044 (0.004)	0.0044 (0.004)	0.0044 (0.004)	0.0030 (0.004)	0.0084 (0.006)	0.0050 (0.007)	0.0048 (0.007)	0.0077 (0.007)	-0.0052 (0.005)	-0.0051 (0.005)	-0.0059 (0.005)
Quick Ratio		-0.0003 (0.001)	-0.0003 (0.001)	-0.0004 (0.001)	-0.0007 (0.002)	-0.0077 (0.002)	-0.0010 (0.002)	0.0011 (0.002)	-0.0004 (0.001)	-0.0004 (0.001)	-0.0003 (0.001)
Debt-to-equity ratio			-0.0001 (0.000)	-0.0001 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)
ROA				0.0305 (0.029)	0.0708* (0.039)	0.0726* (0.042)	0.0705* (0.042)	0.0427 (0.035)	0.0239 (0.029)	0.0237 (0.029)	0.0252 (0.029)
CO <sub>2</sub> equivalent emissions total					-0.0038 (0.004)	-0.0106* (0.006)	-0.0006 (0.009)	0.0016 (0.012)			
Scope 1						0.0085 (0.006)	0.0064 (0.006)	0.0076 (0.007)			
Scope 2							-0.0100** (0.005)	-0.0151** (0.007)			
Scope 3								0.0018 (0.001)			
ESG Score									0.0002*** (0.000)	0.0002 (0.000)	0.0000 (0.000)
ESG Combined Score										0.0000 (0.000)	0.0000 (0.000)
Environmental Pillar Score											0.0002*** (0.000)
Constant	-0.0430 (0.044)	-0.0420 (0.045)	-0.0419 (0.045)	-0.0303 (0.043)	-0.0680 (0.076)	-0.0374 (0.078)	-0.0276 (0.078)	-0.0602 (0.081)	0.0416 (0.048)	0.0411 (0.048)	0.0500 (0.049)
Observations	2457	2457	2457	2457	1749	1658	1628	1181	2457	2457	2457
R-squared	0.0009	0.0009	0.0011	0.003	0.0091	0.0099	0.0129	0.0157	0.0093	0.0093	0.0121
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 16: Regressions for US CAPM

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	0.0093*** (0.004)	0.0093** (0.004)	0.0093** (0.004)	0.0086** (0.004)	0.0119* (0.006)	0.0081 (0.006)	0.0081 (0.007)	0.0111 (0.007)	-0.0003 (0.004)	-0.0001 (0.004)	-0.0010 (0.004)
Quick Ratio		0.0000 (0.001)	0.0000 (0.001)	-0.0001 (0.001)	-0.0005 (0.002)	-0.0008 (0.002)	-0.0009 (0.002)	0.0012 (0.002)	0.0000 (0.001)	0.0000 (0.001)	0.0000 (0.001)
Debt-to-equity ratio			-0.0002 (0.000)	-0.0002 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0002 (0.000)	-0.0002 (0.000)	-0.0002 (0.000)
ROA				0.0145 (0.025)	0.0165 (0.035)	0.0137 (0.038)	0.0125 (0.037)	-0.0169 (0.031)	0.0073 (0.024)	0.0065 (0.024)	0.0081 (0.024)
CO <sub>2</sub> equivalent emissions total					-0.0042 (0.004)	-0.0094 (0.006)	-0.0017 (0.009)	0.0003 (0.012)			
Scope 1						0.0070 (0.005)	0.0048 (0.006)	44065.0000 (0.006)			
Scope 2							-0.0079* (0.004)	-0.0099 (0.007)			
Scope 3								0.0014 (0.001)			
ESG Score									0.0002*** (0.000)	0.0001 (0.000)	0.0000 (0.000)
ESG Combined Score										0.0001 (0.000)	0.0001 (0.000)
Environmental Pillar Score											0.0002*** (0.000)
Constant	-0.0946*** (0.036)	-0.0947** (0.037)	-0.0943** (0.038)	-0.0888** (0.037)	-0.0987 (0.073)	-0.0655 (0.075)	-0.0551 (0.075)	-0.0947 (0.081)	-0.0103 (0.041)	-0.0119 (0.041)	-0.0026 (0.041)
Observations	2457	2457	2457	2457	1749	1658	1628	1181	2457	2457	2457
R-squared	0.0049	0.0049	0.0064	0.007	0.0054	0.005	0.0076	0.0133	0.0163	0.017	0.0207
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 17: Regressions for US 3FF

