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Carbon Emissions Announcements and Market Returns

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Abstract: The paper investigates the impact of carbon emissions on stock price returns of European listed firms. This relationship is assessed across all three emissions scopes, as well as using expectations to detect if future emissions impact contemporary returns. Our findings show that firms with higher expected future emissions deliver lower contemporary returns after controlling for market capitalization, profit and other known return predictors. This result is statistically significant in the post Paris Agreement period for two- to three-year expectations of Scope 2 emissions. However, there is marginal to no significant negative relationship between current emissions and current returns. Overall, the results suggest that more environment-minded investors look further ahead and would expect lower returns from a polluting firm compared to a firm with no carbon emissions after the Paris Agreement.

Keywords: emissions; environmental sentiment; equity returns; Paris agreement

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1. Introduction

Carbon emissions have been attracting increasing levels of attention over the last decade, as the pressure mounts on nations and firms to control climate change. The climate conference in Paris 2015 gathered countries together to agree on limiting global warming to 1.5 °C [1]. The primary way to do this is by limiting greenhouse gas emissions, of which carbon is a key contributor. This would have implications for individual firms as well as investors. Firms need to understand how reducing their emissions will change the cost of their equity capital (required returns on shares). Meanwhile, investors would want to understand what emissions reductions as well as stronger environmental awareness mean for the future returns on their investments. This research aims to see whether there is a relationship between carbon emissions and returns over the last decade.

Reporting of carbon emissions has increased over the past few years, as legislation changed both in the United Kingdom and in the European Union. All large EU firms are now required to publish their emissions for each year. Therefore, there is a growing need to understand the relationship between emissions and stock returns. If no relationship exists, then the funds and stocks that are known to provide a safe return [2] would be chosen, but at the cost of the environment. Oil, gas, and heavy industry stocks have long fallen into this grouping and remain important investments today for several investors.

The existence of two opposing literature strands indicates that an agreement surrounding climate change and market returns is yet to be reached [3]. This also means that the role that carbon emissions play may not be reflected in stock prices yet either. Policies can affect the relationship between carbon emissions and returns. Governments can bring in legislation that limits emissions for firms, such as the EU Emissions Trading Scheme [4]. For polluting firms, if the cap is below their current emissions, they either need to reduce output, invest into cleaner technology, or purchase more allowances of the market. All these options would likely increase costs and reduce the returns. Even when legislations do not exist, the increasing possibility of stricter environmental laws and stronger environmental awareness may incentivize polluting firms to create larger provisions to mitigate potential fines or make adjustments to their business quickly. Such provisions would limit returns. Either way, the actual or potential restrictions on emissions have implications from the investor's perspective. That is, actual restrictions on emissions (i.e., the existence of legislation or strong societal environmental sentiment) mean lower future cash flows. Meanwhile, potential restrictions increase the riskiness of these cash flows. We argue that currently the former is likely stronger than the latter.

On the other hand, the higher riskiness of future cash flows is the more likely reflection of environmental effects. Therefore, investors may require a premium to offset the additional risk, increasing the required returns on the shares of more polluting firms. The empirical evidence of the positive relationship between higher emissions and higher realized returns has been mixed. Ref. [3] indicate that the rationale behind it is valid but poses problems for climate-change-tackling efforts. However, [5] find abnormal returns for funds with low carbon emissions. Both studies use US data, and so understanding whether the relationship between emissions and stock returns might differ in other markets remains to be seen. Our paper aims to address this gap in the existing literature by investigating this relationship for European listed firms.

This study examines the relationship between contemporary stock returns and carbon emissions. Returns are measured by both dividends and stock price changes, as recorded by Refinitiv, on a yearly basis. Emissions are also on a yearly basis, but as greenhouse gas (GHG) emissions are the key driver of climate change, the measure of emissions goes beyond just carbon. Carbon-equivalent emissions are used in the analysis. Each GHG has a different amount of impact on climate change, and so they are each measured by the equivalent of one ton of carbon emissions. Emissions are produced throughout the production and consumption of a good or service. To better understand where in the chain emissions come from, there are different classes of emissions. Scope 1 emissions are those that are directly emitted from the production of the goods and services. These include emissions from the machinery or running the boilers. Scope 2 emissions are those that are emitted indirectly. The most common of these is the emissions from the production of the electricity the firm buys. We will see in our empirical tests that expectations on Scope 2 emissions are the most significant and have the largest impact on contemporary returns. Scope 3 emissions are those that fall outside of scopes 1 or 2, whether up- or downstream. This includes emissions from the use of a good or service, such as the emissions from a car engine a consumer has bought, or the emissions associated with a product purchased from suppliers to use in production. Total emissions include Scopes 1 and 2, but not 3 as this scope is too variable and harder to control.

Our analysis aims to test two propositions. The first is whether current emissions of a firm affect its contemporary returns. The second is whether contemporary returns are affected by the firm's expected future emissions. The way investors form expectations is inherently ambiguous, and so is the length of the future periods they use to form these expectations. To obtain projected future emissions, we regress actual emissions on time (for each firm separately) and use the fitted values as estimates for future emissions. To mitigate possible variance in the length of the future period, we test alternative models using future emissions for the next one, two and three years. Our findings suggest that there is support for the first hypothesis as there is a statistically significant negative relationship between current emissions and contemporary returns, although negligible in terms of the magnitude of the coefficients. The second hypothesis is supported as there is a significant and negative relationship between expectations of future Scope 2 emissions and contemporary returns in the post Paris Agreement period for expectations two and three years ahead.

