

Pricing of climate transition risks across different financial markets

Citation for published version (APA):

Broeders, D., Schouten, B., Tiems, I., & Verhoeven, N. (2023). Pricing of climate transition risks across different financial markets. *Journal of Risk Management in Financial Institutions*, 16(2), 102-115.

Document status and date:

Published: 01/01/2023

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.umlib.nl/taverne-license

Take down policy

If you believe that this document breaches copyright please contact us at:

repository@maastrichtuniversity.nl

providing details and we will investigate your claim.

Practice papers

Pricing of climate transition risks across different financial markets

Received (in revised form): 8th December, 2022

Dirk Broeders

Senior Financial Risk Manager, De Nederlandsche Bank, The Netherlands

Dirk Broeders is a senior financial risk manager for the Financial Markets Division of De Nederlandsche Bank and a Professor of Finance at the School of Business and Economics of Maastricht University.

De Nederlandsche Bank, Westeinde 1, 1017ZN Amsterdam, The Netherlands

Tel: +31(0)20 524 9111; E-mail: d.w.g.a.broeders@dnb.nl

Bernd Schouten

Economist, De Nederlandsche Bank, The Netherlands

Bernd Schouten is an economist for the Financial Markets Division of De Nederlandsche Bank.

De Nederlandsche Bank, Westeinde 1, 1017ZN Amsterdam, The Netherlands

Tel: +31(0)20 524 9111; E-mail: b.p.schouten@dnb.nl

Isabelle Tiems

Economist, De Nederlandsche Bank, The Netherlands

Isabelle Tiems is an economist for the Financial Markets Division of De Nederlandsche Bank.

De Nederlandsche Bank, Westeinde 1, 1017ZN Amsterdam, The Netherlands

Tel: +31(0)20 524 9111; E-mail: i.g.j.tiems@dnb.nl

Niek Verhoeven

Economist, De Nederlandsche Bank, The Netherlands

Niek Verhoeven is an economist for the Financial Markets Division of De Nederlandsche Bank.

De Nederlandsche Bank, Westeinde 1, 1017ZN Amsterdam, The Netherlands

Tel: +31(0)20 524 9111. E-mail: n.verhoeven@dnb.nl

Abstract As the global economy transitions towards net zero, it is conjectured that efficient financial markets reflect the risks involved with this transition. This hypothesis is empirically tested in this paper and signals are found of climate transition risk pricing in options, equity and bond markets, based on greenhouse gas emission levels. The analysis of recent developments in the option market suggests that investors perceive the oil and gas sector to have an elevated risk profile. In the equity and bond market for, particularly, the energy sector, investors appear to demand higher returns to compensate for a higher transition risk. In addition, it is found that the average maturity of newly issued bonds in the carbon intensive coal sector decreased, while the average maturity increased strongly in the renewables sector with low carbon emissions. The reduction of investors' long-term exposure to

the coal sector signals concerns about its long-term viability, while the opposite is the case for the renewables sector. Nonetheless, it is not possible to conclude that climate risk pricing is consistent, as the statistical evidence is not overwhelming and not fully aligned across different markets. Furthermore, as climate indicators and emission data still contain important flaws, climate pricing based on these indicators could also be inadequate. Therefore, this paper aligns with the literature arguing that climate risk pricing is inconsistent and inadequate and that this is important for investors and risk managers to acknowledge. In addition, policymakers are urged to ensure that transition information, like emission data, is correct, timely and comparable to ensure its information value and usability.

Keywords: *climate change, climate transition risks, equity market, bond market, option market*

INTRODUCTION

Since the start of the industrial revolution in 1760, roughly 1.5tn metric tons of carbon have been emitted into the atmosphere.¹ Scientists widely acknowledge that the emission of carbon dioxide and other greenhouse gases (GHGs) contributes significantly to global warming.² As a result, emissions need to be reduced drastically to limit global warming to well below 2° Celsius, and preferably even below 1.5°. In 2015, close to 190 parties committed themselves to these universal goals in the Paris Agreement, which resulted in concrete emission reduction targets for many jurisdictions around the world. For example, the EU has set a GHG emission reduction target of 55 per cent compared to 1990 and a net zero economy by 2050, while the USA has also committed itself to net zero by 2050 and China intends to reach this goal by 2060.

In the coming years, governments are expected to implement policies that incentivise GHG reductions, such as carbon emission tax or trade schemes. In addition, societal preferences and new technologies are likely to provide a push to low-carbon production processes. Decarbonising the global economy means that companies will have to drastically reduce their emissions, inducing climate-related transition risks. Companies with a higher GHG intensity will be more exposed to these transition risks, which will influence their performance and default risk. In this transition, it is likely that certain real assets will face stranding and financial assets will face devaluation. The financial risks that result from this transition are defined as ‘transition risks’.³

Financial theory predicts that efficient financial markets reflect all known information, including

information related to transition risks, in asset prices. As climate indicators and emission data become more available, it is expected that investors will use this information to adjust asset pricing accordingly. In a global comparison of GHG intensive sectors versus green sectors, preliminary signals of such adjustment mechanisms are observed.

