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MEASURING CLIMATE TRANSITION RISK IN THE EUROPEAN EQUITY MARKET

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Introduction

1.1 The climate change discussion

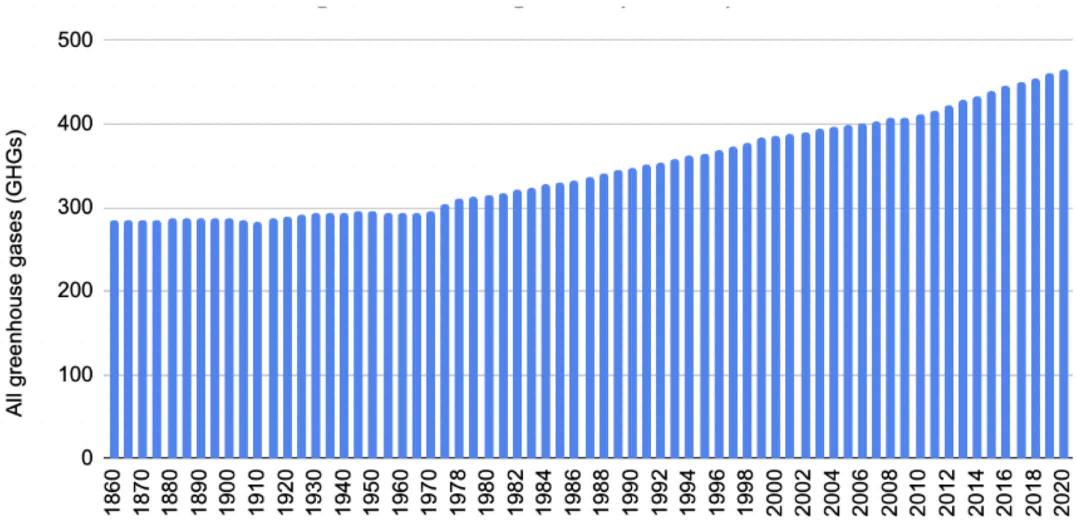
Climate change is the ultimate challenge in economics[1]. This is due to a global negative externality in the form of greenhouse gas emissions (GHG). Human activities surrounding economic growth have led to global warming mainly through the release of greenhouse gases, and caused the Earth's surface temperature to exceed 1.1°C above the average temperature recorded in the pre industrial era (IPCC, 2021).

In 2015, the Paris Agreement was signed with the aim of limiting temperature rise to just 1.5 degrees Celsius above pre-industrial levels. Attaining this objective requires the imperative task of substantially decreasing GHG emissions, one of the most pressing and challenging problems to be addressed in the 21st century (IPCC, 2012).

According to the European Environment Agency (2023), the total CO2 emissions concentration reached 465 ppm in 2020, which is 49 ppm more than 10 years ago, and about 185 ppm more than pre-industrial times (Fig 1).

[1] Nobel Prize lecture, December 8, 2018 by William D. Nordhaus.

Figure 1: Observed trends in greenhouse gases (GHGs) concentration levels



This figure illustrates the yearly time series evolution of GHGs emissions at global level. Data are expressed in CO2 equivalent (CO2e) in parts per million (ppm). Source: European Environment Agency.

In 1988, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) jointly established the Intergovernmental Panel on Climate Change (IPCC). Its primary mission is to provide governments and policymakers across the globe with scientific data that can be used in the formulation of climate-related policies. Presently, the IPCC has 195 nations as members. In their 6th Assessment report, in order to limit global warming to 1.5 degrees Celsius, emissions need to be reduced by approximately 43% by 2030 compared to 2019 levels (IPCC, 2022). This would require immediate and substantial action across all sectors, including energy, transportation, industry, agriculture, and buildings.

Reaching "Net Zero" refers to a state in which the total GHG emissions produced by a particular entity, such as a country or a company, are effectively cancelled out by actions that either reduce emissions or remove an equivalent amount of GHGs from the atmosphere. Today, the critical need to decarbonize is increasingly being accepted. More than 70 countries, including the major emitters like China, the United States, and the European

Union, have committed to net-zero targets, representing approximately 76% of global emissions by December 2022 (UN Environment, 2023).

Reaching Net Zero emissions by 2050 will require a profound overhaul of the global economy. The energy sector stands as a key driver for GHG emissions, responsible for around 75% of global emissions (IEA, 2021). Consequently, tackling emissions from the energy sector would be of critical importance in reducing the consequences of climate change. Achieving decarbonization will require some of the largest investments we have seen over a short period of time. Research to date has estimated required investment to be in the range $3.5 trillion of average annual spending for the Net Zero transition, of which $2.4 trillion should flow into the power sector (IEA, 2021). Others suggest the cumulative spending required to achieve the necessary climate goals from 2021 to 2050 would actually amount to over $9 trillion annually by broadening the spending needed to support other adjustments in specific parts of the economy (Mckinsey, 2022).

In this context, the development of clean technologies becomes critical. A significant portion of the worldwide reduction in CO2 emissions by 2030 can be realised through the use of technologies that are presently accessible (IEA, 2021). Yet, envisioning the path to 2050, it is anticipated that approximately half of the decrease in emissions will rely on technologies that are currently in the demonstration stages[2]. A broad number of emerging technologies under development such as cutting-edge batteries, hydrogen electrolysers, and direct air capture and storage (DAC) represent pivotal opportunities for innovation as we progress toward a future with net-zero emissions.

[2] Bill Gates said recently that "Innovation is key. We couldn't solve the climate problem with existing technology even if we had unlimited resources". GatesNotes: The Blog of Bill Gates, November 13, 2023.

Rapid decarbonization of the global economy is critical to protect nature and human well-being. It will require an immediate, massive increase in investment in low-carbon energy production, manufacturing, and supporting infrastructure. Such investments cannot be funded by government expenditures or philanthropic support alone. The scale required, as seen previously to be estimated to be trillions of dollars per year, is simply too large. As private sector investments are motivated by the expectations of future profits, the path forward is to increase expected returns to low-carbon investments.

In my current role as Head of Goldman Sachs Asset Management in Iberia, I have seen this to be a priority in the financial sector. This subject is also highly relevant to me, as it has been a main concern for investors that are exposed to a large divergence across sustainability metrics and have to direct optimal decision-making according to new regulatory frameworks. The emergence of greenwashing over the past years (see Netto et al. 2020) has limited the success of recent sustainability efforts. I therefore believe it is important to offer a quantitative analysis of the contributions of the sustainability efforts seen in the European market and their effect on equity performance.

In the financial sector, the biggest question is whether companies with better environmental metrics are outperforming the market. Financial markets play an important role in managing and addressing climate risks. A necessary condition for this to work is that prices in financial markets properly reflect climate risk exposures. Currently, there is a limited understanding of the relationship between carbon emissions and stock returns on a global scale. The existing literature has yielded conflicting findings, presenting mixed evidence regarding the pricing of climate risk in the equity market.

The research topic of my thesis involves to what degree are investors pricing carbon risk in asset values. The main objective of my research is to determine the extent to which climate transition risk exposure, as measured by the level of corporate GHG emissions, has been priced in the European equity market from 2007 to 2022. As a second step in the analysis, I will perform the same analysis at a sector level focusing on a couple of sectors only, Consumer Discretionary and Industrials. The selection of these two is based on the fact that Consumer Discretionary is highly impacted by Scope 3 emissions, while Industrials is not.

The two research questions are as follows:

- Is there evidence of climate risk reflected in European Equity prices?
- Do companies with low carbon emissions outperform their peers in the Industrials and Consumer Discretionary sectors?

These are difficult questions to answer ex-ante. Literature is not conclusive about the effect of the green factor on corporate returns. Some academics see a positive risk premia (Bolton, 2021a) and others do not (Pastor, 2021). My null hypothesis is that financial markets do not show evidence yet of a green factor priced in European stocks. This thesis will therefore test and analyse this question empirically.

The research gap to be addressed by this study encompasses three different angles which aims to bring perspective to the academic literature on climate finance. First of all, this is one of the first research studies[3] which includes Scope 3 emissions, therefore involving the measurement of emissions across the whole supply chain. Direct emissions or Scope 1 are the primary source of emissions for the energy, raw material extraction, agriculture, and

[3] See Bolton (2021a) and Cheema-Fox (2021) for the other studies with Scope 3 emissions.

transportation sectors. Otherwise, Scope 3 emissions usually account for more than 70 per cent of a business's carbon footprint[4], and therefore ignoring Scope 3 emissions may lead to an incomplete assessment of a company's environmental impact.

One of the main reasons there are only a handful of research papers using data on Scope 3 emissions is because many entities do not disclose any emissions from their supply and distribution chains, which makes it difficult to build historical series based on this category of emissions, as the data is simply not available. These emissions are also difficult to measure. For example in the case of the automobile sector, the supply chain is usually made up of multiple tiers of suppliers, manufacturers, distributors and service providers, spread around the world, making the task of supply chain carbon accounting very challenging. Then, there is also the argument that Scope 3 emissions are not reliable or that they are "noisy", given the overlap in emissions accounting. The same emissions are reported multiple times by different companies. For example, it could be argued that any company´s Scope 3 emissions will appear under a utility´s Scope 1 emissions (Heal, 2023). This could lead to a misleading impression of total emissions, and more importantly from a mitigation policy perspective, any reduction could be double counted. The solution has been for many researchers to only focus on Scope 1 emissions measurement and make the rest of emissions essentially redundant.

However, even if Scope 3 emissions data may be imperfect, considering the full life cycle of a company throughout the entire value chain is essential for gaining a complete understanding of a company's or industry's carbon footprint and its impact on the environment. There is a valid approach to have clear accountability by emitter, by attributing to a company all the emissions that could conceivably be associated with it. Therefore, there

[4] United Nations Global Compact and GHG Protocol.

is a rationale for including them in order to encourage companies to exert influence over emissions that they don't control directly. For instance, companies can engage in practices such as sourcing from or selling to entities with lower Scope 1 emissions. Additionally, collaborative efforts with suppliers and customers to mitigate greenhouse gas (GHG) emissions throughout their respective value chains represent proactive measures in this regard.

Finally, Scope 3 disclosure will become mandatory very soon in the EU, as published by the ISSB on 1st October 2022. Therefore, the argument of ignoring Scope 3 emissions on the grounds of high measurement errors will not be enough for a company to justify to its potential investors. As shown in my analysis, Scope 3 emissions are also very large in magnitude and for some industries represent the majority of a company's emissions.
In this thesis, I have used two metrics that aim to capture climate transition risk: *Emissions Intensity* is a measure of the economic impact of current emissions scaled for the level of revenues for each company, *Total Emissions,* and it is an absolute measure.

My thesis also aims to focus exclusively on Europe, as this region has been a leader in bringing forward green regulation which makes it an interesting case for study. Europe has been a pioneer in some of the most innovative climate policies such as the EU ETS market or the EU Carbon Border adjustment mechanism. Most studies have predominantly concentrated on the United States like Engle (2020) and Pastor (2021), with only a few exceptions like Bolton (2022) and Zhang (2022) that explore global perspectives. However, there has been only a small number of studies covering Europe like Alessi (2021) and Gimeno (2022). By choosing to focus on Europe in my research, my aim is to contribute to a better understanding of the application of asset pricing theories and models across different markets and regions worldwide.

Finally, most of the academic research papers which have been published so far have worked on data covering a period that ends in 2020. I had thought it was relevant to expand the time period to as close as possible to the present, in order to reflect the latest trends in the market. This may be one of the first studies in the field of green factor pricing that covers the period following the Ukraine war. The extension of the time period until the end of 2022 is interesting, given that the conflict has changed some of the priorities in the agendas of EU leaders and provided a regime shift for investors with a new focus on solving for energy security in Europe.

As the discussion about how to reduce emissions becomes more relevant, and the potential difficulties of applying a carbon tax are evident due to the escalating energy costs in Europe, a potential solution is to leave this to be worked out directly by the financial markets through a difference in their risk premia and their cost of equity.

This thesis highlights the importance of accounting for Scope 3 emissions when constructing portfolios based on carbon emissions. In doing this, it demonstrates that for sectors that are highly polluting across the entire value chain, low carbon emission companies can outperform their peers. This can provide a reason to support the decarbonization efforts of European companies, as investors will start incorporating the transition risk of a firm's supply chain in their assumptions.

1.2 Regulatory Framework

The EU was the world's fourth biggest greenhouse gases emitter after China, the US and India in 2021. The EU has accomplished the most significant proportional reduction in GHG emissions among the major emitters. In 2021, the EU27 saw a remarkable 27.3% decline in fossil CO2 emissions compared to the levels observed in 1990. Notably, the EU's global contribution to emissions has also diminished, decreasing from 16.8% in 1990 to 7.3% in 2021 (EU Science Hub Homepage, 2022).