This research contributes to the existing literature by examining the emissions and returns of the European market, whereas previous work has focused on the United States. Legislation is stricter in Europe, and so this research will also add to the broader understanding of how tighter emissions regulation impacts returns. Second, it examines how investors consider future emissions when making decisions in the present. This helps in identifying the level of myopia investors present when making such investments. With the ever-increasing understanding of climate change and attention to emissions, the findings here will contribute to the carbon risk hypothesis proposed by the literature. Finally, this study will help the investment industry understand whether they can benefit financially while benefitting the planet environmentally. From the findings outlined above, this research would suggest that this can be the case in Europe, although the economic impact might still be not high enough to foster a transition to net-zero emissions.

2. Literature Review and Research Hypotheses

Investors are becoming increasingly conscious of environmental, social, and governance (ESG) investing, as pressure mounts from both governments and individuals to ensure that investments are protected as the world changes. There is growing pressure to disclose carbon emissions from the Carbon Disclosure Project and the Global Reporting Initiative [6–8]. In the UK, for example, all listed companies are required to report on their greenhouse gas (GHG) emissions since 1 October 2013 [9].

ESG investing aims to cover all bases to ensure that each investment made under this guise is in some way contributing to the benefit of society. In practice, the interpretive aspect of this results in investments being classified under one or more of these aspects, despite not appearing to meet the criteria. Looking at firms that directly emit carbon and other gases such as in the oil and gas industry, [10] finds issues with the ESG label on sustainable funds holding shares in oil or gas firms. Greenwashing is often used to explain situations such as these when funds have little to no way to back up their claims of ESG investing whilst trying to misdirect or mislead investors. This highlights one reason why using carbon emissions rather than ESG classifications is a more accurate way to determine the environmental component of performance.

Carbon emissions have already fed into plenty of prior research. Ref. [11] investigated how carbon emissions affects clean energy index prices. The link was positive, though not significant across all markets, including the US. Ref. [12] investigated the relationship between carbon intensity and the cost of equity capital among Korean firms. They find a positive relationship between the two variables, with the relationship growing stronger still for firms in low-carbon-emitting industries. Note that the cost of equity capital (CEC) is important for firms as any increases in costs detract from profits and, in turn, shareholder returns. An alternative approach to the issue of decarbonization is presented by [13], who propose a new metric called "decarbonization selling pressure" applied to mutual funds.

Research into the relationship between the carbon price, measured by the ETS market of carbon allowances, and stock prices of firms found that there is a non-linear relationship [14,15]. Though carbon prices are important, the impact on the environment is not determined by prices. The ETS scheme has room for further tightening as technology improves. [2] focus on energy firms, finding that profits can still be made during tightening, although highly polluting firms' profits are more susceptible to emissions regulations. If this finding applies to other industries, there is a good case for all firms to work towards being less polluting to protect their profits.

Ref. [16] looks at how emissions regulations impact carbon risk, in conjunction with direct emissions. Australia provides a good case for measuring the effects of policy on carbon risk, as regulations have increased in stringency and decreased emissions. Nguyen's findings are encouraging for low polluters, as they are less likely to report negative net incomes, and have a higher Tobin's Q and higher return on equity. Polluters experience the opposite outcomes, financially underperforming compared to non-polluters. The underperformance of Tobin's Q and return on equity is particularly pronounced after the Kyoto agreement.

For carbon emissions to be reduced in a substantial volume, portfolios consisting of low-carbon stocks need to be able to at least match those that have dominated for the past decades. Ref. [17] construct a fossil-free (and thus low-carbon) portfolio and compare it to a conventional equity portfolio. They show that in the earlier years of their sample (2004–2017), the conventional portfolio outperformed the fossil-free portfolio. As one moves through the periods towards 2017, the trend is reversed, and the fossil- free portfolio starts to outperform the conventional portfolio.

Returns to shareholders can be delivered in several ways, but dividends and share value increases are perhaps the leading two. Due to the planned nature of dividends, they do not exhibit the volatility that the stock market imposes on share values. To set a stable dividend policy, future earnings need to be stable enough to forecast. In a study by [18] the authors found that future earnings are less certain the greater the carbon risk. The latter study finds that high polluters are likely to pay a lesser dividend and that the propensity to pay one at all is also decreased. In the UK, they found that the introduction of the EU-ETS in 2005 saw the propensity of dividends from polluters fall. This is not surprising, as the UK is one of the most carbon-intensive countries in Europe [19]. Using carbon risk as a variable is challenging, as it is a future value that has so many contributing components. It does have an important advantage in that it tries to anticipate how companies will behave in response to a threat. Future stability, or the lack thereof, is important to shareholders and so the study is valuable. However, in light of the issues carbon risk poses for forecasting, carbon emissions are a better variable for use in our research. As they are a past value, it will be possible to see how returns have changed over time in response to emissions.

Although the EU now requires this data to be disclosed, this has not always been the case. Hand-collecting data from 2006–2008, ref. [8] studied the effect of disclosing carbon emissions on firm value. At this point in time, there was no cost attached to emissions, and so no incentive to reduce them. The authors correct for the fact that firms have chosen to publish the data, whether that be from investor pressure or a confidence in their low values. They also accounted for firms that did not disclose their emissions and assigned a penalty for not doing so. A negative correlation between carbon emissions and firm value is found, which increases for large companies that emit in large orders of magnitude. Carbon disclosure and its impact on European firms' performance is studied by [20,21], whereas refs. [6,7] focused their empirical analysis on African and South American listed firms, respectively.