Stock prices of GHG intensive sectors, in particular energy and metals and mining, have consistently underperformed the broader equity market index over the last decade. In contrast, ‘green’ sectors, such as renewables, have outperformed (Figure 1). This is also reflected in the development of price-to-book ratios, which, for energy and metals and mining have increasingly been lagging the price-to-book ratio of the MSCI (Morgan Stanley Capital International) World Index since 2012 (Figure 2). The price-to-book ratio compares a company’s market price to its book value. While the market price is a forward-looking metric

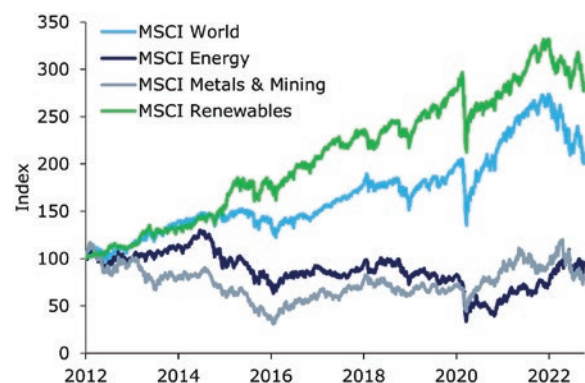


Figure 1: Stock prices of vulnerable sectors underperform, renewables outperform

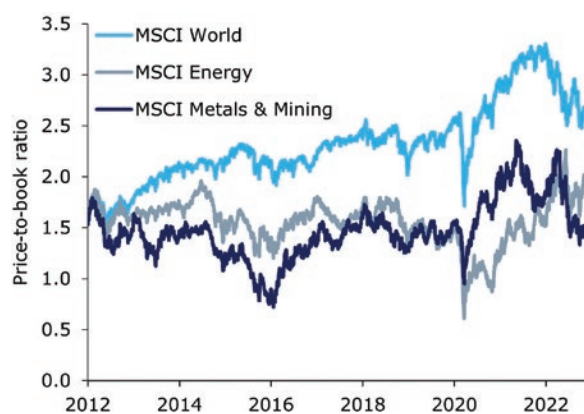


Figure 2: Price-to-book ratios of GHG intensive sectors lag behind the broader market

reflecting a company's cash flows, the book value is based on historical data. The price-to-book ratio, therefore, reflects investors' expectations about the future profitability of a company.

Price discovery in financial markets is necessary for a well-functioning economy. There is growing literature on the extent to which asset prices discount climate-related risks, ie physical risk and transition risks. While there is growing evidence that financial markets have started to price in climate risks, statistical evidence is not overwhelming and consistent across markets. In addition, there are also concerns that current prices do not *fully* reflect these risks.^{4,5} The physical consequences of climate change are, to a large extent, uncertain and cannot be based on historical data. Furthermore, transition pathways and policies are also uncertain, while climate risk indicators often suffer from shortcomings with respect to comparability and transparency. Finally, even though emission data has improved recently, it still contains important flaws, as Klaaßen and Stoll point out.⁶ Reported Scope 3 emissions are particularly difficult to quantify as they are a consequence of the activities of the company but occur from sources it does not own or control. Because of this, scrutiny on the pricing of climate risks is required.

Papers on the pricing of climate risks often focus on a particular asset class. This paper argues that another way to answer the question of whether or not financial markets price climate risks is by analysing if pricing occurs consistently across different financial markets. Through this approach, this paper examines the most

GHG-intensive sectors, namely energy and metals and mining, which are particularly vulnerable to transition risks.⁷ The option, equity and bond markets are investigated. Based on the option market, there is an assessment of whether investors perceive the energy sector to be more risky than the broad market index. Then the pricing of climate transition risks in the equity and bond market is analysed, by comparing securities of high GHG-emitting companies with those of low GHG-emitting companies within the same sector. Throughout this paper, the core data used is company-specific emission data provided by MSCI, as well as financial data provided by Bloomberg.

In the empirical analysis, signals are found that investors discount climate transition risks across different asset classes. In the option market, investors perceive a relatively large risk of a significant price decrease of the EuroStoxx Oil & Gas index, compared to the broad market index. This European stock index is used instead of a global index or the EuroStoxx Energy index due to the availability of option price data in Bloomberg, acknowledging that the two sectors are grossly overlapping because the energy sector is currently largely driven by fossil fuel companies. In addition, pricing differences are observed based on company emission levels in equity and credit markets, in particular for the energy sector. Finally, in the energy market, bond maturities of high-emitting sectors, specifically coal, decreased in the last decade, while maturities of renewables increased significantly. This may indicate a reluctance of investors to finance long-term GHG-intensive projects in the energy sector.

It is concluded that, in the energy sector, transition risks are being priced across all three market segments analysed, ie option, equity and bond markets. This indicates that these risks are a growing feature in asset pricing and that they increasingly play a role in investors' investment decisions and risk managers' processes. However, considering that climate data is still in its infancy, climate risk pricing could be inefficient. In fact, as is noted throughout this paper, many scholars believe climate risk pricing is, at this point, still inconsistent (for example, across different sectors) and inadequate. Encouraging climate-related disclosures and thereby improving climate data quality and availability are,

therefore, key for policymakers to promote efficient market functioning and market integrity.

The remainder of this paper is structured as follows. It begins by reviewing a number of theoretical considerations and the literature. In the subsequent sections, it focuses on the empirical analysis of the energy and metals and mining sectors. First, the paper gauges investors' perceived crash risk based on option prices. Secondly, a cross-section regression of company-specific carbon emissions is run on stock returns to investigate emission-based differentiation within the energy and metals and mining sectors. Finally, the paper turns to the bond market, looking both at spreads of existing bonds issued by polluting versus less-polluting companies and at maturities of newly issued bonds. The paper ends with a conclusion and policy recommendations.