The EU has long been at the forefront in terms of recognizing the urgency of addressing climate change and taking substantial measures to do so through policies (European Commission, 2008). In December 2019, the European Commission made a sweeping commitment to be carbon neutral by 2050 through the European Green Deal (European Commission, 2019). As Covid-19 broke out, the EU faced the economic and health crisis by kick-starting a green recovery. In March 2020, only shortly after the pandemic broke out, the Commission started integrating the Deal into EU law. They proposed a framework for achieving climate neutrality and amending regulation to the European Parliament and the Council. In July 2021, the European Commission published its revised roadmap, "Delivering the European Green Deal", committing to cutting GHG emissions by at least 55% by 2030 compared to 1990 levels, and paving the way for the bloc to become the world's first Net Zero continent by 2050 (European Commission, 2019). The regulation entered into force on 29 July 2021.

To be "Fit for 55", as the EU´s reduction target is also called, the bloc aimed to mobilise at least €1 trillion of capital into sustainable investments. This includes increasing the share of renewables in the energy mix, expanding decarbonisation targets to transport, including a 55% cut in car emissions by 2030 and zero emissions from new cars by 2035, and putting 35 millions buildings for renovation over the next 10 years. It also intends to implement measures to tighten the carbon market by stepping up the Emissions trading Scheme (European Commission, 2019).

Several proposals within the 'fit for 55' package are directed at mitigating GHG emissions associated with energy, which is the main source of emissions for the region, as 77% of emissions in the EU were due to the Energy sector in 2019, followed by 10% Agriculture, 9% Industrial processes and product use and 3% Waste Management (European Environment Agency, 2023). The primary targets aimed to contribute to the 55% net emissions reduction include reaching a 40% share of renewable energy sources by 2030, and achieving significant reductions in both primary and final energy consumption. These objectives will be supported by a higher carbon price through the revision of the EU Emissions Trading System (ETS) and the Energy Taxation Directive. This, in turn, will promote the expansion of renewable energy sources and energy efficiency improvements.

To fund their ambitious Green Deal, the European Commission introduced the Sustainable Europe Investment Plan in January 2020. This plan was designed to draw in a minimum of €1 trillion in both public and private investments over the ensuing decade. Financial institutions were given the task to redirect investments toward sustainable initiatives, thereby influencing the broader transition toward a low-carbon economy. In Europe, this meant that financial institutions had to deal in a very short period of time with new regulations related to sustainability. These were compiled under the EU taxonomy or Sustainable Financial Disclosure Regulation (SFRD). The EU taxonomy serves as a list of "green classification" systems, aiming to provide clarity on what constitutes sustainable economic activities. The EU taxonomy has been one of "the most seminal regulatory developments" driving standardisation in reporting for corporates and asset managers[5].

The SFDR is the first European regulation introduced to improve transparency for sustainable investment products and to prevent greenwashing by financial market participants which has been applicable since March 2021. It aims to reorientate capital flows towards sustainable finance and enforces extensive sustainability reporting obligations on financial entities covering a broad set of environmental, social, and governance (ESG) metrics, applicable to the products they sell to retail investors. The SFDR plays a crucial role in the EU's Sustainable Finance agenda as a response to the Paris Agreement in December 2015 and the UN 2030 Agenda for Sustainable Development, and is considered a cornerstone of its efforts in this field.

There have been a number of challenges with the implementation of SFDR, regarding the lack of clarity when considering which investments are Sustainable investments, and around the Principal Adverse Impact (PAI) requirements. The ambiguity became apparent when the EU decided to incorporate natural gas and nuclear energy within the sustainability framework outlined in the EU taxonomy highlighting the differing perspectives from EU member states concerning the sustainability of these energy sources within the broader environmental and climate goals.

Disagreements have arisen concerning the level of specificity in the regulation. Some advocate for maintaining high-level requirements without being overly prescriptive to avoid

[5] GS Sustain, EU Green Capex - meeting takeaways from companies & EU Commission. 13th November 2023.

limiting the investable universe. On the other hand, there are those who argue that too much flexibility might lead to a lack of legal clarity resulting in different interpretations and potentially expose investors to various risks. This is still a work in progress and the European Commission is expected to provide additional clarity for financial sector EU Taxonomy reporting in the next few months (Tylenda et al, 2023). In my opinion, criticism has also come of the labelling scheme of their investment products under Article 6, 8 and 9, and the difficulty by financial institutions to explain this new classification system to their retail clients.

Europe has been leading the Green transition in the world until the introduction in 2022 of the Inflation Reduction Act (IRA) in the United States. The green subsidies provided by the IRA are roughly comparable in scale to those found in the European Union, except in the case of renewable energy production, where EU subsidies are larger, according to the IAE World Energy Investment. Nevertheless, there are significant qualitative distinctions between the two. Certain IRA subsidies favour domestic producers over foreign ones, whereas EU subsidies do not exhibit such discrimination (European Parliament, 2023).

1.3 The new field of Climate Finance

Sustainability and carbon accounting is a completely new topic for academia, as there are no papers published from even a decade ago (Matsamura et al, 2014). In the world of economics, scholars have only recently begun to focus on researching the diverse impacts of climate change on financial markets. The domain of climate finance is relatively new, and the growing interest it has gathered in the political and business circles in recent times has propelled research efforts in this arena (Hong et al., 2020). The fact that most of the countries and companies in the world have committed to Net Zero over the next couple of decades, has been a major influence. Substantial progress has been made in understanding the link among climate factors, the economy, and asset valuations, with considerable advancements in modelling these relationships (Nordhaus, 1977, 1993).

As new policies are implemented to meet the Paris agreement goals, investment risks and opportunities are likely to be generated in the global financial markets. As an example, Dietz et al. (2016) calculate the yearly climate value-at-risk for financial assets at approximately $2.5 trillion. Additionally, Hong et al. (2019) and Engle et al. (2020) present findings that showcase the market's lack of efficiency in accurately pricing these associated risks and potential opportunities.

The transition to a low-carbon economy at some point in the future may have a material impact on companies' financial performance. Changes in government policy, technology and consumer preferences resulting from the social and economic impact of climate change have significant implications for companies' business models, cost structures and revenue streams. Companies will likely manage this uncertainty differently, creating relative winners and losers in the coming years and decades. Companies that are heavily dependent on fossil fuels are at greatest risk. This includes companies in the energy sector that produce fossil fuels, as well as companies in the transportation and utility sectors that consume large quantities of fossil fuels. Yet even companies that are not heavy users of fossil fuels themselves may face transition risk via their supply chain, such as from the sale of products to companies that are big users of energy. The costs associated with the transition to a low-carbon economy may be either direct costs (e.g., an explicit carbon tax) or indirect costs (e.g., falling consumer demand). These incremental “costs” will be borne by companies all along the carbon value chain and ultimately by the end consumer.

During the shift towards a net-zero economy, there is a likelihood of asset stranding leading to the decreasing use and early retirement of physical assets currently linked to fossil fuels. This situation could result in substantial depreciation, amounting to trillions of dollars in lost asset value. Moreover, there would be a ripple effect impacting assets indirectly dependent on these fossil fuel-related assets. The relevance here is that a substantial number of these assets that could potentially become stranded are present on the balance sheets of publicly traded companies (Atanasova & Schwartz, 2019). This brings about a risk that the book value of these assets may no longer accurately reflect their genuine economic worth. Among these assets are infrastructure, equipment, reserves, and other tangible or intangible elements associated with fossil fuels and industries characterised by high emissions (Welsby, 2021).

While the market has already begun to include climate transition risk in stock prices, this price-adjustment process is not yet complete, and significant downside risk to equity valuations remains (Goldman Sachs, 2020). As more investors focus on the potential financial effects of climate change, companies will likely expand both the scope and breadth of climate-related disclosures. Companies with high carbon emissions are exposed to elevated climate transition risk. Consequently, investors who hold investments in these "brown" firms should require compensation. This compensation will manifest as higher anticipated returns, as a countermeasure for holding this additional climate risk referred to as a "carbon risk premium". This premium means that brown firms will face a higher cost of capital and consequently lower valuations in the future (Bauer et al, 2023).

1.4 The Social Cost of Carbon

CO_2 emissions have associated liabilities. The social cost of carbon dioxide measures the monetized value of the damages to society caused by an incremental metric tonne of CO_2 emissions and is a key metric informing climate policy. It has been used by policy makers and governments for more than a decade to help them make cost-benefit analysis around climate change policy (Stern & Stiglitz, 2021). Although carbon pricing stands out as one of the most powerful policy instruments for channelling investments from high emission companies into green alternatives, many countries have been reluctant to use this strategy (IMF, 2023). Their worry stems from concerns about losing international competitiveness, particularly in industries with high emissions such as steel or chemicals (Chateau et al, 2022).

The momentum for carbon pricing has continued to grow globally, with more countries exploring or implementing carbon pricing mechanisms. As mentioned in the World Bank's State and Trends of Carbon Pricing 2023 report, approximately 25% of worldwide GHG emissions are presently subject to a carbon price. This represents a substantial increase from the 7% coverage observed about a decade ago. A significant driver, particularly in emerging economies, is the prospect of generating revenue through carbon pricing. GHG emissions can be explicitly priced through either a carbon tax or a cap-and-trade system like the EU ETS.

A well-designed carbon price is an essential part of a climate transition strategy aimed at efficiently reducing emissions. An effective carbon-price path starts with a strong price in the present, coupled with a credible commitment to sustaining prices at levels high enough in the future to bring about the necessary changes (IMF, 2023). While higher prices today may be more impactful in driving the needed transformations and might eliminate the need for substantial future increases, they can also entail higher short-term adjustment costs. On the other hand, the generated revenue from carbon pricing can be used to promote growth in an equitable way by reinvesting the revenue through household rebates, supporting economically disadvantaged segments of the population, addressing transitional changes, investing in low-carbon infrastructure, and encouraging technological advancements (World Bank, 2019).

The IMF is advocating for an ambitious increase in carbon pricing from the current levels around $75, to reach $130 per metric ton by 2030 and $235 per metric ton by 2050 in line with the Net Zero emission scenario in IEA (2021) estimates[6]. Carbon pricing, on its own, might not be enough to induce the necessary changes at the speed and magnitude required to meet the Paris target. According to the IMF, a combination of policies is likely to be more dynamically efficient and appealing rather than relying on a singular policy. They estimate a couple of different model projections, the first one is a model policy package that combines a carbon price at $75 a ton by 2030 that is maintained at that level until 2050, with other mitigation policies like subsidies and public green investment. However, the second model has carbon pricing as the sole climate policy, and this would need to price carbon at $280 which may not be politically feasible in many countries. Another argument to support a combination of measures is that the rise in the debt levels will be smaller for every nation in the world (IMF, 2023).

It can be also argued that we need carbon pricing a lot more today than just a few years ago. The truth is that the economic incentives for investing in the energy transformation have

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[6] The Report of the High-Level Commision on Carbon Prices by the Carbon Pricing Leadership Coalition concluded that the explicit carbon-price level consistent with achieving the Paris temperature target is at least US$40–80/tCO2 by 2020 and US$50–100/tCO2 by 2030. Another study estimates the right price to be at $185 per tonne of CO2, a value 3.6 times higher than the US government's current value of $51 per tCO2 (Rennert, 2022).

worsened significantly, both because of cost increases due to inflation and higher interest rates. Making carbon pricing politically acceptable is gaining traction as the most important climate policy to achieving swift and efficient reductions in emissions. A political argument for a global carbon pricing regime is based on the premise that without a harmonised framework that prices emissions, countries which are less committed to environmental policies may develop unilateral initiatives to gain an advantage over others by attracting industries (Yale, 2015).

1.5 Addressing the different stages of Scope emissions

If the world needs to get to Net Zero by 2050, measuring decarbonization will be mandatory, as investors need to know where companies are on their path that aligns with the Paris agreement, and also strive to identify those companies that are improvers and laggards. Investors also need to estimate the carbon intensity of their portfolios. In this thesis, greenhouse emissions are considered a key metric to measure climate transition performance. Rather than relying on E-scores from market providers such as Sustainalytics or MSCI, as a metric to measure "greenness", my analysis of reported data is based specifically on CO2 emissions. This approach offers greater consistency, as highlighted in the findings of Busch et al. (2022b), and provides valuable insights for investors and consumers concerned about a company's environmental footprint.

The Greenhouse Gas Protocol was introduced in 2001 as a collaborative effort involving governments, industry associations, non-governmental organisations (NGOs), and companies in partnership with the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). It is widely recognized as the default methodology for greenhouse gas accounting and reporting. It aims to establish a common language and framework for accounting and reporting emissions, allowing for consistency and comparability across different entities.

The Greenhouse Gas Protocol has classified carbon emissions into three distinct scopes: Scope 1 refers to direct emissions originating from sources and assets directly managed by a company; Scope 2 encompasses indirect emissions stemming from electricity generation; and Scope 3 covers indirect emissions occurring throughout a company's value chain, both upstream and downstream. In a significant number of sectors, the primary source of emissions lies outside their core activities. According to the Carbon Disclosure Project, Scope 3 emissions can account for more than 40% of a company's total emissions. Huang et al. (2009) highlight that Scope 3 emissions make up 70-80% of the overall carbon footprint across most manufacturing industries. As per the following table, this concept is better illustrated by analysing the corporate disclosures for the emissions of three companies belonging to different sectors of the economy. In the case of Repsol, an Integrated Oil & Gas company, and also of BMW, an Automobile manufacturer, the majority of their emissions are Scope 3 Downstream, representing the sale of their products. However, for ArcelorMittal, one of the biggest Steel companies in Europe, the vast amount is from their direct or Scope 1 emissions.