A natural question that follows from such stark changes in value to a firm is whether investors are actually interested in carbon risk. A key paper for our study is [3]. They examine the impact of carbon emissions on US stock returns by analyzing three hypotheses: a carbon premium, a carbon alpha, and a divestment hypothesis. Their study provides a clear theoretical foundation of the research hypotheses developed in our study that are presented below. The carbon premium hypothesis considers whether firms with higher emissions have a positive correlation with their stock returns. The carbon alpha hypothesis considers whether investing long in firms with low carbon emissions and short in firms with high emissions returns a positive return beyond that of the market average. The divestment hypothesis considers whether dirty firms that have been dropped from funds with emissions targets present higher stock returns as a result. Across these hypotheses, emissions are categorized into three types: Type 1 are direct emissions from production; Type 2 are emissions from consumption (such as electricity); Type 3 emissions are indirect emissions from the production of purchased goods and services, whether those be upstream or downstream. The carbon premium, estimated from a cross-sectional regression model using pooled OLS of US firm returns on total emission, is significant. A one-standard-deviation increase across the three emissions types leads respectively to 1.8%, 2.9% and 4.0% annualised increases in stock returns. These findings are also supported by [22], who looked at the impact of policy uncertainty on option market prices.

This study contributes to the current literature by examining the effect of carbon emissions on the cost of equity of European firms, whereas previous research has focused on the US [3]. The performance of the firms will account for the industry in which the firms operate, as well broken down to examine the effect of the market capitalization of the firm. The three different emissions types will be examined to see whether one is more important than the others in determining the cost of equity. The first main hypothesis we test is the following:

H1. *The firm's current emissions affect its stock returns.*

This would be the case if announcements regarding the recent emissions drive the returns. This hypothesis is tested using a variety of proxies for emissions including total emissions, Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions. In the case of total emissions, there are times when this is not published. Another proxy is used to account for this, whereby Scope 1 and Scope 2 are combined to generate values consistent with the formula used in published total emissions.

Ref. [3] also examine the role of investor expectation of future emissions. Forward-looking investors are requiring a greater level of return to compensate for the carbon risk posed. Put another way, ceteris paribus, demand has fallen for high- emissions stocks unless there is an incentive beyond what would otherwise be offered. In their study, the carbon alpha and divestment hypotheses are both rejected, suggesting that the market already prices in carbon risk and investors are not moving away from high-emissions industries. Interestingly, the divestment hypothesis applies when the very highest industries are excluded (oil and gas, utilities, and motor production). These industries are highest by type 1 emissions, so investors divest on this category alone and only at the very highest levels. Motivated by the findings on the interplay between expected future emissions and contemporary returns, we also test the following hypothesis:

H2. *Investor expectations of future emissions affect the firm's current stock returns.*

This hypothesis is tested using projected lead emissions. To obtain the latter, we regress actual emissions on time (for each firm separately) and use the fitted values as estimates for future emissions. In a similar fashion to H1, a variety of proxies are used for emissions. These include total emissions, Scope 1 emissions, Scope 2 emissions and Scope 3 emissions. Again, a total proxy is generated for the cases of missing data using the same method that published data employs. Each of the leads are tested across all proxies. As far as could be seen, this is the first time research has looked at how future emissions impact on present returns.

3. Methodology

3.1. Econometric Model

To test the first Hypothesis (H1), the following model is used:

$$\begin{aligned} Return_{i,t} = \beta_0 + \beta_1 Carbon_{i,t} + \beta_2 Diversity_{i,t} + \beta_3 TotalAssets_{i,t} + \beta_4 Beta_{i,t} + \beta_5 Profit_{i,t} + \beta_6 PPE_{i,t} \\ + \beta_7 MarketCap_{i,t} + \beta_8 ROE_{i,t} + u_{i,t} \end{aligned}$$

where β_0 is the firm fixed effect (FE); *Carbon* can take values of total emissions, Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions over total assets; *Diversity* equals the percentage of women on the board; *TotalAssets* is total value of assets owned by the firm, expressed in US Dollars; *Beta* is the market beta of the firm; *Profit* is the operating profit of the firm; *PPE* is the cost associated with maintaining or replacing fixed assets (property, plant, and equipment); *MarketCap* is the market value for each instrument; ROE is the return on equity of the firm. Robust errors are clustered at the firm level.

The existing literature examines the importance of carbon risk, and how investors assess the importance of this. The work by [3] includes a hypothesis on the carbon premium to this end—whether investors demand returns now to compensate for the higher risk they are exposed to. Although we do not attempt to replicate their carbon premium exercise, we are motivated by their thesis of claiming higher returns associated with higher emissions that is the foundation of their carbon premium hypothesis. Therefore, H2 examines whether there is evidence of this relationship in the data collected here. We do so by replacing the concurrent levels of emissions by the expected level of emissions in the future.