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Total Assets	0.0090** (0.003)	0.0090** (0.004)	0.0090** (0.004)	0.0079** (0.004)	0.0109* (0.006)	0.0070 (0.007)	0.0066 (0.007)	0.0099 (0.007)	-0.0006 (0.004)	-0.0004 (0.004)	-0.0013 (0.004)
Quick Ratio		0.0000 (0.001)	-0.0001 (0.001)	-0.0002 (0.001)	-0.0006 (0.002)	-0.0009 (0.002)	-0.0012 (0.002)	0.0010 (0.002)	-0.0001 (0.001)	-0.0001 (0.001)	-0.0006 (0.001)
Debt-to-equity ratio			-0.0002 (0.000)	-0.0002 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0002 (0.000)	-0.0002 (0.000)	-0.0002 (0.000)
ROA				0.0245 (0.024)	0.0303 (0.036)	0.0279 (0.038)	0.0259 (0.038)	-0.0046 (0.030)	0.0176 (0.024)	0.0168 (0.024)	0.0184 (0.024)
CO <sub>2</sub> equivalent emissions total					-0.0030 (0.004)	-0.0075 (0.006)	0.0013 (0.009)	0.0033 (0.012)			
Scope 1						0.0064 (0.006)	0.0040 (0.006)	0.0039 (0.006)			
Scope 2							-0.0088** (0.004)	-0.0111 (0.007)			
Scope 3								0.0012 (0.001)			
ESG Score									0.0002*** (0.000)	0.0001 (0.000)	-0.0001 (0.000)
ESG Combined Score										0.0001 (0.000)	0.0001 (0.000)
Environmental Pillar Score											0.0002*** (0.000)
Constant	-0.0920** (0.036)	-0.0920** (0.037)	-0.0915** (0.037)	-0.0822** (0.037)	-0.0964 (0.075)	-0.0627 (0.076)	-0.0489 (0.075)	-0.0904 (0.080)	-0.0070 (0.041)	-0.0088 (0.041)	0.0059 (0.041)
Observations	2457	2457	2457	2457	1749	1658	1628	1181	2457	2457	2457
R-squared	0.0046	0.0046	0.0063	0.0078	0.0062	0.0055	0.0081	0.0118	0.0163	0.0171	0.0209
Green Bond Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. Levels of significance: \*\*\* p<.01, \*\* p<.05, \* p<.1.

Figure 18: Regressions for US 5FF

Looking at the US market in this short-term event window, we can observe that the coefficients that are relevant in 3 models are Scope 2 with negative values, ESG score and the environmental pillar score with positive values. As for Europe and in the long-term event window, the number of emissions has an impact on the CAR. The more the emissions of a company, the lower the CARs are.

In the CAPM model, the ROA and the CO2 equivalent emission total are also relevant. The CO2 equivalent emission total continues to prove that if the companies don't adapt to the new way of consuming, they will be penalized. Concerning the ROA, the values are positive which indicates that the more profitable the company is, the higher the CARs are, which is the opposite of the results in the long event window.

The last relevant coefficient is on Total Assets, which is relevant in the 3FF and 5FF models. The coefficient is positive and that suggests that the larger the firm the higher the CARs are.

Concerning the R-squared, we continue to have low values for the same reasons mentioned before.

## 5.3 Discussion

This study analysed the market reaction to carbon risk events and the role of green bonds in mitigating these risks.

### 5.3.1 Regional Differences

Distinct differences between the European and the US markets in their sensitivity to carbon events can be observed. Europe shows more pronounced and immediate reactions compared to the US. This demonstrates a higher sensitivity in the European market to carbon risks. For example, in the long event window, Europe tends to drop immediately after a carbon-related event and starts directly recovering in the next few days. This can be due to stricter regulatory frameworks and higher investors' awareness of environmental issues. In contrast, the US has smoother trends. In the US, we don't observe any pronounced reaction to the events.