Table 1. Example of Companies and Scope 1, 2 and 3 emissions in tonnes of CO2e

Company Name	Sector	Industry	Scope 1	Scope 2	Scope 3 Upstream	Scope 3 Downstream
ArcelorMittal	Materials	Steel	141,300,000	9,500,000	44,979,329	7,181,383
Repsol	Energy	Oll & Gas	22,000,000	400,000	13,509,012	90,100,590
BMW	Consumer Discretionary	Autos	642,885	84,257	43,075,627	58,573,995

Source: S&P Trucost, MSCI. Emissions data as of 31st December 2021.

The material sector often has large Scope 1 emissions due to the nature of its activities such as metal smelting or cement production, which are typically energy-intensive and involve various processes that emit greenhouse gases. The energy sector has large Scope 3 emissions primarily due to the extensive supply chain and customer-related activities associated with the production, distribution, and use of energy. Finally, the largest portion of Scope 3 emissions in the consumer discretionary sector often comes from the use of the products by consumers. The automobile industry is part of this sector and accounts for most of those emissions. For example, if a company produces and sells cars, the emissions from driving those cars, caused by gasoline or fuel combustion, would be considered Scope 3 emissions.

Scope 1 emissions are the most straightforward to measure and hold particular relevance for companies that generate substantial amounts of greenhouse gases (GHG). This category includes fossil-fuel energy companies, materials, mining and chemical companies, as well as large-scale agricultural businesses. In contrast, the majority of other companies, particularly those in the services sector, typically generate only minimal amounts of Scope 1 emissions.

Traditionally, under the GHG Protocol, companies are required to report their Scope 1 and Scope 2 emissions. The reporting of Scope 3 emissions is optional and tends to vary among different firms. However, this is going to change over the next couple of years as there is an upcoming requirement for mandatory disclosure of Scope 3 emissions. In the latest EU legislation called the Corporate Sustainability Reporting Directive (CSRD), which replaces the Non-Financial Reporting Directive (NFRD), all listed companies in the European Union will be required to report their climate and environmental impact.

As mentioned earlier, one of the reasons there has been little research to date using Scope 3 emissions is because they are difficult to measure. The process of assessing GHG emissions throughout the entire value chain is a complex one, and evaluating and predicting Scope 3 emissions can be notably challenging. To assess its Scope 3 emissions, a company must undertake a detailed analysis of its complete value chain. This involves scrutinising the entire lifecycle of its products or services. Some of these emissions can be attributed to the initial acquisition and processing of raw materials (upstream), while some occur due to the subsequent distribution, storage, use and eventual disposal of end-products sold to customers (downstream). While the “ex-post” Scope 3 emissions that arise upstream within the supply chain are considerably more consistent and subject to standardisation, the emissions that occur before the use of a product, typically in the downstream portion of the production process, are challenging to estimate.

The preferred approach when calculating Scope 3 emissions is to use primary data. Primary data involves collecting information regarding emissions directly from the companies themselves, which accurately reflects the actual emissions resulting from their production activities. This method ensures the most accuracy in assessing the emissions linked to a company's value chain. By directly measuring and recording emissions originating from various sources, companies can acquire precise and firsthand data essential for the calculation of their Scope 3 emissions. The sharing of primary emission data throughout the supply chain is important as it provides precise emissions information on both product and company levels. This approach empowers companies to target emission reduction at the most impactful points in the supply chain and creates incentives for the adoption of cleaner technologies that exceed industry standards.

However, when direct collection of primary data for calculating Scope 3 emissions is unfeasible, companies have the option to resort to secondary data sources as an alternative. These sources might involve industry averages or proxy data to estimate Scope 3 emissions. Although the importance of accurately quantifying Scope 3 emissions is widely acknowledged, achieving accurate measurement across the entire value chain presents considerable challenges, especially when dealing with numerous units and subsidiaries. Current estimations of Scope 3 emissions predominantly rely on industry-wide averages and other approximations.

Research conducted by Matsumura et al. (2014) highlights that markets tend to penalise all companies for their carbon emissions, but that there is an additional penalty for those companies that do not disclose emissions information. This indicates that transparency and disclosure of emissions data plays a role in shaping investor perceptions and potentially influencing investment decisions. By providing accurate and comprehensive information about their Scope 3 emissions, companies can boost their credibility and potentially attract investments from stakeholders that have climate issues as a core item in their agenda.

On one hand, from an investor point of view and as environmental concerns grow, more financial institutions and investors will prioritise investments in companies with robust environmental metrics. Accurate Scope 3 emissions data can enhance a company's eligibility for opportunities to access capital. It can lead to improved relationships with stakeholders, including customers, employees, and communities, as it reflects a commitment to addressing carbon emissions throughout the entire value chain. On the other side, from a risk reduction perspective there is also a strong argument that supports it. Thoroughly disclosing Scope 3 emissions indicates that a company understands and actively manages its environmental impacts. This proactive stance can help mitigate potential legal, regulatory, and reputational risks associated with environmental harm.

A recent research by Nguyen has brought to light notable discrepancies in Scope 3 data, drawing from the emission datasets of three major data providers: Bloomberg, Refinitiv Eikon, and ISS. These disparities complicate the ability of investors to accurately assess their real exposure to Scope 3 emissions. On top of that, in terms of the breakdown of Scope 3 emissions, companies often select to disclose specific emission categories that are simpler to calculate, even though these often represent only a relatively small fraction of the total Scope 3 emissions within the value chain. The study also highlights that the most significant categories of Scope 3 emissions vary significantly across various industries. This indicates that the nature of emissions and their impact can change considerably depending on the sector where a company operates (Nguyen et al, 2022).

Given its broad scope, Scope 3 offers the most significant opportunities for reducing emissions. In today's globalised business environment, value chains have evolved into complex networks involving numerous tiers of suppliers across the world. Obtaining an accurate evaluation of Scope 3 emissions demands the exchange of data among companies. While the digitization of production is reducing data measurement expenses, sharing data among firms encounters three main obstacles: legal and regulatory complexities, challenges in ensuring compatibility in the operational chain, and data privacy concerns, as outlined by Stenzel et al. (2023).

First, the exchange of data between companies might be delayed by complex legal and regulatory structures, including data protection laws and ownership rights, which could limit the sharing of sensitive data like information on emissions. Companies must navigate these obstacles to ensure their data sharing practices comply with regulations. In addition to this, companies may use different data collection methods, which can result in operational difficulties. When data systems are not compatible, it becomes challenging to efficiently aggregate and analyse data throughout the value chain. The establishment of uniform data standards and protocols is crucial in order to guarantee smooth data sharing. Lastly, sharing emissions data can also raise concerns regarding the privacy and security of the data being exchanged.

To address these obstacles and thus promote successful sharing of emission data along the supply chain, there are already a large number of initiatives seeking to address these challenges. There is a new area of research being developed on carbon accounting called "E-liability accounting", which seeks to address the flaws on the GHG Protocol (Kaplan, 2021). This approach builds on the latest technology advancements such as blockchain to simplify the process of emissions accounting through complex supply chains.

Regional efforts have also been made to make it mandatory for companies to report on Scope 3 emissions, such as the EU CSRD and the Enhancement and Standardization of Climate Related Disclosures by the SEC in the U.S. Through the implementation of those regulations, governing bodies can establish a uniform framework for reporting Scope 3 emissions, incentivizing companies to gather and exchange the data required. Additionally, policymakers and regulators have the responsibility of ensuring that the data provided by companies is both "timely, reliable, and relevant," (OECD, 2015). The aim of this directive is to enhance disclosure practices and provide investors with the necessary data to assess a company's sustainability (EU Directive, 2022). Notably, the CSRD expands the number of companies obligated to report on sustainability from approximately 11,000 under the NFRD to nearly 50,000.

The new reporting standards introduced by the CSRD include the incorporation of value chain sustainability factors. As part of this, companies will be mandated to report on Scope 3 emissions. The rules of the CSRD will be implemented in stages, starting between 2024 and 2028. Large companies that are already subject to the non-financial reporting directive will have reporting obligations beginning in 2025. Companies currently not subject to the non-financial reporting directive, with over 250 employees and/or €40 million in turnover and/or €20 million in total assets, will be required to report by 2026.

Finally, it is worth highlighting that the pressure to report on sustainability metrics has been directed primarily at publicly traded companies (Pucker, 2021). However, limiting the reporting of greenhouse gas (GHG) emissions to only public entities could create an incentive for some to transition to move to the private markets, and on the other hand, also for private companies to stay private to evade environmental measurement and disclosure requirements. It is important that there is a level playing field for all the companies whether they are in the public or on the private markets to avoid manipulating the system and if we are serious in the fight against climate change.

1.6 The European Union Carbon Policy: the ETS and the CBAM

Emissions trading schemes are market-based mechanisms designed to control and reduce GHG emissions. These schemes typically involve placing a cap on the total amount of emissions allowed within a specific jurisdiction or for a particular group of companies. Under an emissions trading scheme, countries or companies are allocated a certain number of emissions permits or allowances that correspond to their allowed emissions levels. If they exceed their allocated limits, they are required to acquire additional permits to cover the excess emissions. The permits serve as tradable commodities, creating a market where entities can buy and sell them. Companies that have emission reductions below their allocated limits can sell their surplus permits to those who exceed their limits. This establishes a financial motivation for companies to decrease their emissions since they stand to gain by selling permits that go unused.

The European Union Emissions Trading Scheme (EU ETS) is recognized as one of the most significant carbon pricing initiatives globally (European Commission, 2023). It serves as a compelling illustration of the proactive adoption of carbon pricing, resulting in the most substantial decline in carbon emissions among major global economies in the last ten years. According to the Environmental Protection Agency (EPA), it covers 45% of the EU's GHG emissions, constraining emissions from over 11,000 installations, including generating plants and larger industrial facilities like cement and chemical factories, as well as emissions from airlines operating within the EU.

The EU ETS was launched in 2005 as one of the most important policies of the EU to comply with the Kyoto agreement. It is the world's largest cap-and-trade program today, not only in terms of allowances distributed but also with regards to the number of facilities covered, and it was worth around €751 billion in 2022. The available evidence suggests that the EU ETS has had a robust negative impact on them (Martin, 2016).

The policy operates by setting a cap on the total annual carbon dioxide (CO_2) emissions, which is accomplished through the allocation of a certain amount of pollution permits known as European Union Allowances (EUAs) to participating emitters. Each year, emitters must surrender one EUA for every ton of CO_2 emitted, with the option to purchase additional EUAs or sell surplus ones on the international permit market. The primary goal of this cap-and-trade policy is to achieve a given reduction target for aggregate CO_2 emissions at minimal cost. In the long term, carbon credits play a crucial role in offsetting emissions that are difficult to mitigate, especially in hard- to-abate industries that lack viable alternatives for achieving significant reductions in emissions.

In April 2023, the European Parliament granted approval for revisions to this system to align it with the emission reduction objectives of the European Green Deal. These reforms involve a reduction of emissions in sectors falling under the Emissions Trading System, targeting a 62% decrease by 2030 compared to the levels recorded in 2005.

Within the 'fit for 55' package, there are four key initiatives aimed at enhancing the effectiveness and reach of the EU Emissions Trading System (ETS). These proposals intend to elevate the ambition of the EU ETS, enhance its operational efficiency, expand its coverage to include maritime transport, road transport, and building sectors, and facilitate the involvement of airlines in the international CORSIA offsetting scheme. Additionally, these measures are complemented by the new carbon border adjustment mechanism, which serves to preserve international competitiveness by incorporating the carbon emissions associated with imports. Furthermore, there's a proposal for the establishment of a social climate fund designed to address the social consequences of extending the EU ETS to road transport and buildings.

The EU’s carbon border adjustment mechanism (CBAM) began to take effect in October 2023. Carbon leakage refers to the phenomenon where unilateral climate regulations in a particular region may result in the relocation of polluted activities to other jurisdictions with less strict regulations, rather than achieving actual reductions in greenhouse gas (GHG) emissions on a global scale. The launch of the EU’s CBAM marks the first step in the right direction to prevent carbon leakage as it reinforces the incentives for the bloc’s trading partners to implement equivalent carbon pricing systems in their own jurisdictions to exempt them from the border tax (European Commission, 2021).

It is designed to target specific carbon-intensive commodities, where calculating embedded carbon can be relatively straightforward. These commodities include steel, cement, fertilisers, hydrogen, and others. The CBAM aims to address carbon leakage by placing a carbon price on certain imports based on their embedded carbon content, ensuring that imported goods face a similar carbon cost as their EU-produced counterparts. This targeted approach allows for a more practical implementation of the mechanism while focusing on sectors with significant carbon intensity. One of the most interesting features of this new policy is that for exporters selling goods into the European Union from countries with lower domestic carbon prices, the additional tax revenue generated from the EU's carbon pricing measures will accrue to the EU rather than benefiting the exporter's home country.

Literature Review

2.1 Climate finance literature: Physical and Transition risks

Climate finance literature is in the early stages. The literature on climate finance is marked by two primary themes. The first revolves around climate change science and its associated risks. The second looks into the financial implications of climate change, particularly in terms of how it influences asset pricing (Hong, 2020).