To test the second Hypothesis (H2), the following model is used:

$$Return_{i,t} = \beta_0 + \beta_1 LeadCarbon_{i,t} + \beta_2 Diversity_{i,t} + \beta_3 TotalAssets_{i,t} + \beta_4 Beta_{i,t} + \beta_5 Profit_{i,t} + \beta_6 PPE_{i,t} + \beta_7 MarketCap_{i,t} + \beta_8 ROE_{i,t} + u_{i,t}$$

where *LeadCarbon* can take values of total emissions, Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions. Since future emissions are not observable, we cannot use actual emission values to obtain *LeadCarbon* values. Rather, we need to use the expected levels of future emissions. As mentioned earlier, the way investors form expectations and the length of the future periods they use to form these expectations are ambiguous. However, we argue that while investors are unable to perfectly predict future emissions, they would be able to estimate them with good accuracy. Hence, we obtain the expected future emissions by regressing the actual emissions of each firm (separately) on time. Specifically, we consider carbon emissions values up to 2015 and estimate the following model for each firm:

$$Carbon_t = \beta_0 + \beta_1 Time_t + \varepsilon_t$$

We then calculate the fitted values for the resulting models (for each firm in each period), which we use as the expected emissions (i.e., $Carbon\_exp_t = \hat{Carbon_t}$). Hence, *LeadCarbon* values will be equal to the lead values of $Carbon\_exp_t$ (for example, $LeadCarbon_{t+1} = Carbon\_exp_{t+1}$). In order to avoid the looking-ahead bias, we use those expectations that are estimated up to 2015 to evaluate the impact on firms' contemporary returns in the post 2015 Paris Agreement period.

To address the expectation length issue, we carry out three experiments to reflect the different ways investors could integrate future emissions into the compensation they expect from the firm. In the first experiment, *LeadCarbon* is equal to the expected emissions for the following year. Meanwhile, in the second and third experiments *LeadCarbon* is equal to the average expected emissions for the following two and three years, respectively.

3.2. Dataset

This study uses listed companies in the European Union (EU) as it stands in 2022 (27 countries), the European Economic Area, and Switzerland, as available through the Refinitiv platform data base. Including the countries outside of the EU is relevant as these countries conform to the rules set by the EU to maintain frictionless trade. Including these countries therefore increases the sample size and helps to capture the effects of the relationship between carbon-equivalent emissions and returns. The listed companies collected are from a variety of economic sectors, as defined by the Refinitiv platform. These are summarised in Table 1.

For each firm, we collect yearly data between 2012 and 2021 (inclusive) across all variables measured. In 2012 emissions data regulations became much more stringent and firms began publishing the data. Data of a higher frequency would have been preferable, ideally at a weekly level; however, this was not possible due to constraints on the quantity of data retrievable from the Refinitiv database.

Panel data are used for the analysis as they contain more samples than time series data or cross-sectional data would. After screening and data cleaning, there were 744 firms remaining in the sample out of the original 7028, with 2445 total observations. The high level of attrition seen (7028 down to 744 firms) is somewhat indicative of the recency with which emissions reporting has been introduced. Firms of less than 500 employees were not required at all to report their emissions [23]. This is a very likely component of why there are missing observations for so many firms. Higher frequency data, while beneficial in many respects, may have been even more prone to reporting limitations. We also filtered out a few abnormal observations by restricting the distribution of stock returns within two standard deviations.

Table 1. Firms Distribution by Economic Sector and Geographic Area.

	Consumer Non-Cyclicals	Consumer Cyclicals	Basic Materials	Technology	Industrials	Financials	Utilities	Real Estate	Healthcare	Energy
Luxembourg	1	3	5	2	1	0	0	2	0	1
Germany	6	16	15	23	28	7	4	7	10	3
Spain	2	8	4	3	12	7	5	1	5	4
Sweden	5	16	12	9	20	9	0	9	5	1
Switzerland	6	7	8	9	19	12	1	3	7	1
Austria	0	1	4	3	7	4	1	1	0	2
Greece	1	1	0	1	2	5	2	0	0	1
France	12	27	5	10	25	6	3	9	7	6
Italy	1	12	1	5	12	17	7	1	3	3
Republic of Ireland	6	4	3	2	3	3	0	0	4	0
Poland	1	1	2	2	3	9	1	0	0	2
Norway	7	3	4	4	8	6	0	1	0	9
Belgium	1	2	3	4	1	3	1	2	4	1
Cyprus	1	0	1	0	0	0	0	0	0	0
Finland	3	7	6	4	9	3	1	2	1	1
Denmark	3	2	3	1	6	7	1	0	7	1
Portugal	2	0	2	2	2	1	2	0	0	1
Czech Republic	0	0	0	0	0	1	1	0	0	0
Hungary	0	0	0	1	0	1	0	0	1	1
UK	0	0	0	0	3	0	0	0	0	1
Ukraine	1	0	0	0	0	0	0	0	0	0
Malta	0	1	0	0	0	0	0	0	0	0
Slovenia	0	0	0	0	0	0	0	0	1	0
Liechtenstein	0	0	0	0	0	1	0	0	0	0
Romania	0	0	0	0	0	2	0	0	0	0
USA	0	0	0	0	0	0	0	0	0	1

Perhaps the most important part of this research is accurate collection of carbon data. Pure carbon emissions data are hard to come by, as they are not what firms are required to report. Instead, carbon-equivalent emissions data are reported. These include carbon dioxide (CO_2) emissions in tons, but they also include other relevant greenhouse gases not measured by tonnes of emissions, but their equivalent impact of tonnes of carbon dioxide emitted. These other gases are methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCS), per fluorinated compound (PFCS), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Emissions are reported across type 1, 2, and 3. Total emissions are defined as type 1 plus type 2. Type 3 emissions are not included as these are further along the supply chain. Product use by consumers falls into this category, for example. While important, it is harder for these emissions to be controlled by a firm and so are not included in the total emissions calculation. Further to this, emissions from use of a product would have increased uncertainty on the accuracy of the data.