THEORETICAL CONSIDERATIONS AND LITERATURE

The price of an asset is the present discounted value of the uncertain future cash flows that the asset will yield to investors under different states of the world. Investors prefer stable cash flows across different states of the world over uncertain cash flows. Bonds, therefore, have a high price relative to the expected cash flows and a low expected return. Equities, on the other hand, have a relatively low price and a high expected return, as the cash flows on equities are high in good states of the world. The value placed by investors on these high cash flows in good states of the world is low. Climate transition risks can affect the cash flows in different states of world, and these different outcomes should accordingly be weighted by the marginal utility in the state of the world in which they occur.⁸

A key challenge regarding climate risks is that the process of climate change is complex and characterised by fundamental uncertainty.⁹ This fundamental uncertainty stems from the unknown development, timing and impact of climate change features such as non-linearities, tipping points, feedback loops and interactions. Furthermore, the policy measures that governments will take to transform to a climate-neutral economy are also uncertain, as are technological developments and societal preferences. Finally, adequate pricing of

climate risks is impeded by a lack of data, consistent methodologies, standardised metrics and comparable disclosures on climate risks.¹⁰

Climate indicators such as GHG emission data, fossil fuel use, environmental, social and governance (ESG) ratings and transition goals help investors to better incorporate climate transition risks into asset prices. Empirical evidence suggests that investors indeed use these indicators to do so. Engle *et al.* show that asset prices respond to climate change-related news and construct portfolios whose short-term returns hedge for news about climate change over the holding period.¹¹ However, there are also concerns that current asset prices do not discount climate risks in full.¹² The uncertainties and externalities associated with climate change can lead to a situation in which the true social costs are not sufficiently captured in asset pricing.¹³ For instance, a majority of finance experts, academics, professionals, economists and regulators in a recent survey believe assets prices currently underestimate climate risks.¹⁴ Furthermore, the survey respondents regard transition risk as the main climate-related risk for the next five years, but consider physical risk key over the next 30 years.

The transition to a global low-carbon economy could result in stranded assets: companies that do not adapt may be left with assets that they may, by law, no longer exploit, or that may involve such high penalties that exploitation no longer pays off as the price falls below break-even. Transition risks present challenges for companies operating in high GHG sectors, as they might necessitate balance sheet depreciation due to stranded assets. There are indications that stock markets price in these transition risks by demanding a higher return from companies that are relatively more GHG-intensive. Bolton and Kacperczyk, for instance, document that the stocks of US companies with higher total carbon emissions earn higher returns, after controlling for size, book-to-market and other typical return predictors.¹⁵ A follow-up paper with a global sample supports the finding for the USA only.¹⁶ Furthermore, the authors find a time horizon effect. Companies located in countries with lower economic development, greater reliance on fossil energy and less inclusive political systems are more exposed to short-term transition risks, whereas companies in countries with stricter local climate

policies are more exposed to long-term transition risk. It should be noted that transition risks and physical risks could interact negatively. A quick and strong transition towards a net zero economy could limit the long-term physical impact of climate change but increase short-term transition risks.¹⁷

Transition risk also reflects in measures of default risk. Kabir *et al.*, for instance, find global evidence that carbon emissions are positively correlated with companies' default risk.¹⁸ These authors document a significant and negative impact of carbon emissions on companies' distance-to-default. The impact of carbon emissions on the distance-to-default is stronger for companies operating in more carbon-intensive industries and more environmentally aware economies. Similarly, Capasso, Gianfrate and Spinelli document that European companies with a large carbon footprint are perceived by the market as more likely to default.¹⁹ Interestingly, Carbone *et al.* find that companies disclosing emissions and setting a forward-looking target to cut emissions have lower credit risk.²⁰

In the following sections, three markets are analysed: the option, equity and bond markets. Existing literature reports cases in which option markets price transition risks. For instance, Ilhan, Sautner and Vilkov show that the cost of protection against downside tail risks is larger for companies with more carbon-intensive business models.²¹ Further, similar to Bolton and Kacperczyk,²² the impact of GHG emissions on stock returns in equity markets is analysed. Finally, the credit spread of high- and low-emitting companies in bond markets is compared. This relates to work from Xia and Zulaica on the term structure of carbon premia.²³

OPTION MARKET AND CRASH RISK

This paper adds to the work of Ilhan, Sautner and Vilkov²⁴ by analysing the option-implied crash risk of the European Oil & Gas sector. A crash risk is defined as a price decrease of 20 per cent or more, on month ahead. A European index is used due to the availability of option price data in Bloomberg. The index, the Stoxx 600 Oil & Gas Index, comprises 20 listed European energy companies. Unfortunately, there are no option prices available for the Stoxx 600 Metals & Mining index or

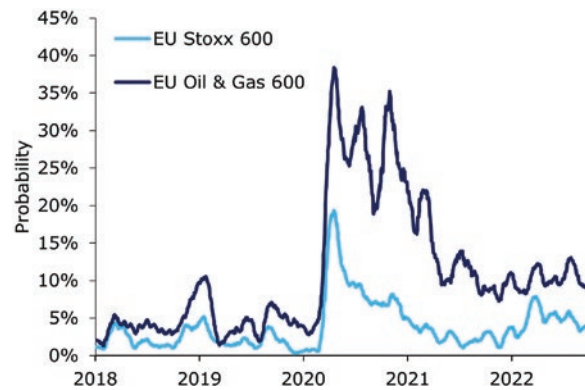


Figure 3: Elevated crash risk in European oil and gas stocks

comparable alternatives, so the focus here is on the energy sector. The analysis is based on options with a remaining time to maturity of one month, because these have the largest trading volume and, therefore, the price discovery process should be most accurate for these options. The analysis is constructed on risk-neutral probability densities for the future price movements of the index, based on option prices at different strike prices.²⁵ From these risk-neutral probability densities, the probability of a price decrease of 20 per cent or more is deducted and its evolution over time is tracked. Figure 3 shows the evolution of this metric for the Stoxx 600 Oil & Gas index and the Eurostoxx 600 index, which serves as a proxy for the broader European market.

Option prices reveal that European oil and gas stocks exhibit higher (negative) tail risks, pointing to more uncertainty about the sectors' future viability. Currently, investors see roughly a 10 per cent probability of a 20 per cent or more decline in the European oil and gas index, even though the sector's short-term profitability has benefited from the recent surge in oil and gas prices. The crash risk is substantially higher than for the broader European market, for which this probability is only 5 per cent. The divergence is fairly recent; in the 2018–19 period the crash risks were roughly similar. However, the COVID-19 pandemic induced a steep increase of crash risk in the energy sector from March 2020 onwards, which has not yet normalised to pre-pandemic levels. This persistent elevation could reflect recent regulatory climate developments, such as the EU Green Deal in 2020 and the EU

'Fit for 55' package from 2021, that require the oil and gas sector to adjust to a renewables-driven economy. The elevation could also be caused by non-climate risk related factors. Therefore, in the following sections the differences within the polluting sectors are investigated, based on GHG emissions of individual companies.