First, the risks associated with climate change can be divided into physical and transitional risks (Carney, 2015). Physical risks make reference to the adverse effects of climate and weather-related occurrences on various aspects, including company operations, the population, and supply chains (Tankov & Tantet, 2019). There are two categories of physical risk: Acute climate risks associated with abrupt and severe weather events that have the potential to cause major damage and disruptions. Examples include floods, extreme droughts, heatwaves and wildfires. Chronic climate risks are associated with gradual changes that unfold over an extended period. These risks cover phenomena such as rising sea levels, alterations in precipitation patterns, and gradual increases in temperature (Giglio et al., 2021).

In contrast, transitional risks are linked to diverse scenarios aligned with the transition to lower carbon emissions and the adoption of cleaner and sustainable energy sources. Consequently, these risks encompass all implications for fossil fuels and sectors dependent on them (Curtin et al., 2019). For instance, policies and market forces driving the adoption of renewable energy and technologies aimed at reducing carbon emissions can create transitional risks for industries dependent on fossil fuels. These industries may face challenges in terms of declining demand, stranded assets, and changes in regulatory environments. Also for businesses, there are reputation risks associated with how they respond to and manage climate change. Stakeholders, including investors and customers, increasingly consider a company's climate-related actions when making decisions. A poor response to climate change or a perceived lack of commitment to sustainability can negatively impact a company's reputation and long-term prospects. Finally, the transition to a low-carbon economy involves advancements in technology to support sustainable practices (Chu et al., 2020). Companies that fail to adapt or invest in relevant technologies may face transitional risks as they become less competitive in the changing market landscape.

With respect to the financial consequences of climate change in asset pricing, the climate finance literature explores the financial implications of climate change and can be divided based on the type of financial risk and asset analysed, as well as the methodology used. Recent research indicates that climate change has the potential to impact various categories of financial risks. Specifically, studies in climate finance have highlighted that climate change may influence (i) credit risks; (ii) underwriting risks; as well as (iii) operational and (iv) market risks (Venturini, 2022).

First, climate change can impact credit risk, which refers to the risk of borrowers being unable to meet their debt obligations. As climate-related events and changes affect companies and industries, their creditworthiness may be affected, leading to potential credit risks for investors and lenders (Painter, 2020). Second, underwriting risk is also involved which is the risk faced by insurance companies when they issue insurance policies. Climate change can influence the frequency and severity of natural disasters and extreme weather events, affecting insurance claims and the financial stability of insurance providers (NGFS, 2020).

Third, climate change can introduce operational risks for businesses. These risks arise from the physical impacts of climate-related events on a company's infrastructure, supply chains, and operations. For example, extreme weather events could disrupt production, supply, and distribution chains, leading to financial losses and operational challenges; and finally there is a market risk, which refers to the potential losses that investors and financial institutions may face due to changes in market conditions. Finally climate change can affect the market value of various assets exposed to physical risks, meaning assets whose value may be influenced by climate-related events. Among several assets whose market value may be exposed to physical risks, are real estate (Giglio et al, 2021), municipal bonds (Painter, 2020) and derivatives (Schlenker & Taylor, 2021).

In this thesis, I focus on the implications of climate change on the stock market by looking at Transition risks, which may be defined as a combination of policy risk, technology risk and preference changes (Semienuk et al 2021).

Transitional risk = f (policy risk, technology risk, preference change)

The term **“policy risk”** refers to the risks and opportunities that arise from climate mitigation policies aimed at addressing climate change and reducing greenhouse (GHG) emissions. With an unexpected increase in climate change concerns, policymakers are more likely to propose and implement legislation that could impact brown firms’ cash flows negatively in comparison to green firms. The primary goal of climate mitigation policies is to reduce the level of greenhouse gas (GHG) emissions in the atmosphere, especially carbon dioxide (CO2) emissions as it is considered to be a major contributor to human-induced global warming (Nordhaus, 1977, 1993).

Climate mitigation policies can be implemented through two main types of mechanisms. The first one involves putting a price on carbon emissions to incentivize companies to reduce their carbon footprint. There are two forms of carbon pricing: Carbon Taxes and Cap-and-Trade schemes (Metcalf, 2009). On the first one, governments impose a tax on carbon emissions which means that firms have to pay a fee for each unit of CO2 they emit. This creates a financial incentive for companies to lower their emissions to avoid higher costs. On the other hand, the Government sets a limit (cap) on total allowable emissions, and companies are allocated permits corresponding to their emission allowances. Firms can buy and sell these permits in the market. This system encourages companies to reduce emissions, and those that can achieve lower emissions can sell their excess permits to other firms.

Non-market-based mechanisms are policy instruments that do not involve direct carbon pricing but aim to promote environmentally friendly practices, and are related to i) Environmental Regulation: Governments may introduce regulations that mandate emissions reductions or impose specific environmental standards on industries ; ii) Green Subsidies: Governments may offer financial incentives, grants, or subsidies to support the adoption of low-carbon technologies or renewable energy sources and iii) Voluntary Commitments: Both governments and companies may make voluntary commitments to reduce emissions by adopting sustainable practises without regulatory mandates (Bolton & Kacperczyk, 2021b).

The implementation of these climate mitigation policies can create both risks and opportunities for businesses. Brown firms may face increased costs and reduced cash flows due to the added expenses associated with reducing emissions or complying with environmental regulations. On the other hand, green firms, which have already embraced sustainable practices, may benefit from policy support and market demand for their products and services.

In prior studies within the field of climate finance, there is often an assumption that the greater a company's scope emissions, the more environmentally impactful or 'browner' the firm is perceived to be (Bolton & Kacperczyk, 2021a). Companies with high emissions often rely on non-renewable energy sources like fossil fuels (coal, oil, and natural gas), which are major contributors to pollution and GHG emissions. The opposite holds for ‘green’ firms. Additionally, considering these sources of scope emissions, three distinct measures at the firm level can be obtained, as outlined by Hsu et al. (2020). The first is the total level of emissions, that may be decomposed for each type of scope emission subcategory. One could also compute an emission intensity measure, quantifying carbon emissions per unit of sales (Bolton & Kacperczyk, 2021a) or assets (Hsu et al., 2020). Finally, the year-by-year variation in emissions measures the annual growth rate of corporate emissions. Each of these measures can be used to estimate the degree of exposure a company may have to different climate mitigation policies.

The variable **“technology risk”** makes reference to the implementation of cost-effective technologies aimed at promoting the widespread adoption of low-carbon energy sources. Despite the predominant reliance on fossil fuel energies by society, which constituted over 80% of the energy supply in 2020 (Rapier, 2020), various factors are compelling companies to embrace low-carbon alternatives. In particular, investors are progressively taking environmental considerations into account when making investment decisions. As a result, firms may face pressure from investors to adopt sustainable practices, including the shift to low-carbon energy sources (Azar et al, 2021). Anticipated future costs and liabilities related to environmental regulations and policies can incentivize firms to adopt low-carbon energy sources to mitigate potential financial risks (Chu et al, 2020), or simply firms may choose to adopt low-carbon energy sources to stay competitive in the market, as sustainability practices and environmentally-friendly initiatives become more important to consumers and stakeholders (Trinks et al, 2020).

To model technology risk effectively, researchers require firm-level information, including: (i) Innovation data: This includes data on abatement costs (Akey & Appel, 2021), research and development (R&D) expenditures, and patents aimed at reducing firm emissions (Chu et al., 2020); (ii) Emission data: information about a firm's emissions for assessing the scale of potential environmental impacts and the effectiveness of carbon management practices.; and (iii) Investor holdings: this allows researchers to analyse how corporate governance structures and shareholder interests might influence firms´ sustainability practices.

The motivations driving firms to adopt carbon management practices are interconnected. Both policy risk (expected liabilities from environmental policies) and technology risk (challenges in adopting low-carbon technologies) are closely linked and can influence a firm's decision to implement sustainability measures.

Finally, the term “**preference change”** may be related to “two non-mutually exclusive channels” (Pástor et al., 2020). The first refers to unexpected preference changes in consumers' preferences towards environmentally friendly products, which could positively impact the financial performance of "green" firms.

The second channel is characterised by unforeseen changes in investor preferences favouring carbon-intensive assets. Investors may change their preferences regarding these assets for both financial and non financial reasons. In the first case, they may be perceived to have a higher downside risk, with a greater likelihood of these assets losing value or underperforming in the market. This perception can lead investors to reconsider their allocation of funds, potentially reducing their exposure to carbon-intensive assets (Ilhan et al., 2021b). Secondly, non-financial reasons are related to the “ethical benefits an investor derives when holding climate-friendly assets” (Fama & French, 2007). Investors who are environmentally conscious may be motivated to shift their preferences away from carbon-intensive assets to support sustainable and climate-friendly options.

Ardia et al. (2022) and Pastor et al. (2022) have formulated a theoretical framework that explains the divergence in preferences, attributing it to a growing demand for green assets from investors and an increasing demand for environmentally friendly products from consumers. To model the investor channel and better understand these shifts in preferences, researchers and analysts require data related to two main aspects: (i) investor surveys (Krueger et al., 2020); or (ii) financial flows toward green labelled funds (Ceccarelli et al., 2019).

Conducting surveys among investors can provide valuable insights into their preferences, concerns, and motivations (CFA, 2020). These surveys can ask specific questions about their attitudes towards carbon-intensive assets, their understanding of climate risks, and their willingness to support green investments. An additional data source involves the examination of financial flows, specifically those directed towards green-labelled funds. Green-labelled funds are investment vehicles explicitly dedicated to environmentally friendly and sustainable projects. Monitoring the investment inflows into these funds can provide insights into the degree to which investors are adjusting their preferences toward climate-friendly assets. Hence, the actual returns from green investments may deviate substantially from their anticipated returns if there are unforeseen changes in risk perceptions or preferences over time. For example, a sudden surge in preferences for sustainable investments might result in fluctuations in green asset prices. Consequently, realised returns from green stocks could surpass those of brown stocks, even if initial expectations were for lower returns from green investments. Additionally, an increase in public awareness and attention to corporate carbon footprints could elevate the demand for green assets, leading to price increases and higher returns (Pastor, 2021).

Therefore, as proposed by Lontzek et al. (2022), a sequence of substantial negative climate shocks, such as extreme weather events and natural disasters, can elevate perceptions of climate risks. This heightened awareness of climate risks may spark increased interest among investors in sustainable assets, consequently driving up valuations and returns of green assets over time. Indeed, these scenarios align with the broader trend of higher awareness on concerns around climate and the rising popularity of sustainable investing practices observed over the past decade. This trend has led to a notable surge in the volume of assets managed under Environmental, Social, and Governance (ESG) criteria.

I believe that understanding the complexities of climate change, its implications on businesses, and the associated risks and opportunities may require time and effort. As investors educate themselves and gain insights into the potential financial implications of climate-related factors, their views are likely to evolve. Some may perceive climate risks as immediate and substantial, while others might not fully appreciate the potential risks and opportunities associated with environmental issues.

2.2. Modelling climate risks in the equity market: The asset pricing model

Analysing the impact of climate risks on the equity market is a complex and multifaceted task. The Climate finance literature has been actively engaged in exploring different methodologies and models to better understand the relationship between climate risks and equity prices. One of the key challenges in climate finance is how to connect transition risks, which arise from the shift to a low-carbon economy, to equity prices. These transition risks encompass various factors, such as changing regulations, technological advancements, shifts in consumer preferences, and evolving societal attitudes toward sustainability. The uncertainty surrounding the timing and magnitude of these transitions poses a challenge for investors and researchers trying to assess their impact on financial markets (Semieniuk et al, 2019).

The fundamental debate in climate finance revolves around whether climate risks should be considered as an anomaly or an additional source of systematic market risk (Giglio et al., 2021). An anomaly would suggest that climate risks are not fully priced into asset valuations, potentially leading to mispricing and investment opportunities. On the other hand, if climate risks are systematically priced into financial markets, it means that investors are already incorporating these risks into their decision-making, and there may not be any distinct advantage in focusing solely on climate-related factors.

The classic Capital Assets Pricing Model (CAPM) of Sharpe (1964) has long shaped the way academics think about average risk and returns. The central basis of the model is that the market portfolio is mean-variance efficient in the sense of Markowitz (1952). The efficiency of the market portfolio means that expected returns on securities are a linear function of their market betas, the slope in the regression of a security's return on the market's return, and that market betas suffice to describe the cross-section of expected returns.

CAPM Model

$$R_{it} - R_{Ft} = \alpha + \beta_i (E (R_{Mt}) - R_{Ft}) + \varepsilon_{it}$$

where the excess return of a company *i* on day *t*, depends on the market portfolio and the risk level of the company or beta (β). According to the CAPM, we would expect to receive a positive correlation between risk and return of financial assets. Therefore, browner companies would be expected to deliver higher returns on average under the CAPM model.

In traditional finance theory, the Capital Asset Pricing Model (CAPM), proposed by Sharpe in 1964, suggests that the market portfolio is the sole factor driving asset returns. However, in practice, researchers have identified additional factors, beyond the market portfolio, that seem to explain variations in asset returns. These additional factors are often referred to as "anomalies" because they contradict the mean-variance efficiency assumptions of the CAPM and the broader Efficient Market Hypothesis (EMH) advanced by Fama in 1970.