As mentioned earlier, there are a large number of instances where type 1, 2 and 3 emissions are reported, but not the total carbon-equivalent emissions. In these instances, a proxy for total carbon is generated, using the sum of reported type 1 and type 2 emissions.

$$sumcarbon = carbon1 + carbon2$$

To maximise the number of observations in the regression, a new variable netcarbon is generated which takes the value of either reported total emissions or the user-generated sum, whichever is higher.

$$netcarbon = max\ (totalcarbon, sumcarbon)$$

In our main models, carbon equivalents are normalised by total assets, showing relative size of emissions per £1 of assets, or in other words the relative contribution to emissions by a company relative to other companies. However, if companies differ significantly in size (or when it comes to the largest companies), environment-minded investors would care less about the relative contribution and more about the total amount of emissions (measure by logs). Therefore, a natural logarithm is taken as a robustness test to make the coefficients more interpretable [2,3]. The variables that are transformed this way are therefore netcarbon, carbon1, carbon2, and carbon3.

The carbon-equivalent emission variables are subsequently winsorised, as there are noticeable outliers which skew the data. The winsorising is performed at the 5% and 95% percentiles to reduce bias in the estimators [24]. Linear regression models [8,12] are used for the analysis. As a measure of performance of the firm, the total return is obtained. This incorporates both the price change of the firm as well as any dividends that are paid during the year. It is important to include both price and dividends in the performance measure as this is what potential investors consider when deciding whether to invest in a listed firm. Total return is defined as a percentage change against the previous period. We also wished to control for fixed effects in the model to ensure that the regression is only measuring the effects of each variable, and not the effects of each individual firm and/or industry. The unobserved heterogeneity is thereby controlled for [25]. Applying a fixed effects model to this regression controls for each of the 744 firm's characteristics. Table 2 provides a description of each variable used in the regressions and how the data were acquired.

Table 2. Variable Descriptions and Data Sources.

Variable Name	Description	Source
return	Total return to a shareholder. Price change and any dividends paid that year. Expressed as a percentage change	Refinitiv
Instrument1	Each firm used in the panel data regression, stored by its RIC (Refinitiv Instrument Code)	Refinitiv
totalcarbon	The total carbon-equivalent emissions reported by a firm across type 1 and type 2.	Refinitiv
carbon1	The type 1 carbon-equivalent emissions reported by the firm	Refinitiv
carbon2	The type 2 carbon-equivalent emissions reported by the firm	Refinitiv
carbon3	The type 3 carbon-equivalent emissions reported by the firm	Refinitiv
diversity	The percentage of women on the board	Refinitiv
totalassets	The total value of assets owned by the firm, expressed in US Dollars	Refinitiv
beta	The market beta of the firm	Refinitiv
profit	The operating profit of the firm (difference between revenues and costs and expenditures before any deductions). Expressed in US Dollars	Refinitiv
ppe	Property, plant, and equipment—accumulated depreciation and impairment: This is the cost associated with maintaining or replacing fixed assets.	Refinitiv
marketcap	The market value for each instrument	Refinitiv
roe	Return on Equity: profitability ratio defined as the net income divided by total equity	Refinitiv
sumcarbon	The sum of carbon1 and carbon2	User Defined
netcarbon	The greatest value out of totalcarbon and sumcarbon	User Defined
netcarbonToTolAsset	netcarbon as percentage of total assets	User Defined
carbon1ToTolAsset	carbon1 as percentage of total assets	User Defined
carbon2ToTolAsset	carbon2 as percentage of total assets	User Defined
carbon3ToTolAsset	carbon3 as percentage of total assets	User Defined
lead1netcarbon	A one-year expectation of netcarbonToTolAsset	User Defined
lead1carbon1	A one-year expectation of carbon1ToTolAsset	User Defined
lead1carbon2	A one-year expectation of carbon2ToTolAsset	User Defined
lead1carbon3	A one-year expectation of carbon3ToTolAsset	User Defined
lead2netcarbon	A two-year average expectation of netcarbonToTolAsset	User Defined
lead2carbon1	A two-year average expectation of carbon1ToTolAsset	User Defined
lead2carbon2	A two-year average expectation of carbon2ToTolAsset	User Defined
lead2carbon3	A two-year average expectation of carbon3ToTolAsset	User Defined
lead3netcarbon	A three-year average expectation of netcarbonToTolAsset	User Defined
lead3carbon1	A three-year average expectation of carbon1ToTolAsset	User Defined
lead3carbon2	A three-year average expectation of carbon2ToTolAsset	User Defined
lead3carbon3	A three-year average expectation of carbon3ToTolAsset	User Defined