EQUITY MARKET AND GHG INTENSITIES

If investors perceive a higher risk, finance theory assumes that this will translate into higher expected returns. This paper therefore turns to the equity market, studying the impact of GHG emissions on total stock returns within the two sectors. Sectoral cross-sectional regression analyses are conducted and included in the two samples, respectively, which are 338 global energy companies and 325 metals and mining companies for which emissions data is available in the MSCI Climate Data and Metrics database. The sample for the energy sector is dominated by fossil fuel companies, with only a few companies that operate in the renewable energy sector.

Following Bolton and Kacperczyk,²⁶ the impact of GHG emissions on total stock returns is analysed. The main difference with the work of Bolton and Kacperczyk is that this study focuses on relative climate-risk pricing *within* a sector, while they analyse the broad market. In the main regression here, the impact of Scope 1 and 2 emissions on the total return of a company's stock is analysed. A number of variables that are inspired by the Fama-French factor model are controlled for, specifically size (market capitalisation), value (price-to-book ratio) as well as the return on equity and stock price return volatility. The main regression specification reads as follows:

$$R_{j,t} = \beta_0 + \beta_1 GHG_{j,t-1}^{Scope1,2} + \beta_2 RoE_{j,t} + \beta_3 \log(MC_{j,t}) + \beta_4 PB_{j,t} + \beta_5 Vol_{j,t} + \epsilon_{j,t}.$$

where $R_{j,t}$ is the annual total return of stock j in year t . The main variable of interest, $GHG_{j,t-1}^{Scope1,2}$ represents backward-looking Scope 1 and 2 emission data, namely GHG intensities calculated as a company's GHG emissions in year $t-1$ in CO₂-

equivalent metric ton per US\$1bn of sales. Scope 1 emissions are direct GHG emissions that occur from sources that are controlled or owned by a company. Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat or cooling. The following control variables are used: $RoE_{j,t}$ is the return on equity over year t , $\log(MC)_{j,t}$ is the natural logarithm of the market capitalisation at the end of year t , $PB_{j,t}$ is the price-to-book ratio at the end of year t and $Vol_{j,t}$ is the return volatility of stock j over year t . Table 1 (below) summarises these variables. The most recent data available is used, and the returns are calculated over the period 1st October, 2021–1st October, 2022. This period is chosen because MSCI only recently started to report several of the variables that are included here.

Other emission variables that could capture the transition risk of a company are also looked at. First, GHG intensities measured by Scope 1, 2 and 3 emissions are used. Scope 3 emissions are a consequence of the activities of a company, but occur from sources it does not own or control. This can be both upstream or downstream in the production processes, ie emissions from external suppliers in the production process or from the use of the company's products. Companies often do not report Scope 3 data, in which case MSCI uses estimates. In the sample in this paper, less than 25 per cent of the companies report on Scope 3. Secondly, an objective and forward-looking metric is included to see whether investors reward future actions that possibly mitigate transition risks. Specifically, a dummy variable with a value of one is used if a company has a reduction target. Thirdly, the MSCI Carbon Emissions score is included, which is a forward-looking metric by MSCI on emissions performance, and ranges on a scale of 0–10. In this metric, MSCI attributes higher scores to companies that invest in low-carbon technologies and that work to increase carbon efficiencies, while companies that solely exploit differences in climate regulatory frameworks, for instance, score low. The emission variables used in the regression concern emissions in 2021, as MSCI does not provide data prior to 2021 for most emission variables. The only variable that MSCI does provide historic data for is the variable GHG intensity based on Scope 1 and 2.

Table 1: Description of variables used the empirical analysis

Name	Description	Unit
GHG intensity scope 1 and 2	The company's most recently reported or estimated Scope 1 and Scope 2 greenhouse gas emissions normalised by sales in US\$. This allows for comparison between companies of different sizes.	(t/\$bn sales)
GHG intensity scope 1, 2 and 3	The most recent aggregate GHG emissions of the company (Scopes 1 and 2 and estimated Scope 3 emissions) relative to its most recent sales in €m.	(t/€bn sales)
Reduction target	Dummy variable that is 1 when a company has a reduction target and 0 otherwise.	[0,1]
MSCI carbon emissions score	A subjective performance score, provided by MSCI, with the following criteria: 'Companies that proactively invest in low-carbon technologies and increase the carbon efficiency of their facilities or score higher on this key issue. Companies that allow legal compliance to determine product strategy, focus exclusively on activities to influence policy setting, or rely heavily on exploiting differences in regulatory frameworks score lower'.	[0,10]
Return on equity	The amount of net income returned as a percentage of shareholders equity. Return on equity measures a corporation's profitability by revealing how much profit a company generates with the money shareholders have invested.	%
Price/book ratio	Ratio of the stock price to the book value per share	–
Stock volatility	Volatility of stock price returns over the last 260 trading days. The variable equals the annualised standard deviation of the relative price change.	%
Market cap	Market capitalisation refers to the total dollar market value of a company's outstanding shares. Commonly referred to as 'market cap', it is calculated by multiplying a company's shares outstanding by the current market price of one share.	\$

Table 2 shows the results for the energy sector, Table 3 for the metals and mining sector (both tables below) and the Appendix shows the results for other time periods, where possible.