For a period of close to 30 years, the CAPM dominated the academic literature when it came to asset-pricing models. Then, in the 1990’s the work initiated by Fama and French changed this. The work of Fama and French in 1992 and 1993 significantly contributed to the understanding of these anomalies. They introduced the three-factor model, which added two new factors to the traditional market factor: the size factor (SMB), which captures the performance of small-cap stocks relative to large-cap stocks, and the value factor (HML), which reflects the performance of value stocks compared to growth stocks.

In a series of articles, Fama and French (1992, 1993, 1995, 1996) show that the Capital Asset Pricing Model (CAPM) could no longer explain the cross-section of asset returns in the US, and they proposed an alternative model which included, apart from the market factor, a factor related to book-to-market (B/M) which they call HML, and a factor related to size (MV) called SMB. In the FF 3-factor model, the “size premium" is a factor that is motivated by the observed historical outperformance of small-cap stocks relative to large-cap stocks over time. This premium suggests that smaller companies tend to have higher expected returns compared to larger, more established companies. The “value premium" is another risk factor inspired by the tendency of value stocks to outperform growth stocks over the long term. Value stocks are those that are considered undervalued by the market based on fundamental metrics such as price-to-earnings (P/E) ratios and price-to-book (P/B) ratios.

Fama French 3 factors model:

$$R_{it} - R_{Ft} = \alpha + \beta_i \left(E\left(R_{Mt}\right) - R_{Ft}\right) + s_i \, SMB_t + h_i HML_t + \varepsilon_{it}$$

The Fama-French methodology categorises an equity investment universe according to predefined characteristics (e.g. size or book-to-market). Quantile portfolios are created from the sorted securities, and held for a specific holding period, typically annually. At the end of the holding period, the investment universe is rebalanced, new quintile portfolios are created and another period of performance is calculated for each quantile portfolio. Factor returns are found by taking the return differences between the top and bottom quintile portfolios (Fama and French, 1993).

Their model, called the FF model, did a good job during a long period of time in explaining equity returns, until Carhart (1997) added a fourth factor to the Fama and French (1993) 3-factor model: the *momentum factor*, related to an anomaly where stocks with high returns over the last year tend to have high future returns and vice versa. This return momentum pattern is left unexplained by the 3-factor model of Fama French as well as by the CAPM. Here portfolios are created, grouping those companies that have had higher returns in the past, and those which have had lower returns, named Winners Minus Losers (WML).

Carhart 4 Factors model:

$R_{it} - R_{Ft} = \alpha + \beta_i (E(R_{Mt}) - R_{Ft}) + s_i SMB_t + h_i HML_t + m_i WML_t + \varepsilon_{it}$

In recent years, there has been ongoing research to expand the traditional factor models in asset pricing to include additional fundamental factors that may provide better explanations for stock returns. Hou and Fama and French introduced two such factors, profitability and investment patterns, to enhance the explanatory power of their asset-pricing models.

The profitability factor, named Robust minus Weak (RMW) focuses on the expected discounted profitability of a firm. It states that companies with higher profitability, measured by metrics like return on equity (ROE), are likely to have higher expected returns. This factor reflects the idea that profitable companies tend to be more financially stable and efficient, making them attractive investments for investors seeking higher returns (Hou, 2014).

The investment-to-asset ratio is used as a proxy for the investment factor. This factor called Conservative minus Aggressive (CMA) suggests that companies with lower levels of investment relative to their total assets are more likely to have higher expected returns. The rationale behind this factor is that firms with lower investment may have more flexibility in their financial decisions, leading to potentially higher returns for investors (Fama, 2015).

Fama French 5 factors model:

$R_{it} - R_{Ft} = \alpha + \beta_i (E (R_{Mt}) - R_{Ft}) + s_i SMB_t + h_i HML_t + r_i RMW_t + c_i CMA_t + \varepsilon_{it}$

Factor models offer a valuable framework for analysing the systematic drivers that explain the cross-section of asset returns. Specifically, linear factor models, which are a special case of the arbitrage pricing theory (Ross, 1976), assume that an asset's return can be explained by a combination of underlying risk factors.

By using factor models in climate finance research, analysts can better understand how climate-related risk factors and anomalies affect the performance of different asset groups. Studies in climate finance often use factor models and portfolios rather than single stocks to analyze the cross-section of stock returns because using portfolios rather than individual stocks allows for more stable and reliable beta estimation, justifying this assumption in light of more stable beta estimations (Petersen, 2009). Individual stock returns can be more volatile and subject to noise, while portfolios provide a smoother and more robust representation of market exposure. Also, it allows researchers to analyse the performance of different groups of stocks with similar characteristics (e.g., green and brown stocks, high and low emission companies). This aggregation helps to reduce the impact of idiosyncratic noise and provides more consistent results, as the overall trends and patterns are emphasised.

The field of climate finance is still relatively young, and while theoretical models have proposed various factors that could influence the relative performance of green and brown stocks, empirical research has faced challenges in reaching a clear consensus regarding the relative performance of green and brown stocks. See **Table 2** on Summary of the Literature.

Table 2. Summary of Literature: Climate Risk Factors and the cross sections of stocks returns

Study	Climate risk measures	Economic rationale	Countries	Period	Is climate risk priced?
Matsumura et al. (2014)	Disclosed emissions	Firm value effect	USA	2006-2008	Yes
Chava (2014)	Environmental concern measures	Cost of capital	USA	1992-2007	Yes
Bolton and Kacperczyk (2020)	Three emission factors	Transition risk proxies	USA	2005-2017	Yes
Engle et al. (2020)	E-scores	Hedging assets	USA	2009-2016	Yes
Hsu et al. (2020)	Emission intensity	Climate Policy risk	USA	1991-2016	Yes
Pastor et al. (2021)	E-scores	Preference changes	USA	2012-2020	No
Ardia et al. (2021)	Emission Intensity	Preference changes	USA	2010-2018	No
Cheema-Fox (2021)	Two emission measures	Investor irrationality	USA	2013-2020	In some industries
Nagar and Schoenfeld (2021)	Text mining index	Economic tracking	USA	2003-2019	
Bolton and Kacperczyk (2021a)	Three emission factors	Transition risk proxies	77 countries	2005-2018	Yes
Görgen et al. (2020)	BrownGreen scores	Transition risk proxies	Multiple	2010-2017	No
Gostlow (2019)	FTS scores	Climate risk proxies	USA, EU and Japan	2008-2017	No
Hong et al. (2019)	PDSI index	Forecast of firm profit	31 countries	1985-2014	
In et al. (2017)	Emission intensity	Investor irrationality	USA	2005-2015	
Ilhan (2021)	Option market pricing	Protection against tail risk	USA	2010-2017	Yes
Zhang (2023)	Two emission measures	Transition risk proxies	Global	2009-2021	No
Bauer (2023)	Two emission measures	Transition risk proxies	USA	2010-2021	No
Aswani et al. (2023)	Three emission	Disclosed vs estimates	USA	2005-2019	Yes

Expanded table to include start of the art as of December 2023. Source: Venturini (2022), my own research.

The absence of a consensus can be attributed to various factors, including differences in methodologies, sample periods, and specific characteristics of the studied assets. Some studies have found evidence supporting the presence of a carbon premium, which suggests that higher-emitting firms have higher returns (Bolton and Kacperczyk, 2021, 2022). This finding aligns with basic asset pricing theory, as it implies that investors are compensated with higher returns for taking on the additional risk associated with higher carbon emissions. This observation could be due to various factors, such as increased investor demand for sustainable assets, shifts in preferences, and growing awareness of climate-related risks and opportunities. It's important to note that the apparent discrepancy in findings does not necessarily imply that one group of studies is incorrect or invalid. Instead, it reflects the complexity of the relationship between climate-related factors and stock returns, as well as the multifaceted nature of sustainable investing. Different methodologies, data sources, and time periods can lead to diverse outcomes, making it difficult to draw definitive conclusions about the performance of green versus brown stocks.

Examples of studies that support the carbon premium include papers by Bolton and Kacperczyk in 2021 and 2022, where they use panel regressions of equity returns on CO2 emissions and find that higher-emitting firms indeed have higher returns. Chava et al (2014) finds that more carbon intensive firms, the higher their cost of capital and the higher the expected returns demanded by investors. Bansal et al. (2021a) argue that climate change risk is priced in the stock market, as variations in global temperature have a negative effect on asset valuations and carry a positive risk premium. An earlier study showed evidence that the US markets penalise all firms for their carbon emissions; and firms that do not disclose their carbon emissions face a further penalty for non-disclosure (Matsamura, 2017).

In contrast, other studies have also highlighted positive returns for portfolios that adopt a long position in green stocks and a short position in brown stocks (Garvey et al., 2018; In et al., 2019; Pastor et al., 2022, Jimeno, 2022). The evidence from research in the US market (Bauer. 2023) indicates that green stocks have demonstrated outperformance compared to brown stocks, providing support for sustainable and environmentally friendly investment strategies.

However, some researchers have pointed out that positive returns for green stocks do not necessarily disprove the existence of a carbon premium. Pastor et al. (2022) and Ardia et al. (2022) provide evidence to suggest that green stocks may have exhibited higher realised returns compared to brown stocks, and this phenomenon could be attributed to growing concerns about climate change. However, it is important to note that their expected returns might have been similar or potentially even lower.

The theoretical framework proposed by Pástor et al. (2021) provides a plausible explanation for the outperformance of green stocks despite having lower expected returns. The combination of increasing investor demand for green assets, increasing consumer demand for green products, and heightened public awareness of environmental issues can create unexpected shifts in preferences, driving up the prices and realised returns of green stocks relative to brown stocks. This highlights the complex interplay of investor behaviour, market dynamics, and sustainability considerations in shaping the performance of ESG assets in the financial markets.

Finally, another study by Gorgen (2020) was unable to prove the significance of a carbon risk premium, and Cheema-Fox (2021) performs an analysis of industry effects including Scope 3 emissions to check for returns dispersions.

Several factors can contribute to the lack of consensus in empirical research on green and brown stock performance and the most relevant has to do with the lack of consistency in the methodologies used in the up-to- date state of research in climate finance. The most relevant studies often employ different methodologies, sample periods, and data sources, leading to variations in results. The choice of factors, portfolio construction methods, and statistical techniques can also impact the findings.

First, assessing the sustainability of companies involves various methods and metrics, such as measuring GHG emissions for a company which can be done in different ways. In academic research, emissions intensity or the level of emissions adjusted by a company's revenue is commonly used, followed by unscaled emissions or the total level of emissions by a company. Then, different studies focus more on Scope 1 and 2 only, and not on Scope 3 emissions, which can have a significant effect on the overall result as Scope 3 constitutes the majority of emissions for certain industries. Other researchers have used environmental scores like the "E" factor in ESG ratings offered by various financial data providers.

However, the evidence shows that there is an “aggregate confusion” due to the substantial divergence of ESG ratings based on data from six prominent ESG rating companies which makes it difficult to evaluate the sustainability of companies (Berg, 2022). Also, recent studies have shown that whether emissions data is estimated by the data vendor or it is actually disclosed by firms can lead to different results (Aswani, 2023).

A second important difference has to do with the selection of the sample, including the region of the world selected for analysis and the time period. With few exceptions, like Bolton (2021), most academic papers focus exclusively on companies in the United States. The time period is also very relevant and may account for the divergent results. While the lack of available data makes it difficult to analyse a relatively long sample, the focus has been on the period of 2010-2020, and this has also influenced the results as for most of the past decade, green stocks tended to outperform brown stocks. This period coincided with the post Global Financial Crisis era of zero interest rates, which helped to support growth stocks significantly, and as the evidence shows there is a strong correlation between growth factor and green stocks. However, those studies including 2022 shows that the green momentum has faded in light of the energy crisis and the rapid increase in interest rates by central banks which has penalised growth stocks in favour of traditional (brown) stocks.

Finally, the choice of methodology in academic research has played a role in shaping the outcomes of the ongoing debate about the relative performance of green and brown stocks. Different empirical approaches can lead to varying results, and researchers in climate have used either panel regressions or portfolio methods, leading to return disparities in the results. The most robust evidence supporting the existence of a carbon premium comes from the panel regressions conducted by Bolton and Kacperczyk in 2021 and 2022. Nevertheless, these findings appear to be somewhat contingent on the specific regression model and the inclusion of control variables (Aswani, 2022). In contrast, most reports indicating superior returns for green firms compared to brown firms do not rely on regression analysis. Instead, they are based on portfolio sorting and portfolio returns, using classical methods from empirical asset pricing (Bauer, 2023).

The Review of Finance has recently published three papers from prominent academic researchers, each reaching different conclusions regarding the relationship between emissions and asset prices (Aswani et al. 2023, Bolton and Kacperczyk, 2023) . While they concur that there is no statistically significant association between emissions intensity (carbon emissions to sales revenue ratio) and asset prices historically, Bolton and Kacperczyk argue that absolute emissions play a crucial role, and that there exists a significant relationship between asset prices and absolute emissions. This aligns with the understanding that addressing climate change requires absolute reductions in carbon emissions. Relative measures, such as emissions intensity, may create a false impression of progress. Intensity alone is not a comprehensive measure of carbon transition risk. Another reason the absolute size of carbon emissions matters is that Net Zero commitments typically involve targets for absolute emission reductions.