3.3. Control Variables

It is important to control for other factors that could be causing the dependent variable to exhibit its behaviour. The market beta is included in line with work by [12]. The market beta is an indicator of the risk the firm faces relative to the market. As the sample of firms is across multiple economic sectors, controlling for the risk that they present is important. The regression also controls for total assets, which are a proxy for how capital-dependent the firm is. Firms operating in the financial sector will be a lot less dependent on physical assets than firms in the production of consumer or non-consumer goods. The existing literature [8] makes use of total assets as a control variable for similar reasons. Profit is important to control for, as firms that are more profitable may be able to pay better returns. Isolating the level of return attributable to profits against carbon emissions is critical in producing meaningful results. Higher profits may also allow firms to report more accurately and precisely, and so profit also helps in controlling for omitted variable bias [8]. Property, plant, and equipment (PPE) are included as [3] note that there is little evidence on what factors lead to carbon emissions. Following their lead, firm-level variables are included, such as PPE. Return on equity is used in several pieces of literature [3,16] as both independent and control variables. In this research, ROE is used as a control variable. [3] use ROE in much the same way as they use PPE. The work by [16] uses ROE as an independent variable, but this only serves to show the importance of controlling for such an important variable in this research. Diversity is included to control the number of women on the board influencing the level of carbon-equivalent emissions. There is evidence of higher diversity on boards leading to more responsible banking [26], as well as increasing corporate social responsibility [27]. This is a control variable not seen in existing literature surrounding this topic; however, there is clear common ground between corporate social responsibility and carbon-equivalent emissions. The work by [27] was carried out by looking at listed firms and so has relevance to the sample used in this research.

3.4. Summary Statistics

Included below in Table 3 are the summary statistics for each variable used in the regression analysis. These state the number of observations for each variable (N), the mean and standard deviation, as well as the maximum and minimum values for each variable.

Table 3. Summary Statistics.

Variables	N	Mean	Sd	Min	Max
year	2445	2016	2.863	2012	2021
totalcarbon	671	2.702×10^6	9.835×10^6	431	1.207×10^8
carbon1	2445	3.830×10^6	1.780×10^7	0	1.817×10^8
carbon2	2445	448,454	1.352×10^6	0	2.100×10^7
carbon3	1818	1.203×10^7	5.794×10^7	0	1.113×10^9
diversity	2445	22.58	13.92	0	75
totalassets	2445	1.056×10^{11}	6.105×10^{11}	2.805×10^7	1.097×10^{13}
beta	2445	0.961	0.474	−0.271	7.414
profit	2445	3.604×10^9	2.248×10^{10}	-1.720×10^{10}	5.267×10^{11}
capex	2445	2.172×10^9	1.588×10^{10}	0	3.700×10^{11}
ppe	2445	1.586×10^{10}	1.476×10^{11}	-9.077×10^9	3.872×10^{12}
marketcap	2445	4.620×10^{10}	4.126×10^{11}	6309	1.046×10^{13}
return	2445	12.89	44.83	−95.40	345.7
sumcarbon	2445	4.279×10^6	1.861×10^7	0	1.920×10^8
netcarbon	2445	4.834×10^6	1.920×10^7	0	1.920×10^8
Number of instrument1	758	758	758	758	758

As the leads increase, the number of observations fall as data are shifted, resulting in later years not having any data.

4. Results

The key findings of this research are reported below. We first assess our baseline model to test H1, and then the one year and average of two- and three-year leads of net emissions and Scope 1 emissions are presented to test H2.

4.1. Baseline Model

The results from the baseline models are shown in Table 4. Note that carbon emissions in year *t* are not always observable exactly at the end of the year, as disclosures are normally delayed by a few weeks. We argue that while investors might be able to observe current emissions, they would be able to estimate them with a high level of accuracy. To support this argument, we use lagged rather than concurrent emission values. The independent variables for netcarbon, carbon1 and carbon3 all have negative and significant coefficients between contemporary stock returns and carbon emissions. However, those values are extremely small in magnitude.

Table 4. Baseline Model.

	(1)	(2)	(3)	(4)
netcarbonToTotAssets	−0.000323 *** (5.54×10^{-5})			
carbon1ToTotAssets		−0.000816 *** (0.000122)		
carbon2ToTotAssets			−0.0829 (0.0532)	
carbon3ToTotAssets				−0.000241 *** (3.24×10^{-5})
Observations	1454	1454	1454	1161
Adj R-squared	0.009	0.009	0.010	0.018
Number of instrument1	528	528	528	425
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES

Controls include diversity, total assets, beta, profit, market cap and PPE. Robust standard errors are clustered at the firm level and reported in parentheses. *** $p < 0.01$.

In order to further inspect the sign of the coefficients, we also looked at the absolute magnitude of those emissions as environment-minded investors might also be driven by total amount of emissions rather than the relative contribution only. When looking at the log transformation of carbon emissions as reported in Table A1 in the Appendix A, the signs of each coefficient of interest are negative (except the logcarbon3); however, from these models we cannot observe the effect of carbon emissions causing the contemporary returns of a company to move in a specific direction as the results are not significant. The control variables indicate that total assets are significant. However, the magnitude of the movement caused by the total assets is very small, 6.32×10^{-11} in the case of the effect of net carbon. We also test the model by considering the post-2015 period as investors would be more conscious about carbon emissions as a result of the Paris Agreements. Results are robust and estimations are reported in Appendix A Table A2 for the carbon emissions to total assets.

The first Hypothesis (H1) is therefore supported, although the magnitude of the impact is almost negligible.