In Table 2, the following is observed for the energy sector. First, in Column (1) higher average total stock returns of energy companies with a high GHG intensity Scope 1 and 2 over 2021 are correlated. For every additional metric ton of Scope 1 and 2 GHG emissions per US\$1bn of sales, the average total stock return increases by 12 percentage points per year. This supports this paper's hypothesis that investors require compensation for the higher perceived transition risk that stems from high emissions. Secondly, this finding is confirmed if GHG intensity Scope 1, 2 and 3 is added to the regression in Column (2). The additional variable is significant and positive, even after controlling for GHG intensity Scope 1 and 2. This implies that investors demand a higher return from companies with higher Scope 3 emissions. However, the results

should be interpreted with caution, as the Scope 3 emissions are an estimate by MSCI and not actually measured and reported by companies. Thirdly, energy companies' GHG reduction targets are not significant in Column (3). There are several possible explanations for why reduction targets do not reflect in stock valuations. Investors may be sceptical about the level of ambition in the reduction targets or they may feel that the progress on reduction targets is not being tracked consistently, which could reduce its information value to investors. Another explanation could be that investors focus on reducing the carbon footprint of their own portfolios, rather than on global carbon output, and, therefore, are less concerned with forward-looking metrics such as reduction plans. Fourthly, the negative correlation between stock returns and the MSCI Carbon Emissions Score in Column (4) implies that investors attach some value to the future carbon profile of companies. Investors seem to require lower stock returns for companies with 'good' carbon

Table 2: Regression results of GHG emission variables on stock returns in the energy sector²⁷

Variable	Energy sector			
	(1)	(2)	(3)	(4)
GHG intensity Scope 1 and 2	12.7***	7.44***	12.8***	8.07***
GHG intensity Scope 1, 2 and 3		0.97***		
Reduction target			-1.79	
MSCI Carbon emissions score				-5.27***
Return on equity	0.28*	0.24	0.28*	0.2
Log (Market cap)	4.43***	4.13**	4.64***	5.38***
Price-to-book ratio	0.14	0.14	0.13	0.11
Stock volatility	0.65***	0.55**	0.65***	0.46**
Observations	338	325	338	338
Adjusted R-squared	0.12	0.15	0.12	0.16

Significance levels: *95%, **97.5%, ***99%

Table 3: Regression results of GHG emission variables on stock returns in the metals and mining sector

Variable	Metals and mining sector			
	(1)	(2)	(3)	(4)
GHG intensity Scope 1 and 2	-0.96	-1.07	-1.07	-2.47
GHG intensity Scope 1, 2 and 3		0.71**		
Reduction target			-9.8***	
MSCI carbon emissions score				-1.71*
Return on equity	0.26**	0.27*	0.27**	0.26**
Log (Market cap)	3.13**	1.56	4.20***	3.89**
Price-to-book ratio	2.26**	1.78	1.93*	1.95*
Stock volatility	-0.24	-0.48***	-0.25*	-0.25*
Observations	325	286	325	323
Adjusted R-squared	0.10	0.12	0.11	0.10

Significance levels: *95%, **97.5%, ***99%

performance, as judged by MSCI, implying a lower perceived risk profile. This reduces the likelihood that investors focus solely on reducing the current carbon footprint of their portfolios.

This study's findings are less pronounced in the same analysis for the metals and mining sector in Table 3. First, the economic impact of the main variable GHG intensity Scope 1 and 2 is not significant in Column (1), implying that investors do not differentiate between companies in this sector based on their Scope 1 and 2 emissions over the last year. However, GHG intensity Scope 1, 2 and 3 is significant and positive in Column (2). Thus, investors do seem to consider the emissions profile of

the end-product more than of the initial production process itself. It is possible to attribute the less pronounced results in the metals and mining sector at least partially to its more ambiguous role in a net zero economy of the sector, making the future viability of the sector different from that of the fossil-fuel dominated energy sector. The OECD, for example, notes that the use of metals could double in 2060.²⁸

Secondly, a significant negative effect of the reduction target on total returns is observed in Column (3). An explanation could be that investors see less risk in companies with a clear target, but it could also be the case that they see the target hurting future profits, or a combination of both. Thirdly, for

the MSCI emission score in Column (4) a similar result is seen as in the energy sector, although it is borderline significant for the metals and mining sector.

BOND MARKET AND AVERAGE CREDIT SPREAD

In this section, the paper turns to bond markets to see whether signals of climate transition risk pricing are found. For this analysis, the credit spread of high- and low-emitting companies in both the global energy and metals and mining sectors are compared.²⁹ All outstanding senior non-preferred bonds of companies in the global energy sector are analysed based on Bloomberg classification (ie BICS). Only bonds from the investment grade universe are included to control for creditworthiness. Specific credit ratings within the investment grade universe are not the subject of focus, as the sample size would become too small.³⁰ Based on annual emission data from Bloomberg, the 20 per cent highest and lowest emitters are identified and the spread performance of these two groups in the consecutive year are considered. The high- and low-emitting groups are recalibrated annually, based on their emission data. Figure 4 shows the spread development of these groups for the energy sector from 2017 to 2022.

The average credit spread of bonds issued by the high emitters from 2019 is found to consistently hover above the low emitters in the energy sector. These findings for

energy companies are in line with Barth, Hübel and Scholz, who find that good ESG ratings are correlated with lower credit risk and lower CDS spreads.³¹

Furthermore, the exogenous shock to the energy market in 2020 as the COVID-19 pandemic hit seems to have had a stronger impact on the high-emitting group, as the average credit spread of this group climbed to ~600 basis points, while that for the low-emitting group did not rise beyond 500 basis points. This divergence may indicate a growing awareness among bond investors of climate transition risks. However, these results should still be interpreted with caution as no credit rate distinction *within* the investment grade universe was made. Thus, the observed spread could partially result from an overrepresentation of high emitters in lower credit rating buckets (BBB) within the investment grade universe. This, however, would not necessarily downplay this study's findings, as credit rating agencies are increasingly factoring in climate risks in the credit ratings they issue for companies. In this context, recent actions by S&P, which downgraded several energy companies due to their vulnerability to climate risks, are highlighted.³²