Research Design, Data & Methodology

3.1 Overall research design and data strategy

The time period for my thesis focuses on a 15-year period covering the range 2007-2022 on European stocks. The sample start date is motivated by data availability. The data uses the MSCI Europe Index representing 424 large and mid cap companies across 15 Developed Markets countries in Europe in 11 industries. This index covers approximately 85% of the free float-adjusted market capitalization across the European markets equity universe.

Focusing on Europe in my study rather than the commonly studied regions like the US or global markets offers several compelling reasons: i) Geographic Diversity: Europe represents a diverse and dynamic region with highly heterogeneous economies, industries, and regulatory environments[7]. I can capture the unique characteristics of different European countries and their financial markets, providing a more comprehensive understanding of how climate-related factors impact asset pricing and investment decisions in this region; ii) Specific Climate Policies: The EU been at the forefront of implementing climate-related policies and initiatives, such as the European Green Deal, and this allows me to analyse the implications of these specific climate policies on asset pricing, which may differ from other regions with alternative regulatory approaches; iii) Data Availability: Access to relevant data is crucial in empirical research.

This regional focus has provided me with better access to data specific to European companies, allowing for more accurate and reliable analyses. In summary, my study offers an

[7] The heterogeneity of the energy mix at the country level within Europe is addressed in Portela et al (2023).

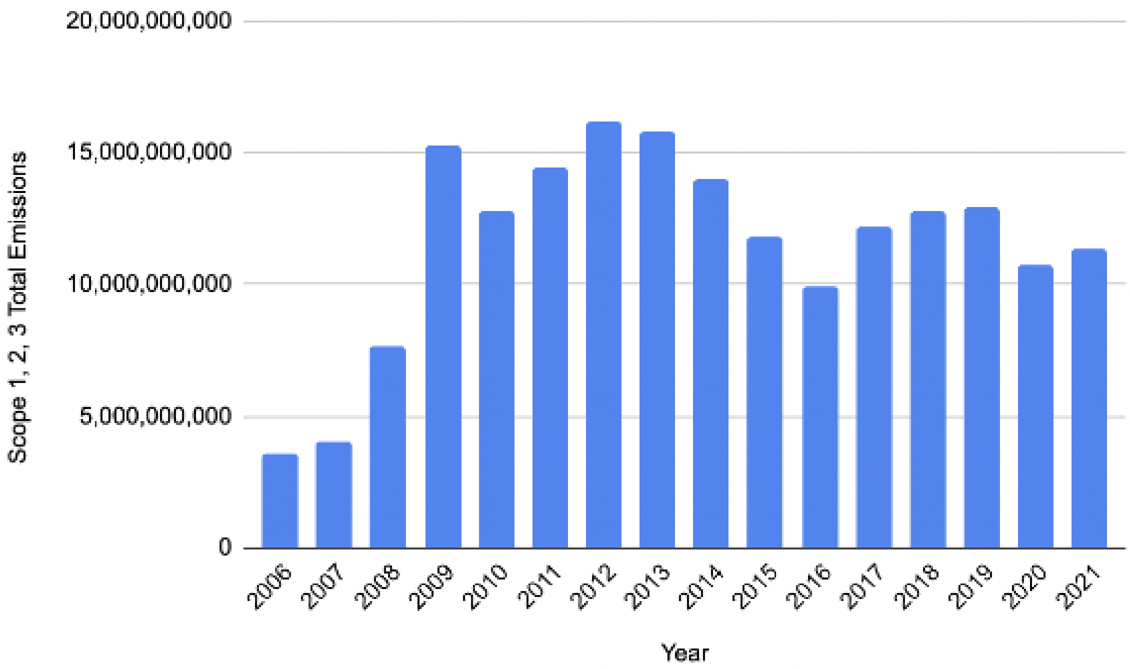
opportunity to contribute to the growing body of research on climate finance and its implications for investors and policymakers in the region, as well as facilitate comparisons with studies from other regions to draw broader conclusions about the global impact of climate-related risks on asset pricing.

3.2 Measuring climate risk: GHG emissions

In order to construct the climate risk factor of interest, one needs first to determine the climate risk proxy at the portfolio level. For my study, the three emissions data, Scope 1, 2 and 3, have been used for European companies according to the GHG protocol.

Our data set comprises 64,409 observations and is divided into two categories: My primary emissions data (Scope 1, 2 and 3) comes from several providers (Trucost, MSCI, Bloomberg and IHS Energy Reserves Data). Coverage of GHG emissions by European companies is improving over time (see Tabla 2). For data on stock returns, I have used monthly price data in Euros for all MSCI Europe index components for the January 2007-December 2022. Returns come from Factset using ISINs as main identifiers, and are calculated based on monthly price changes, expressed in Euros on a Net total return basis.

Figure 2: Evolution of the MSCI Europe index GHGs emissions



This figure shows the annual time series evolution of GHGs emissions (Scope 1, 2 and 3) at the MSCI Europe Index. Data is expressed in millions of tons of CO2 equivalent. Source: S&P Trucost, MSCI, Bloomberg.

There are several reasons that support my choice of metric of GHG emissions above any other metric measuring environmental sustainability. First of all, I have tried through this study to be as objective as possible, and carbon emissions is the most relevant environmental metric which can be measured in an objective way. The "E" rating metric has proven to be rather subjective and without consistency among providers, also been described as "aggregate confusion" by Berg et al. in their awarded paper in 2022. According to the OECD, some ESG rating agencies may put less emphasis on the "E" (Environmental) aspect compared to the other two components of ESG (Boffo, 2020). This imbalance can lead to situations where companies with high ESG scores may not necessarily have strong environmental performance, including effective management of carbon emissions.

The study highlighted that some companies might be receiving high ESG scores despite not effectively addressing their environmental impacts, including carbon emission, which raises concerns about greenwashing. Finally, it found that companies that provide well-crafted climate strategies may receive higher E scores, even if the actual implementation and the quality of the path or the steps to reduce emissions is unclear. Another reason which influenced my decision to select GHG emissions as the metric for my study is because it is also the metric which companies have selected as the key target for their own decarbonization plans and investors will continue to care more about progress towards Net Zero commitments and the overall level of emissions vis a vis the potential introduction of a carbon tax.

To illustrate the coverage of firms in my data, Table 2 reports summary statistics of emissions data for the sample period from 2006 to 2021 Between 2006 and 2021, the number of firms in the MSCI Europe with available GHG emission data increased from 68% to 100%, reflecting full disclosure of this very important sustainability metric. This increase reflects a greater tendency of firms to report emissions data and the improving coverage of the database, and this is due to several factors, including changing regulations, growing awareness of climate change and its impacts, investor demands, and corporate sustainability initiatives.

Table 3. MSCI Europe coverage: Percentage of Firms with Emissions Data Disclosed

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
68.7	72.4	78.5	80.7	82.6	85.5	86.8	97.9	97.9	98.4	97.0	98.4	97.1	100	100	100

Note: This table reports the percentage of firms in the MSCI Europe universe with available greenhouse gas emissions data for each year (%D). The start date is December 2006, where my sample begins. Source: S&P Trucost, MSCI.

Overall, reporting GHG emissions has become a standard practice for many companies in Europe, driven by the need to address climate change, comply with regulations, respond to investor demands, and improve their sustainability performance. The EU has established various directives and regulations that mandate GHG reporting for specific sectors, such as the EU Emissions Trading System (EU ETS) for large emitters. Institutional investors and stakeholders expect companies to disclose their environmental impact, including GHG emissions, as part of their ESG reporting. In this context, those firms that provide transparent and comprehensive GHG emission data are more likely to attract investment. Reporting GHG emissions allows companies to benchmark their performance against industry peers and identify areas for improvement. Publicly available data also enables consumers and stakeholders to compare companies' sustainability efforts and make informed choices.

Another original feature is the inclusion of Scope 3 emissions in my analysis. There are several compelling arguments for including Scope 3 emissions in my research. First of all, because it allows us to have a complete picture of a company's carbon footprint. Scope 3 emissions account for a significant portion of a company's total carbon footprint and ignoring them may lead to an incomplete assessment of a company's environmental impact. Second, including scope 3 emissions encourages companies to take responsibility for their entire supply chain. Many companies outsource parts of their production process or rely on suppliers for raw materials. By considering scope 3 emissions, companies are motivated to engage with their suppliers to reduce emissions collectively. Policymakers are increasingly considering scope 3 emissions when formulating climate policies and regulations such as the EU and the SEC. Companies that proactively address their scope 3 emissions are better positioned to adapt to future regulatory changes.

Finally, while most studies focus on the period leading until 2020, my thesis expands the research period for the first time until the end of 2022. Expanding the study of environmental impact on emissions until the end of 2022 is important considering the energy crisis and post-pandemic recovery. The energy crisis that occurred during the period leading up to 2022 had significant implications for energy consumption, production, and emissions. Studying this period should allow us to understand how changes in energy availability and pricing influenced emission levels in different sectors and regions.

It is also vital to understand the post-pandemic effect. The COVID-19 pandemic had a profound impact on human activities and the global economy. Lockdowns, travel restrictions, and reduced industrial activities led to a temporary drop in emissions in 2020. However, the post-pandemic recovery might have resulted in a rebound effect with emissions potentially surging back. By analysing the data until the end of 2022, my aim is to better understand the longer-term effects of the pandemic on emissions and whether there was a sustained shift in behaviour towards more sustainable practices.

Finally, environmental impact studies often require a long-term perspective to identify patterns and trends. Extending the series until 2022 allows for a more comprehensive analysis of emission trajectories and helps distinguish between short-term fluctuations and long-term patterns.

3.3. Constructing the expected Green Factor

The “Efficient Market Hypothesis” (Fama, 1970) states that an individual investor should not be able to outperform in an efficient market in which all relevant information has been incorporated into asset prices. The question that several studies have been trying to prove is whether climate risk is incorporated already into prices by financial markets.

The Gibbons, Ross, and Shanken (GRS) test is a widely used statistical F-test to evaluate the empirical validity of asset-pricing models, including the traditional factor models and more complex models that incorporate additional fundamental factors (Affleck-Graves, 1989). The GRS test aims to determine whether the model adequately captures the systematic variation of asset or portfolio returns by examining the intercept terms in the asset-pricing equations. In the null hypothesis of the GRS test, the intercept terms of the asset-pricing equations are jointly equal to zero. In other words, the expected excess return or alpha for the portfolios in the model is zero. If the test fails to reject the null hypothesis, it implies that the model adequately explains the systematic variation of returns, indicating that the factors included in the model are sufficient to account for the differences in returns across assets or portfolios. A small p-value indicates that we can reject the null that H,:ai = 0 for all of i.

Ho: The green factor is not priced in the European equity markets
H1: There is evidence of a green factor in the European equity markets

Empirical asset pricing models are a type of financial model used to explain and predict the average returns of financial assets based on observed data rather than theoretical assumptions. These models work backwards in the sense that they start with observed patterns in average returns and then attempt to construct models that can capture and explain those patterns. One basic conceptual difficulty with the choice of asset pricing model in the context of a complex pricing model like climate change risk is that such a model has not yet been formulated (Bolton, 2021).

My analysis is based on a cross sectional regression model relating individual company's stock returns to carbon emissions both at the total firm level and at the level of emissions intensity by company. My methodology choice uses a "simple spread" approach, which is commonly used in empirical asset pricing and capital market anomaly literature. Pastor et al. (2022) use a similar method to construct their “green-minus-brown” factor, although using E-scores as the metric to rank companies. Overall, my objective has been to adopt a methodology that aligns with established academic research in climate in order to allow for meaningful comparisons and interpretations of the results for future studies.

Similar to prior academic studies which have looked at Europe such as Gimeno (2022) and Alessi (2021), I propose to build a new factor called "Green Minus Brown" (GMB) to account for the exposure of European companies to climate transition risk, specifically focusing on their CO2 emissions. The GMB factor would be constructed by creating a portfolio that goes long on companies with low emissions and short on companies with high emissions. By incorporating the GMB factor into my model, my aim is to capture the potential impact of climate change-related risks on the valuation of companies. My proposed models would be represented by the following equations, would include the existing Fama-French and Carhart 3, 4 and 5 factor models with their factors (MKT, SMB, HML, RMW, CMA, and MOM) alongside the new GMB factor.

It is important to highlight that my thesis diverges from the other European studies mentioned in expanding the period until the end of 2022. I also rebalance the portfolios each year to account for changes in emissions instead of using the last emissions data as a static metric. Contrary to some previous academic literature (see Gimeno, 2022), I found that the portfolios did change each year specially on the Green portfolios with some companies exiting the portfolios, and this justifies the rebasing of the portfolios based on new emission data becoming available. Finally, as noted I also incorporate Scope 3 emissions and I look both at intensity and unscaled emissions.