4.2. One-Year Expectation Models

One-year expectation models test the relationship between the investor's expectations of carbon-equivalent emissions for the following year and the present (contemporary) year's returns. Note that expectations are formed in the pre-Paris Agreement (up to 2015), and results for the post 2015 Paris Agreement period are presented in Table 5. The results show in almost all models that a key variable of interest has a positive relationship and effect on the reported contemporary returns; however, no coefficients were significant when considering the carbon emissions over total assets. Robustness exercises confirm these results even if we use log transformation of carbon emissions (not tabulated). Overall, these results do not support the second hypothesis with one-year expectations of emissions on contemporary returns.

Table 5. One-Year Expectation Model.

	(1)	(2)	(3)	(4)
lead1netcarbon	0.000293			
	(0.000782)			
lead1carbon1		0.000358		
		(0.000766)		
lead1carbon2			−0.0239	
			(0.0162)	
lead1carbon3				6.90×10^{-5}
				(0.00332)
Observations	280	280	280	193
Adj R-squared	0.021	0.021	0.024	0.021
Number of instrument1	145	145	145	104
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES

Controls include diversity, total assets, beta, profit, market cap and PPE. Robust standard errors are clustered at the firm level and reported in parentheses.

4.3. Two-Year Average Expectation Models

Two-year expectation models test the relationship between the investor's average expectation of carbon-equivalent emissions over the following two years and the present year's returns. When testing the model in the post-2015 period after the Paris Agreement as reported in Table 6, coefficients for netcarbon, Scope 1 and Scope 3 are positive although not significant. Scope 2 emissions are significant at 10% and negative. We also note that the magnitude of the coefficient is considerably higher than in the baseline model. Investors would seem to be conscious about Scope 2 carbon emissions as a result of the Paris Agreements having a larger impact on contemporary returns, supporting H2 after this event.

Table 6. Two-Year Average Expectation Model.

	(1)	(2)	(3)	(4)
lead2netcarbon	0.000296			
	(0.000953)			
lead2carbon1		0.000426		
		(0.000895)		
lead2carbon2			−0.0331 *	
			(0.0170)	
lead2carbon3				−0.00159
				(0.0106)
Observations	283	283	283	195
Adj R-squared	0.020	0.020	0.025	0.019
Number of instrument1	146	146	146	104
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES

Controls include diversity, total assets, beta, profit, market cap and PPE. Robust standard errors are clustered at the firm level and reported in parentheses. * $p < 0.1$.

4.4. Three-Year Average Lead Models

The three-year average expectation models also show no significant effect between average expectations of future emissions (net, Scope 1 and Scope 3 to be precise) and current returns when assessing the post 2015 Paris Agreement period, as reported in Table 7. In line with the findings from the previous test, we report negative and statistically significant coefficients for Scope 2 emissions with a similar magnitude as shown in the two-year average lead model. The second hypothesis with a three-year average expectation is therefore supported for Scope 2 emissions when considering the post Paris Agreement period.

Table 7. Three-Year Average Expectation Model.

	(1)	(2)	(3)	(4)
lead3netcarbon	0.000457			
	(0.00151)			
lead3carbon1		0.000648		
		(0.00147)		
lead3carbon2			−0.0343 **	
			(0.0170)	
lead3carbon3				−0.00189
				(0.00960)
Observations	283	283	283	195
Adj R-squared	0.020	0.020	0.024	0.019
Number of instrument1	146	146	146	104
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES

Controls include diversity, total assets, beta, profit, market cap and PPE. Robust standard errors are clustered at the firm level and reported in parentheses. ** $p < 0.05$.

4.5. Robustness Tests

We ran a battery of robustness tests to further investigate the relationship between carbon emissions, both reported and expected, and current market returns of European companies.

We first considered an alternative measure of carbon emissions in the form of log transformation of Scope 1 to 3 reporting values. Although the ratios of emissions values to total assets would show relative size of emissions per £1 of assets, or in other words the relative contribution to emissions by a company relative to other companies, we believe that the absolute magnitude of those emissions could also be used by investors. Environment-minded investors would care less about the relative contribution and more about the total amount of emission. We therefore tested our model using log transformation of the carbon emission variables.

Second, we split the sample by considering the post 2015 period that is supposed to capture the post Paris Agreement trend in the market. Investors' consciousness of ESG- and ecology-related issues is arguably higher in the most recent period than at the beginning of the study period.

We tested all combinations of measures of carbon emissions and time periods to exhaust all possibilities, and the results are presented in the Appendix A. Some of the robustness tables are not tabulated for conciseness and are available from the authors upon request.

5. Discussion

The returns variable consists of two components. One component is dividends, which are announced in the year of the reported emissions. The other component in the returns variable is the price change of the stock. The discussion on how emissions impact returns largely revolves around how these two components respond to changes in the varying proxies for emissions. The dividends are announced in the same period as the emissions occur. However, dividends are announced throughout the year, whereas emissions are reported after the year has ended, as they are a final value. The sensitivity between emissions and dividends is likely to be low as a result. Stock values can change much more quickly, as they are subject to investor sentiment. This is a very sensitive aspect, and any changes in company policies can be reflected in the price in a very short period. Specifically in the models used here, any changes to emissions policies or announcements of previous-year emissions can cause the price component to change. Of the two components, the price is more likely to be the driving aspect of the relationship seen between emissions and returns.