### 5.3.2 Green Bond Effectiveness

The results suggest that green bonds have a role in the mitigation of carbon risk, but the effectiveness varies depending on the model or the region. For Europe, the CAPM model supports the hypothesis that green bonds positively impact the firms' resilience against the carbon risk, this is observed in the significant t-values. Nevertheless, the 3FF and 5FF models

are not significant which means that green bond effects are less pronounced or not well captured by the factors of the model. On the other hand, in the US market, the CAPM and 3FF models show a positive impact of the green bonds but the overall significance is weak. This could be because of the 500 US companies listed on the S&P 500, only 35 companies have issued green bonds. The problem can also be the same for Europe where of the 600 companies listed on the Stoxx 600, only 120 issued green bonds. The lower amount of green bonds issued, limits their influence on the market trends.

### 5.3.3 Regression Key Determinants

In the regression analyses, we observe that several variables influence how the market views the carbon risk. First, the Total Assets and the ROA have divergent effects across regions. In Europe, these factors indicate that the larger the firm is, the more attention they have from the investor and the more penalized they are concerning carbon risks. Concerning, the United States, the bigger firms are seen as better equipped to manage the carbon risks in the best way. Next, the total CO<sub>2</sub> equivalent emissions and Scope 3 reflect that firms with higher exposure are more penalized. However, Scope 1 and Scope 2 are less significant, which suggests that the value chain emissions are more impactful in explaining CARs than the direct and indirect emissions of the company. The ESG Scores and ESG combined Scores are often significant, suggesting that strong performance is positively valued by investors.

### 5.3.4 Event windows

In the long event window, European markets exhibit more pronounced and volatile reactions, with CARs initially declining after events before recovering. This suggests a dynamic adjustment process where investors incorporate new information about carbon risks over several days. In contrast, the US market shows smoother trends, particularly under the 3FF and 5FF models, indicating a more stable response to carbon events.

In the short event window, US CARs show greater reactivity, with significant declines immediately after events. This suggests that while US markets may appear less sensitive in the long term, they react sharply to short-term carbon risks. European markets, however, continue to exhibit positive CARs in the short window, reinforcing their stronger resilience to carbon-related events. These findings underscore significant regional differences in how markets respond to carbon risks.

### 5.3.5 Model Comparisons

The CAPM model captures more variation and highlights its sensitivity to overall market factors and its ability to explain more economic reactions to carbon-related events. However, the 3FF and 5FF models offer a more detailed view by including factors like company size, value, profitability, and investment. These factors allow a deeper understanding of a specific company's characteristics. These multi-factor models show smoother trends, particularly in the US, because they consider more variables that may affect the market behavior.

Despite being more detailed, the 3FF and 5FF models may still have difficulties in explaining the effects of green bonds on carbon events in some cases. This can be observed in the R-squared results that are low across all models, which signifies that only a small portion of the variation is explained by the variables. This indicates that other external factors, for example, investor sentiment, regional policy differences, or broader economic conditions may have an important role in influencing the market reaction to green bonds and carbon-related risks.

Additionally, while the 3FF and 5FF models provide more specific insights, their complexity can sometimes reduce the visibility of green bonds' effects, as seen in the weaker trends in some analyses. This shows the difficulty of isolating the influence of green bonds on carbon risk and highlights the need for future research to include more variables or to improve models to better capture these effects.

### 5.3.6 Limitations and Implications

While the findings offer valuable insights into the effectiveness of green bonds, several limitations should be noted. The low R-squared values across all models indicate that a significant part of the variation remains unexplained, likely due to external factors not captured in the models. Additionally, the smaller sample size of green bond issuers in the US limits the generalizability of the results for this region.

The results underscore the importance of green bonds as a tool for reducing carbon risk, particularly in Europe, where markets are more sensitive to carbon-related events. However, the mixed findings in the US suggest that further research is needed to understand the factors influencing the effectiveness of green bonds in this region. Policymakers and firms should consider these regional differences when designing strategies to enhance the adoption and impact of green bonds.

## 6. Conclusion

This thesis provides an analysis of the effectiveness of green bonds in reducing the risk related to carbon, with a special focus on understanding the variation between regions and firm-specific dynamics. The results reveal several differences in the European and US market reactions to carbon-related events and green bond issuances. European markets show a larger sensitivity to carbon risks, with immediate and significant reactions to environmental events. The larger environmental awareness in Europe and the stronger regulatory frameworks are most likely the cause of the pronounced market responses. Oppositely, the US market demonstrate smoother trends, since there are not many firms that have issued green bonds and a less inconsistent regulation.