The goal of my methodology is to construct a factor that captures the performance difference between green and brown stocks based on their reported emission levels or intensities.This green factor would be the proxy metric to measure climate risk. In order to build the GMB factor, I need to form portfolios. My methodology is based on similar academic studies by constructing "green and brown" portfolios which rank companies based on their GHG emissions intensity and total emissions data for the MSCI Europe ex-Financials, using the top and bottom quintiles based on that data.

All the vendors used in this study follow the Greenhouse Gas Protocol that sets the standards for quantifying corporate emissions at the firm level, distinguishing from three different sources of GHG emissions. Scope 1 emissions refer to the direct emissions from plants owned or controlled by a company. Scope 2 emissions arise from the generation of purchased steam, heat and electricity consumed by the firm, while scope 3 emissions come from sources not owned or controlled by the company, such as emissions from outsourced activities.

The frequency of the emissions and reserves data is annual, but I have joined it to the constituents of MSCI Europe on a monthly basis and fed forward the emissions/reserves data for 11 months where it is missing. This effectively creates a monthly time series.

From these companies, I rank companies based on their annual reported carbon footprint in three separate categories: By Scope 1 and 2 emissions Intensity, by Scope 1, 2 and 3 emissions intensity, and finally by their total Scope 1, 2 and 3 Emissions.

The factors I use throughout this thesis in addition to GMB are the FF three factors, the FF five factors and the momentum factor (MOM). I download the excess return on all factors as well as the risk-free rate from Ken French's data Library.[8] I start the analysis looking to sort the relevance of each factor to explain the excess return of each model. To assess the relevance, I use the coefficient of determination, or R2 , a measure that provides information about the goodness of fit of a model. In the context of regression it is a statistical measure of how well the regression line approximates the actual data. In a first step, I regress the established factors in the literature with the GMB factor to test for their explanatory power. As a second step. I consider the different versions of the models with their GMB factor and I repeat the same process using the Fama French and Carhart models, until I incorporate all factors. Finally, I proceed to calculate the different regressions using variations of Scope 1, 2,

[8] https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

3 intensity and Scope 1, 2, 3 Total to test the significance of each of the factors to explain returns. As it would be expected, the market factor has the most significance in explaining the excess return in comparison with the other factors.

Expanded Fama French 3 factors model with GBM factor:

$R_{it} - R_{Ft} = \alpha + \beta_i (E (R_{Mt}) - R_{Ft}) + s_i SMB_t + h_i HML_t + g_i GMB_t + \varepsilon_{it}$

Expanded Carhart 4 factors model with GBM Factor:

$R_{it} - R_{Ft} = \alpha + \beta_i (E (R_{Mt}) - R_{Ft}) + s_i SMB_t + h_i HML_t + m_i WML_t + g_i GMB_t + \varepsilon_{it}$

Expanded Fama French 5 factors model with GMB Factor:

$R_{it} - R_{Ft} = \alpha + \beta_i (E (R_{Mt}) - R_{Ft}) + s_i SMB_t + h_i HML_t + r_i RMW_t + c_i CMA_t + g_i GMB_t + \varepsilon_{it}$

In order to evaluate if the proposed GMB factor has a real relevance compared with other factors already used in the literature, we have to check if this GMB factor has a capacity to explain the evolution of the stock prices. I start from the monthly return of each of the companies in the MSCI Europe index. I subtract the risk-free rate to obtain the excess return for each company. I estimate performance relative to the Fama French 3-factor, and 4 and 5-factor models. In my study, the cross section of stocks returns is regressed on well-known risk factors in order to determine the significance of the green factor.

As a starting point, I use the universe of companies that is part of the MSCI Europe Index. From 424 companies, excluding those corporates operating in the financial sector, since they are eminently companies with a very low carbon footprint, and in order to avoid mixing the green factor with a "financial sector" factor in the same portfolio. This reduces my sample to approximately 350 companies. To create the "green-minus-brown" factor, I sort stocks into quintiles based on their emission levels and intensities. As it is the standard in the academic literature, I calculate intensity using companies´ annual revenues and I also rank them based on unscaled emissions.

At the end of December of each year between 2006 and 2021, I allocated MSCI Europe stocks to five groups within each of the emissions categories as described above. The breakpoints are the 20th and the 80th percentiles on MSCI Europe stocks based on their emissions ranking. Each quintile represents a portfolio of stocks with varying degrees of carbon intensity, with the highest emission stocks in one quintile and the lowest emission stocks in another. There are an average of 70 companies per quintile. Then, I form two equal-weighted portfolios of stocks, the "Green" and "Brown" portfolios as the equal-weight average of firms with the highest 20 percent emissions and the equal-weight average of firms with the lowest 20 percent of emissions respectively.

Next, the GMB is built as a compound portfolio that is long on the green portfolio and short in the portfolio of brown companies (GMB). I hold the portfolios for one year, then on January 1 of each year, I construct new portfolios based on their new emissions ranking. The portfolios are rebalanced annually based on new corporate emissions data becoming available each year end which may alter the position of some of the companies in the ranking. This means that some companies will no longer be on the top quintile by emissions and as a consequence, they would come out of the Brown portfolio and similarly other companies which have reduced their emissions would replace others in the Green portfolio.

Then, I calculate the average return for each portfolio using reported monthly returns in FactSet. In order to control for firm size, my methodology uses equal-weighted returns within each quintile in order to reduce the impact of the very large firms that may dominate the portfolio's value-weighted returns. This is also standard practice in academic literature. I build a time series of monthly returns on each quintile portfolio from 1st January 2007 to 31st December 2022. This comprises a set of 64,409 observations.

Once the portfolios have been built, I follow the more common approach in empirical asset pricing and use the quintile spread. The simple spread return is then calculated as the difference between the average returns of the quintile portfolios with lowest emission levels or intensities (Green portfolios) with the highest emissions levels of intensities (Brown portfolios) for each of the past 15 years, that is from 2007 to 2022. This spread measures the performance difference between the green and brown stocks in my study.

Finally, testing the correlations among factors is important as it helps identify multicollinearity, which occurs when two or more factors are highly correlated with each other. Correlations among factors can influence the interpretation of their individual significance as multicollinearity can make it challenging to determine the unique contribution of each factor to explaining asset returns in the model. Factors that are highly correlated might be capturing similar risk exposures, like the growth and green factors, which can impact the interpretability and effectiveness of the model.

In terms of extra data analysis, it is also essential as a final step to perform a Robustness Test. For this, I have conducted an out-of-sample test using a couple of different industries in Europe to evaluate its robustness. Out-of-sample testing involves applying the model to a new and independent dataset that was not used in the model development process. The first is doing the same analysis but at the FF Industry level by creating GMB returns using the relative emissions level scores for the companies within each industry. I have selected two sectors, Industrials and Consumer Discretionary to test for industry level significance of the green factors.

Data Results Analysis

4.1 Largest emitters in Europe by country and industry

Starting by showing the largest emitters by country and by sector in Europe before moving into the regressions is important in order to provide context for this study, as it helps to grasp the magnitude of emissions and understand the key players and industries contributing most significantly to GHG emissions in Europe.

In Table 4, on the next page, I have calculated the total emissions for the countries within my sample.

Table 4. Carbon Emissions by Country

Country	Number of Companies	GHG emissions in millions of tons of CO2
Austria	5	232.2
Belgium	11	88.6
Denmark	18	90.3
Finland	12	134.9
France	65	241.2
Germany	59	619.0
Ireland	7	173.4
Italy	21	221.8
Luxembourg	4	518.0
Netherlands	28	579.1
Norway	12	355.3
Portugal	3	168.2
Spain	19	225.0
Sweden	43	79.5
Switzerland	44	195.8
United Kingdom	77	192.6

This table measures the firm-level average from the sample (by country) of Scope 1, Scope 2; Scope 3 carbon emissions measured in millions of tons of CO2e. Source: S&P Trucost, MSCI.

The evidence in the data shows that Germany with 61.90 emissions in millions of tons of CO2 is the largest emitter of all countries in Europe, and the title for the lowest emitter is for Sweden. This is due to several factors. First, Germany houses some of the biggest auto companies in the world and autos is one of the sectors with highest Scope 3 emissions. Germany is also not decarbonising as fast as other large emitters due to the decision by its government to phase out nuclear energy following the Fukushima disaster. At the time, nuclear power was contributing around a quarter of Germany's electricity from 17 operating nuclear reactors. As Table 5 shows, using Scope 1, 2 emissions only, Materials are the most intensive sector, followed by Utilities & Energy. If you include Scope 3 emissions, Energy is by far the most intensive sector. Another important finding is that Consumer Discretionary is much more intensive as a sector when Scope 3 emissions are included, and the reason for this is because of Automobiles.

Table 5. Carbon Emissions Intensity by Sector

Sector	Scope 1 & 2 Intensity	Scope 1, 2 & 3 Intensity
Materials	767.01	1,938.31
Utilities	618.22	1,701.59
Energy	416.75	3,815.52
Industrials	61.86	655.89
Consumer Staples	33.93	352.53
Consumer Discretionary	31.00	1,550.53
Communication Services	15.46	150.67
Health Care	9.63	121.75
Real Estate	8.42	41.56
Financials	6.41	275.67
Information Technology	3.44	66.57

This table measures average Scope Intensity data across firms within each MSCI Europe industry in millions of metric tons at the end of 2022. MSCI uses the GICS sub-industry classification. Source: S&P Trucost, MSCI.

Energy, materials, and utilities are the sectors with the highest emissions for several reasons: The energy sector is a significant contributor to emissions because it involves the extraction, production, and consumption of fossil fuels like coal, oil, and natural gas. Burning these fossil fuels for electricity generation, heating, and transportation releases large amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. As one of the primary sectors responsible for supplying energy to industries and consumers, its emissions are substantial. The materials sector encompasses industries involved in the production of various materials like cement, steel, aluminium, and chemicals. Many of these materials are manufactured through energy-intensive processes, such as cement production, which releases a significant amount of CO_2 during the chemical transformation of limestone into cement. Additionally, the production of steel and aluminium involves high-temperature processes, often powered by fossil fuels, leading to substantial emissions.

Finally, the utilities sector includes companies responsible for electricity generation, distribution, and retail. Traditionally, many power plants in this sector have been reliant on fossil fuels to produce electricity, leading to substantial CO_2 emissions. Although efforts are being made to transition to cleaner sources of energy, such as renewables, many countries still over-depend on coal and natural gas for electricity generation, contributing to high emissions in this sector.

The common factor among these three sectors is their heavy reliance on fossil fuels. Fossil fuels have been the primary energy source for decades due to their abundance, affordability, and existing infrastructure. However, this excessive reliance on fossil fuels has come at the cost of increased GHG emissions. These sectors play crucial roles in the global economy, supporting industrial activities, infrastructure development, and daily living. As a result, their emissions are tied to the overall economic growth and consumption patterns of societies. Transitioning to cleaner and more sustainable practices in these sectors is essential for reducing their contribution to GHG emissions and promoting a low-carbon and resilient future.

Historically, alternatives to fossil fuels, such as renewable energy sources, have faced challenges related to cost, scalability, and infrastructure development. Although the transition to low-carbon alternatives is underway, it takes time and significant investment to replace existing fossil fuel-based systems with cleaner alternatives. According to the latest report from the IEA, although power sector emissions increased by 3.4% in 2022, greater deployment of clean technologies has played a crucial role in preventing further emissions growth in the face of a geopolitical crisis like the Ukraine-Russia conflict. For the first time in the EU, electricity generation from wind and solar PV combined exceeded that of gas or nuclear in 2022. This highlights the critical importance of clean energy sources for the world.

4.2 GMB quintile portfolio analysis: Assessing the significance of the GMB factor

The question of whether equity markets price carbon transition risk is of great importance, not only in the realm of finance but also in the global efforts to combat climate change. In this empirical study, I have focused my efforts to analyse whether investors demand a carbon risk premium as compensation for their exposure to carbon transition risk within the European market. To explore this, I explored the relationship between stock returns in the MSCI Europe index and the type of emissions across industries over the past 15 years. Specifically, I examined how the performance of green stocks compared to that of polluted stocks, which has previously been ranked according to their emissions intensity and total emissions for scope 1, 2, and 3.

Table 6 on the next page, shows that the brown portfolio is dominated by materials, energy and utility companies, while the green portfolios are represented by IT and communication services companies.

Table 6. Sector breakdown of Green and Brown Portfolios by number of companies

	#Co. Scope 1, 2 Intensity		*#Co.* Scope 1,2,3 Intensity		*#Co.* Scope 1,2,3 Total	
Sector	Brown	Green	Brown	Green	Brown	Green
Materials	25	0	23	0	17	0
Energy	12	0	12	0	11	0
Utilities	23	0	13	0	12	0
Industrials	5	9	12	15	13	10
Consumer Discretionary	3	21	10	1	13	3
Consumer Staples	2	4	2	7	5	5
Communication Services	0	14	0	24	1	13
Healthcare	1	7	0	10	2	15
Real Estate	1	2	0	0	0	12
Information Technology	0	14	0	14	0	11

The table reports the distribution of unique firms in my sample with regard to MSCI industry classification. *#Co.* represents the total number of firms in each industry for the Brown and Green Portfolios.