This is not a surprise, given that the emissions examined in this situation are published after the returns have been determined. The lack of magnitude (economic significance) in the H1 models lends credibility to the second hypothesis, in that any relationship between contemporary returns and emissions can be driven by future emissions. Even with a fuller dataset it is unlikely that the first hypothesis would be supported, due to the timing of the emissions data. This is marginally alleviated when using lagged rather than concurrent emissions values to limit the "looking-ahead" bias of the estimators.

There was no literature identified that examined whether past emissions determine current returns (or a similar variable). The findings from this research do indicate that there is a marginal relationship here, and it would be interesting to explore it further. The small magnitude of the coefficients may be the result of the past reporting being so limited. Investors might not yet use this as a guide to future performance. However, as reporting increases, there may a relationship that will become identifiable in the future.

5.1. H2 Models

When expectations of future emissions are incorporated, with a one-year lead, results suggest firms announce their emissions targets just ahead of the reported year's beginning. Investors tend to respond to this in a meaningful manner, with the results having negative coefficients for Scope 2 emissions, although they are not statistically significant. Results from one-year lead models suggest that this is not something that affects the returns. Investors appear not be pricing emissions into their expectations.

In the case of two-year and three-year average expectations, all the models show negative and significant coefficients for Scope 2 emissions, meaning that increasing emissions means reducing returns when restricting the model to the post Paris Agreement period (post 2015). Differently from the baseline model, here the economic significance (magnitude) of those coefficients is much higher. This would seem to foster the thesis of investors becoming more environmentally conscious after the Paris Agreement. One possible cause for this only occurring in the two- to three-year expectations is that as investors look further ahead, with the increased level of uncertainty surrounding emissions regulations and future technology, investors would rather invest in firms that operate in an environmentally sustainable way. It would be interesting to explore this transition further; however, applying longer leads reduces the sample size available for the regression, and it may be necessary to collect data from a longer period so that the longer leads still have an appropriately sized sample.

5.2. Outside the EU

While the firms included in the regressions are listed in the EU, the implications are not subject to the same constraints. The UK, for example, is still closely aligned to the legislation that the EU has on emissions. Analysis of UK firms would need to be undertaken to obtain more localized values, but the key relationships and order of magnitudes are likely to hold. This means that UK firms wishing to increase their returns could exploit the findings from the EU. For firms further afield, the degree to which these findings would hold is less certain. The US and Asia both differ from the EU on legislative environments, with the US having less restrictive emissions rules. Globally the momentum is in a direction of fewer emissions however, and so these findings may be relevant in the future to these markets. In the case of firms with multinational operations, there may be operational and cost benefits to implementing their European emissions policies across the firm.

6. Conclusions

This study examines the relationship between contemporary returns and carbon emissions. Overall results indicate a negative relationship, with significance levels varying. The first hypothesis was only marginally supported by empirical evidence. That is, present carbon emissions do negatively influence present returns. The results were statistically significant but very small in magnitude for any of the proxies employed in place of emissions. This would suggest a lack of economic significance of the relationship. Considering the rapid growth of interest in emissions, it is possible that future findings might differ from those of this research.

The second hypothesis found much more support from the data; that is, the firm's future emissions significantly influence the returns only when considering longer expectations of emissions two and three years ahead. In this scenario, the relationship is negative and significant for the Scope 2 emissions variable when considering the post Paris Agreement period. Part of the existing literature claims that the increasing possibility of stricter environmental laws and stronger environmental awareness may increase costs for polluting firms and thereby limit their returns. The study also highlights the role of market sentiment to attain desired environmental effects. We believe this is a key indication to policymakers that more action is likely needed if they want to achieve their environmental objectives within the desired timeframes.

To further understand and test the second hypothesis, a greater number of leads should be implemented, especially for those firms who set long-term policies and targets for emissions. Understanding how a target set for 10 years from now will impact returns is beyond what this research can offer. A much larger dataset would be required, as increasing the number of leading years reduces the data available for analysis in the future years very quickly. At the time of writing, it is becoming increasingly common for firms to pledge the year that they will reach net-zero emissions. Understanding how returns will be affected beyond this point, when emissions would have to be negative to have any impact, will become of increasing relevance to firms and shareholders.

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Appendix A

Table A1. Baseline Model with Log transformation of Carbon Emissions.

	(1)	(2)	(3)	(4)
lognetcarbon	−0.798			
	(1.200)			
logcarbon1		−0.0373		
		(1.674)		
logcarbon2			−4.212	
			(1.867)	
logcarbon3				0.550
				(0.964)
Observations	2444	2435	2429	1812
R-squared	0.006	0.006	0.008	0.007
Number of instrument1	758	756	754	572
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES

Controls include diversity, total assets, beta, profit, market cap and PPE. Robust standard errors are clustered at the firm level and reported in parentheses.

Table A2. Post 20215 Paris Agreement Exercise on Baseline Model.

	(1)	(2)	(3)	(4)
netcarbonToTotAssets	−0.00161 ***			
	(0.000150)			
carbon1ToTotAssets		0.0361		
		(0.0229)		
carbon2ToTotAssets			0.0467	
			(0.0774)	
carbon3ToTotAssets				0.00577 ***
				(0.00208)
Observations	1397	1397	1397	1033
R-squared	0.005	0.005	0.004	0.013
Number of instrument1	596	596	596	451
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES

Controls include diversity, total assets, beta, profit, market cap and PPE. Robust standard errors are clustered at the firm level and reported in parentheses. *** $p < 0.01$.

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