In the metals and mining sector, a pricing differential is less apparent (Figure 5). The credit spreads of high and low-emitting companies have been almost equal for the past two years. It is observed that high-emitting companies had a lower spread before the pandemic, indicating some improvement in the past few years. The lack of pricing of direct GHG

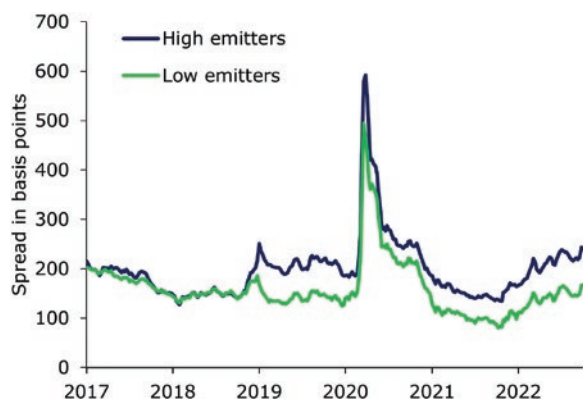


Figure 4: Credit spread of high emitters diverges from spread of low emitters (investment grade bonds in the energy sector; y-axis in bps)

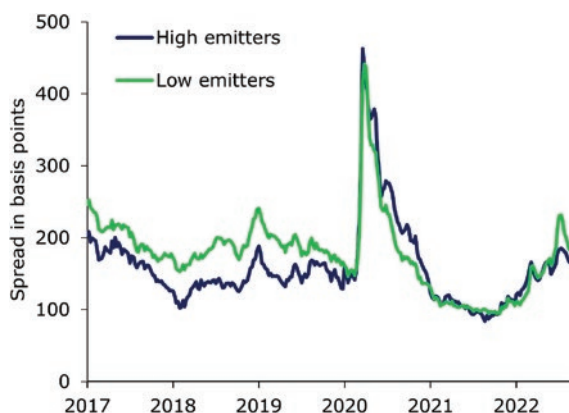


Figure 5: Credit spread of high emitters is similar to spread of low emitters (investment grade bonds in the metals and mining sector; y-axis in bps)

emissions in the bond market of the metals and mining sector is similar to the analysis of the equities market carried out for this paper. This could again be attributed to the more ambiguous future of the metals and mining sector versus the energy sector.

In conclusion, signals are found that investors in the energy sector demand higher returns for bonds issued by more polluting companies, as bonds from these issuers have higher credit spreads on average. This leads to the assumption that bond investors demand compensation for a higher transition risk in the form of higher yields. This is similar to the relationship found in the previous section on stock returns.

As a further indication of how investors perceive the future viability of GHG-intensive industries, the average maturity of newly issued bonds in different segments of the global energy sector are looked at.³³ A divergence in the average maturity of newly issued bonds is observed between companies with high carbon emissions (coal) and low emissions (renewables). While the average maturity of newly issued bonds in the renewables sector has more than doubled in the last decade, the average maturity of new bonds issued by the coal sector has roughly halved to approximately three years (see Figure 6). This may suggest that investors and issuers in more polluting sectors such as coal are less keen to buy or sell long-term bonds, primarily due to uncertainty about the long-term viability of the sector. The reduced attractiveness of the coal sector among investors is also illustrated by its shrinking overall project pipeline, as final investment decisions are now

80 per cent lower than five years ago, according to the International Energy Agency (IEA).³⁴ In addition, the IEA estimates that, in a net zero scenario, coal-fired power generation should decrease by an annual average of ~9 per cent between 2022 and 2030 and be completely phased out by 2040.

CONCLUSION AND POLICY RECOMMENDATIONS

The need to drastically reduce global GHG emissions and decarbonise the economy in order to limit climate change raises the question as to what extent financial markets reflect the risks that come with this transition. This paper finds, in line with existing literature, tentative signals across the option, equity and bond markets that investors are starting to price climate risks into the assets of more polluting companies in the energy sector and, to a lesser extent, in the metals and mining sector.

Based on an analysis of the options markets, investors perceive the European oil and gas sector to be relatively risky. Although the exact impact of the energy transition on energy companies is opaque, option prices suggest that European oil and gas stocks exhibit higher (negative) tail risks, indicating greater uncertainty about the sector's future viability.

In addition, the paper finds that investors in the equity and bond markets demand compensation for the higher perceived risks in the form of higher returns on both stocks and bonds. This is in line with financial theory, as well as the academic literature (eg Bolton and Kacperczyk³⁵), which suggests that investors desire to be compensated for higher risks in the form of higher returns. At the same time, it is found that bond maturities in the coal sector in particular are being shortened. This suggests investors want to limit their long-term exposure to companies vulnerable in the transition to a net zero economy. The less pronounced results in the metals and mining sector, which is attributed to the more ambiguous future of the sector in a net zero economy, may support claims that unclear transition pathways complicate adequate climate risk pricing.

This study attributes the integration of climate risks in asset pricing at least partially to the growth of ESG considerations in financial markets, as well as to tightening climate regulation, developments in the

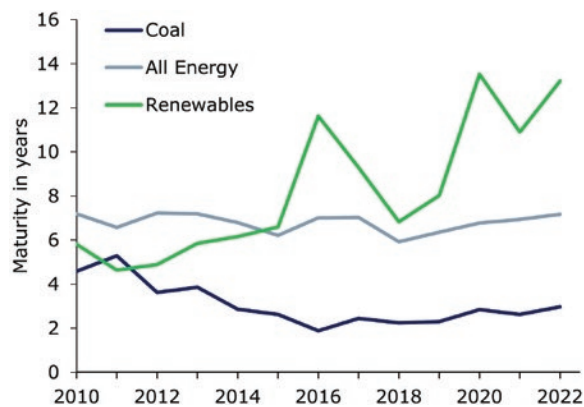


Figure 6: Average bond maturities for different energy subsectors diverge strongly (y-axis shows maturities in years)

available emissions data, more advanced disclosures and the establishment of taxonomies. These findings carry the following key messages for both private and public actors in the financial system.