The event study analysis shows that green bonds have a high potential to reduce carbon risk, principally in Europe, where the cumulative abnormal returns observed were significant for the firms that issued green bonds. However, the average results from the three different models, CAPM, 3FF, and 5FF, suggest that the impact of green bonds is not always captured across all methods. This demonstrates the complexity of measuring the financial and environmental benefits of green bonds, and the need for better consistency in green bond approval and reporting.

The regression analyses give more information about how the specific company factors influence the market reaction to carbon-related risks. Factors like Total Assets, Carbon Emissions, and ESG scores were found to have significant impacts on the CARs. Top firms and those that have high ESG scores tend to show better stability, while the companies with high Carbon Emissions have negative impacts, proving that investors prefer businesses that are more environmentally responsible. These results show companies that they need to align their strategy with sustainability goals to reduce carbon risk and to continue to be competitive in the market.

In conclusion, this thesis underscores the significant role of green bonds as a financial tool for addressing carbon risks and fostering sustainable growth. While green bonds have demonstrated success in various contexts, their effectiveness is influenced by factors such as market development, regulations, and investor participation. The findings of this study provide valuable insights for policymakers, investors, and companies seeking to utilize green bonds to promote sustainability. By presenting both the potential benefits and challenges of green bonds,

this thesis contributes to the ongoing discussion about how finance can facilitate the achievement of global climate goals.

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## Appendix

Figure 19: Definition of Variables

Variable	Definition	Type	Source	Reference
Total Price Index	The market price of all the indices companies	Control Determinant	Refinitiv Eikon	Bachelet et al. (2019)
Total Asset	Sum of all the resources owned by a company	Dependent Variable	Refinitiv Eikon	Flammer, C. (2021)
Quick Ratio	Company's ability to meet its short-term obligation	Dependent Variable	Refinitiv Eikon	Liang, H., & Renneboog, L. (2020)
Debt-to-Equity Ratio	Company's financial Leverage	Dependent Variable	Refinitiv Eikon	Flammer, C. (2021)
ROA	Company's profitability relative to its Total Assets	Dependent Variable	Refinitiv Eikon	Flammer, C. (2021)
CO2 Equivalent Emission Total	Total greenhouse gas emission	Dependent Variable	Refinitiv Eikon	Flammer, C. (2023)
Scope 1	Direct greenhouse emission	Dependent Variable	Refinitiv Eikon	Flammer, C. (2023)
Scope 2	Indirect greenhouse emission	Dependent Variable	Refinitiv Eikon	Flammer, C. (2023)
Scope 3	Other Indirect greenhouse emission	Dependent Variable	Refinitiv Eikon	Flammer, C. (2023)
ESG Score	Rating of a company's performance in ESG	Dependent Variable	Refinitiv Eikon	Flammer, C. (2021)
ESG Combined Score	Overall rating that integrates a company's performance in ESG	Dependent Variable	Refinitiv Eikon	Flammer, C. (2021)
Environment Pillar Scores	Company's performance on environmental factors	Dependent Variable	Refinitiv Eikon	Flammer, C. (2023)
Green Bond Issuance	List with all the green bonds issued	Dependent Variable	Refinitiv Eikon	Flammer, C. (2021)
3FF	An approach that considers 3 key factors to evaluate the performance or risk	Control Determinant	Kenneth R. French	Bachelet et al.(2019)
5FF	An approach that considers 5 key factors to evaluate the performance or risk	Control Determinant	Kenneth R. French	Bachelet et al. (2019)

Figure 20: Events Financial Costs

Region	Date	Total Damage, Adjusted ('000 US\$)	Monetary Damage Rank
Europe	2009-03-09	3'200'000.00	9
Europe	2010-03-19	4'230'000.00	8
Europe	2014-03-21	4'800'000.00	7
Europe	2017-07-31	2'300'000.00	10
Europe	2022-01-03	6'297'123.00	6
United States	2012-11-23	66'356'661.00	5
United States	2017-08-28	118'091'963.00	1
United States	2017-09-12	70'855'178.00	4
United States	2021-08-30	73'091'612.00	3
United States	2022-09-30	104'116'407.00	2