First, as markets show tentative signs of climate risk pricing, investors and risk managers should be precautionary and integrate transition risks in investment decisions and risk management processes with the aim of limiting unexpected asset devaluations.

Secondly, both public and private actors widely acknowledge that current climate metrics and emissions data are still — at least to some extent — flawed. This adds uncertainty to the question of whether climate risks are, in fact, being *adequately* addressed. As has been laid down in this paper, market participants, policymakers and academia are concerned that climate risks are insufficiently addressed in asset pricing. Uncertainty about the timing and intensity of climate risks is also insufficiently reflected in climate indicators, which could cause investors to underestimate these risks, leaving them vulnerable to future price shocks. Thus, the tentative signals of climate risk pricing should not be confused with the conclusion that investors are *adequately* pricing in transition risks.

Finally, as financial markets adopt climate risk practices, policymakers should acknowledge the previously identified flaws and try to improve them. Opaque, unaccounted or underpriced climate risks can hamper the stability of market functioning, while data or measurement flaws (intentional or unintentional) can affect market integrity. As financial markets respond to new climate information, policymakers must try to ensure that this new information is correct, timely,

understandable and comparable to ensure its usability. Otherwise, financial stability may be affected and the resilience of financial markets may be put to the test.

It is, therefore, important to continue developing consistent and globally applied standards for measuring and reporting on climate transition risks. Recently, several international frameworks (eg the EU taxonomy and the TCFD reporting standard) have developed metrics and disclosure requirements that will assist in creating the transparency required to quantify transition risk. In order to improve the global comparability of these frameworks, global harmonisation is advised. In working towards harmonisation, policymakers should ensure the integration of forward-looking climate metrics and credible transition plans, and, preferably, verification of transition progress. Finally, it bears mentioning that the financial system — as an intermediary in our economies — is dependent on the reporting and disclosures of its actors (ie corporates, households etc).

ACKNOWLEDGMENTS

The views expressed are those of the authors and do not necessarily reflect the official position of De Nederlandsche Bank (DNB). We thank Aerd Houben and David Rijsbergen for their valuable suggestions.

APPENDIX

Below, as a robustness check, the impact of the key variables is analysed in four annual regressions (Tables A1 and A2). In short, it appears that, for the

Table A1: Analysis of key variables for the energy sector in four annual regressions

Variable	Energy sector			
	2018	2019	2020	2021
GHG intensity Scope 1 and 2	0.42	0.21	2.98	15.5***
Return on equity	0.40***	-0.05***	0.11	1.02***
Log (Market cap)	1.93	2.95*	-2.24	1.53
Price-to-book ratio	-1.44	2.16**	1.29	-3.66
Stock volatility	-0.15	-0.23	-0.21*	2.22***
Observations	215	238	235	222
Adjusted R-squared	0.060	0.051	0.0044	0.227

Significance levels: *95%, **97.5%, ***99%

Table A2: Analysis of key variables for the metals and mining sector in four annual regressions

Variable	Metals and mining sector			
	(2018)	(2019)	(2020)	(2021)
GHG intensity Scope 1 and 2	-9.13***	-3.22	-2.84	0.70
Return on equity	0.43*	0.33	-1.31	0.39
Log (Market cap)	3.49	8.28***	18.8**	2.08
Price-to-book ratio	0.52	19.8***	9.66***	2.42
Stock volatility	0.46	1.48***	3.84***	5.05***
Observations	183	238	247	236
Adjusted R-squared	0.0874	0.344	0.466	0.361

Significance levels: *95%, **97.5%, ***99%

energy sector, the impact of emissions on stock returns is a recent phenomenon. The findings in the metals and mining sector are, again, less pronounced.

References and notes

- Ritchie, H., Roser, M. and Rosado, P. (2020) 'CO₂ and Greenhouse Gas Emissions', available at: <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions> (accessed 2nd November, 2022).
- See, for instance, IPCC (2021) 'The Sixth Assessment Report. Working Group 1: The Physical Science Basis', available at: <https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-1/> (accessed 27th October, 2022).
- NGFS (2019) 'A Call for Action. Climate Change as a Source of Financial Risk', available at: https://www.ngfs.net/sites/default/files/medias/documents/ngfs_first_comprehensive_report_-_17042019_0.pdf (accessed 5th December, 2022).
- See, for instance, IMF (April 2020) 'Climate Change — Physical Risk and Equity Prices', in 'Global Financial Stability Report' (Chapter 5), available at: www.imf.org/en/Publications/GFSR/Issues/2020/04/14/Global-Financial-Stability-Report-April-2020-49020 (accessed 20th October, 2022); or: NGFS (2022) 'Enhancing Market Transparency in Green and Transition Finance', Technical report, available at: https://www.ngfs.net/sites/default/files/medias/documents/enhancing_market_transparency_in_green_and_transition_finance.pdf (accessed 20th October, 2022); or: Campiglio, E., Monnin, P. and von Jagow, A. (2019) 'Climate Risks in Financial Assets', available at: <https://www.cepweb.org/climate-risks-in-financial-assets/> (accessed 2nd November, 2022).
- It is not possible to be conclusive about when climate risks would, in fact, be adequately priced in adequately by financial markets. It is unlikely that market prices account for climate-related information that is not known. Further, the research mentioned here also points at underpricing in the sense that markets do not seem to account for all available climate-related information.
- Klaaßen, L. and Stoll, C. (2021) 'Harmonizing Corporate Carbon Footprints', *Nature Communications*, Vol. 12, No. 6149, <https://doi.org/10.1038/s41467-021-26349-x>
- See, for instance, Vermeulen, R., Schets, E. and Lohuis, M. *et al.* (2018) 'An Energy Transition Risk Stress Test for the Financial System of the Netherlands', *De Nederlandsche Bank Occasional Studies*, Vol. 16, No. 7, pp. 7–68.
- Litterman, R. (2011) 'Pricing Climate Change Risk Appropriately', *Financial Analysts Journal*, Vol. 67, No. 5, pp. 4–10.
- Broeders, D. and Schlooz, M. (2021) 'Climate Change Uncertainty and Central Bank Risk Management', *Journal of Risk Management in Financial Institutions*, Vol. 14, No. 2, pp. 121–30.
- See, for instance, OECD (2021) 'Financial Markets and Climate Transition: Opportunities,

- Challenges and Policy Implications', OECD, Paris.
- 11 Engle, R.F., Giglio, S., Kelly, B., Lee, H. and Stroebel, J. (2020) 'Hedging Climate Change News', *Review of Financial Studies*, Vol. 33, No. 3, pp. 1184–1216.
 - 12 See, eg European Central Bank (2021) 'Climate-related Risk and Financial Stability', ECB/ESRB Project Team on climate risk monitoring, available at https://www.ecb.europa.eu/pub/pdf/other/ecb_climateriskfinancialstability202107~87822fae81.en.pdf (accessed 24th January, 2023).
 - 13 Nordhaus, W. (2019) 'Climate Change: The Ultimate Challenge for Economics', *American Economic Review*, Vol. 109, No. 6, pp. 1991–2014, <https://doi.org/10.1257/aer.109.6.1991>
 - 14 Stroebel, J. and Wurgler, J. (2021) 'What Do You Think About Climate Finance?', available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3898013 (accessed 24th January, 2023).
 - 15 Bolton, P. and Kacperczyk, M. (2021) 'Do Investors Care About Carbon Risk?', *Journal of Financial Economics*, Vol. 142, No. 2, pp. 517–49.
 - 16 Bolton, P. and Kacperczyk, M. (2022) 'Global Pricing of Carbon-transition Risk', (*Journal of Finance*, forthcoming), available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3550233# (accessed 15th February, 2023).
 - 17 See, for instance, Lord, R., Bullock, S. and Birt, M. (2019) 'Understanding Climate Risk at the Asset Level: The Interplay of Transition and Physical Risk', available at: <https://www.spglobal.com/marketintelligence/en/documents/sp-trucost-interplay-of-transition-and-physical-risk-report-05a.pdf> (accessed 24th January, 2023).
 - 18 Kabir, N., Rahman, S., Rahman, A. and Anwar, M. (2021) 'Carbon Emissions and Default Risk: International Evidence from Firm-level Data', *Economic Modelling*, Vol. 103, DOI: 10.1016/j.econmod.2021.105617
 - 19 Capasso, G., Gianfrate, G. and Spinelli, M. (2020) 'Climate Change and Credit Risk', *Journal of Cleaner Production*, Vol. 266, <https://doi.org/10.1016/j.jclepro.2020.121634>
 - 20 Carbone, S., Giuzio, M., Kapadia, S., Krämer, J.S., Nyholm, K. and Vozian, K. (2021) 'The Low-carbon Transition, Climate Commitments and Firm Credit Risk', ECB Working Paper Series No. 2631.
 - 21 Ilhan, E., Sautner, Z. and Vilkov, G. (2021) 'Carbon Tail Risk', *The Review of Financial Studies*, Vol. 34, pp. 1540–71.
 - 22 Bolton and Kacperczyk, see ref 15 above.
 - 23 Xia, D. and Zulaica, O. (2022) 'The Term Structure of Carbon Premia', BIS Working Papers No. 1045.
 - 24 Ilhan et al., see ref 21 above.
 - 25 For the methodology, see Blake, A. and Rule, G. (2015) 'Deriving Option-implied Probability Densities for Foreign Exchange Markets', Centre for Central Banking Studies, London.
 - 26 Bolton and Kacperczyk, see ref 16 above.
 - 27 See the appendix for some robustness checks on historical data. The main result (regression 1) is consistent if analysed over 2021, but in earlier years the GHG intensity variable is insignificant. Other emission variables are, unfortunately, not available historically.
 - 28 OECD (2019) 'Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences', OECD Publishing, Paris, doi.org/10.1787/9789264307452-en
 - 29 The zero-volatility spread (Z-spread) is used, which is a constant spread that equals the price of a security to the present value of its cash flows when added to the yield at each point on the spot rate treasury curve. The Z-spread is an often used spread and is easily available on Bloomberg.
 - 30 In this Bloomberg BQL-analysis, the development of the average Z-spread is calculated in the two respective groups per year, after applying the following filters to the whole bond universe: active bonds, bics_level_1_sector = Energy, payment rank = senior unsecured, BB-composite =>BBB-.
 - 31 Barth, F., Hübel, B. and Scholz, H. (2022) 'ESG and Corporate Credit Spreads', *Journal of Risk Finance*, Vol. 23, No. 2, pp. 169–90.
 - 32 See Reuters staff (2021) 'S&P Downgrades Exxon and Chevron on Climate Risks, Dour Earnings', available at <https://www.reuters.com/article/us-usa-oil-credit-idUSKBN2AC29C> (accessed 5th December, 2022).

- 33 In this Bloomberg BQL-analysis, the unweighted average maturity per year is calculated, after applying the following filters to the whole bond universe: active bonds, payment rank = senior unsecured. And, respectively, bics_level_1_sector_name = 'Energy', bics_level_2_industry_group_name = 'Coal Operations' or bics_level_2_industry_group_name = 'Renewable Energy'.
- 34 International Energy Agency (2021), 'World Energy Outlook', available at <https://www.iea.org/reports/world-energy-outlook-2021> (27th October, 2022).
- 35 Bolton and Kacperczyk, see ref 16 above.