I construct GMB sorted portfolios to test if the BMG factor is able to improve the explanatory power of common factor models. With the available data I sort the companies into annually rebalanced quintiles, such that Quintile1 contains the firms with the lowest GMB, i.e: the brownest firms, and Quintile 5 contains the firms with the highest GMB, i.e: the greenest firms. I then run time-series regressions on the quintile´s equal-weighted monthly excess returns on the Fama French models, on the Carhart model and on the expanded model including the GMB factor.

To assess the significance of the proposed GMB factor compared to other factors already used in previous studies, I need to examine its ability to explain the fluctuations in stock prices. My study proceeds by classifying companies into two categories: green and brown. by their carbon emissions and select the 70 companies[9] with the lowest carbon footprint and the 70 companies with the highest footprint in Europe. This allows me to build equally weighted portfolios for green and brown companies which change every year to allow for rebalancing according to the available emissions data. I calculate in Table 7, the annual return and standard deviation of the Green and the Brown portfolios using the different Scopes. The highest volatility is always for the portfolio with the highest emissions. Finally, the GMB factor is built as a compound portfolio which is long on Green companies and short on Brown companies, hence the Green Minus Brown (GMB) factor name.

Table 7. Green and Brown Portfolios: Key metrics

	Scope 1, 2 Intensity		Scope 1,2,3 Intensity		Scope 1,2,3 Total	
	Brown	Green	Brown	Green	Brown	Green
Mean Return	6.86%	5.26%	5.33%	3.92%	7.30%	4.71%
Volatility	18.73%	17.39%	20.03%	15.90%	18.77%	16.35%

Table 7 shows the annual returns and volatility measured as the standard deviation number for the Green and Brown portfolios for the 2007-2022 period, using Scope 1,2 Intensity and Scope 1, 2, 3 Intensity and Scope 1,2,3 Total emissions.

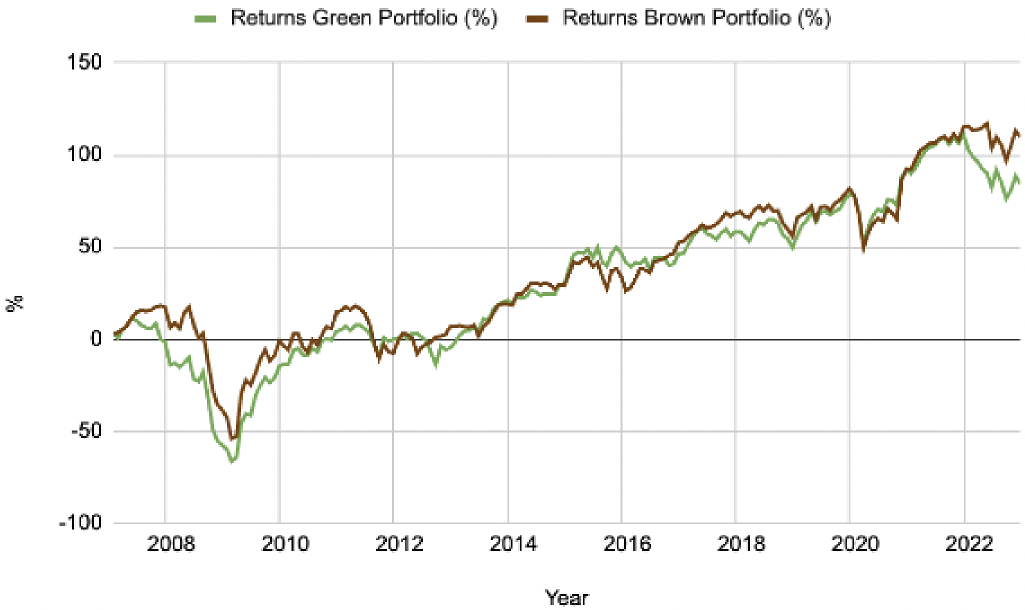
The cumulative returns of these portfolios are visually presented in the following graphs. Fig. 1, 2 and 3 illustrate the cumulative returns of these portfolios across the sample period 2007-2022, where the green lines represent the green portfolios and the brown lines represent the polluter portfolios.

Regardless of the variations in carbon emissions, the trends in these graphs follow a similar trajectory and there are indeed some similarities in the evolution of the green and brown portfolios in the three graphs. There is a consistent pattern of all the portfolios of negative

[9] Depending on the year, the MSCI Europe index has a different number of companies ex-Financials.

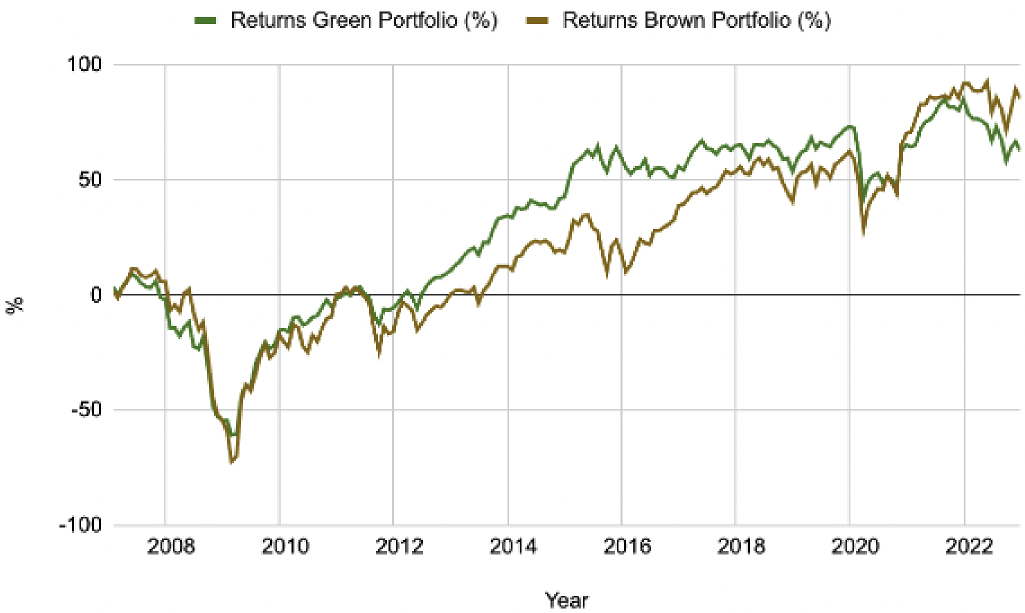
returns during the Global Financial Crisis of 2008, followed by subsequent periods of positive returns for the second decade of the 21st century. All of them experienced a downturn at the onset of the pandemic and then moved again in an upward trajectory.

Figure 3. Returns on Green and Brown Portfolios on Scope 1, 2 Intensity



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 84.2 and 109.72, implying brown stocks outperformed green by (108.72− 84.2) × 100 = 25.52 percentage points over this period.

Figure 4. Returns on Green and Brown Portfolios on Scope 1, 2, 3 Intensity



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 62.7 and 85.31, implying brown stocks outperformed green by (85.31− 62.7) × 100 = 22.61 percentage points over this period.

Following the discovery of Covid-19 vaccines, a notable shift occurs where the Brown portfolios, particularly those including Scope 3 emissions, start outperforming the Green portfolios. This differential in returns continues to widen over time. In all the methodologies, the brown portfolios outperform the green portfolios since 2021. It's noteworthy that the portfolios built using Total Scope 1, 2, and 3 emissions exhibit the most significant differential in returns for the brown portfolios up until the end of 2022.

Interestingly, external events such as the energy crisis and the Russia-Ukraine conflict have played a role in shaping the performance trends. These geopolitical and energy-related factors have contributed to companies with higher emissions to experience better performance relative to the green companies. However, the evidence shows that this difference starts to materialise earlier, in post-COVID period when Scope 3 is considered.

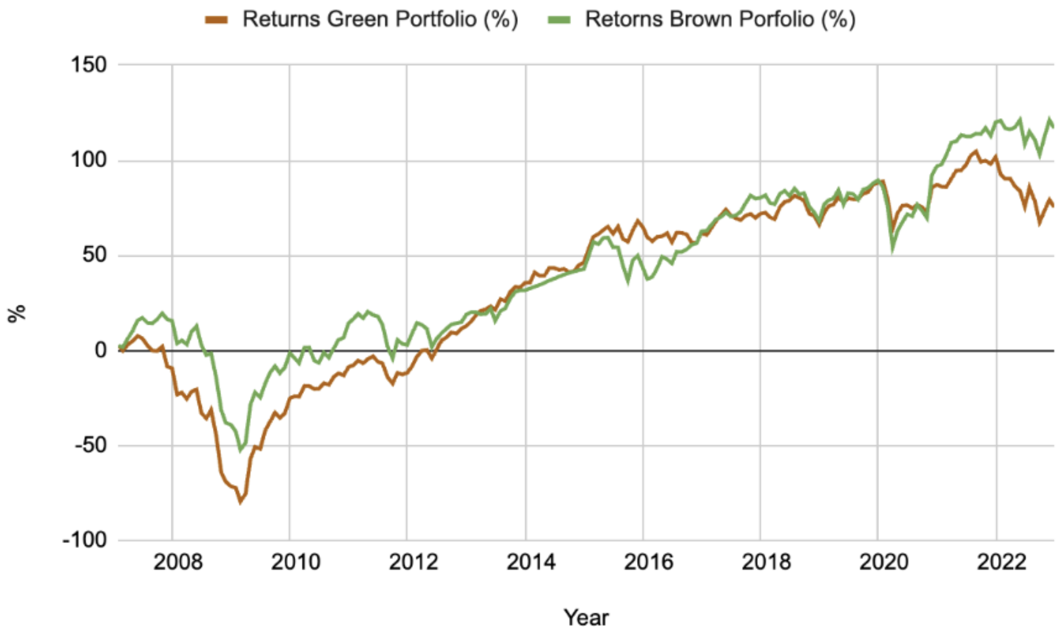
There are also some patterns worth highlighting. As we can see, the green portfolio clearly outperforms the brown portfolio during most of the first decade using the three different methodologies, but this trend changes drastically towards the end of 2020, coinciding with the onset of the energy crisis in Europe.

Since then and until December 2022, which is the end of the sample period of my empirical research, the green portfolios underperformed the brown ones. The cumulative alpha is the largest for the Brown portfolios using Total Scope 1,2 3 emissions showing a carbon risk premia in the double digits[10]. An explanation is the greater than expected post-Covid demand for fossil fuels as well as the war has caused returns in fossil fuels to soar earlier in a context

[10] The cumulative alpha of the Brown Minus Green portfolio is -41.5% for Scope 1, 2 & 3 Total Emissions.

of underinvestment that started already in 2014, as highlighted by Cervera and Figuerola-Ferreti (2023).

Figure 5. Returns on Green and Brown Portfolios on Scope 1, 2, 3 Total



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 75.34 and 116.84 implying brown stocks outperformed green by (75.34 − 116.84) × 100 = 41.5 percentage points over this period.

On the graph above, the performance of the GMB is illustrated for the 15 year period. It can be seen that the GMB factor performs well in the period after the Global Financial Crisis until the oil price shock of 2014-2016 when it takes a sharp downturn. Then starts to rebound and increases during the pandemic, but the GMB factor performance decreases sharply with the start of the energy crisis at the end of 2020 coinciding with the end of the restrictions associated with the pandemic due to the shortages in energy, and it only gets worse due to the Russian invasion of Ukraine. This is a reflection of the lack of investment in new energy capacity, due to the underinvestments in fossil fuels, under higher than expected post-Covid demand and the war in Ukraine. The poor returns in energy stocks during the 2015-2016 period, saw capital redirected from “old economy” stocks to those of the “new economy”[11]. The insufficient investments for several years into those stocks resulted in a deficit in the supply. The extent of these limitations in the supply became evident as the global economy transitioned into a recovery phase from the pandemic, revealing the strain on capacity. This effect was further exacerbated in Europe by the Ukraine war causing a huge spike in gas and electricity prices.

It is interesting to highlight that the worse overall returns in this last downturn are for the GMB factor constructed using Total Scope 1, 2 and 3 emissions. This is unsurprising, given that the level of emissions is unscaled. One line of reasoning supporting the use of unscaled emissions over emissions intensity for assessing firms' carbon performance is that, from a regulatory standpoint, the total volume of emissions is crucial, as it emphasises the aggregate impact of a company's carbon footprint, rather than just the intensity per unit of production (Aswani, 2023).

4.3 Correlation among factors

The regression analysis aims to determine the extent to which the GMB factor, along with other relevant factors, can account for the variations in stock prices. By evaluating the explanatory power of the GMB factor in comparison to established factors, we can assess its real relevance and potential contribution to the understanding of stock market dynamics. I used several explanatory variables, including well-known factors from various asset pricing models: the MKT Factor derived from the Capital Asset Pricing Model (CAPM) proposed by Sharpe (1964), Lintner (1965), and Black (1972), representing the excess return of the market portfolio over the risk-free rate. Also called market beta, It captures the systematic risk associated with exposure to the overall market.

[11] “The revenge of the old economy” Jeff Curry, Goldman Sachs. Financial Times, October 21, 2021.

The SMB and HML Factors introduced by Fama and French (1993), the SMB (Small Minus Big) factor measures the excess return of small-cap stocks over large-cap stocks, while the HML (High Minus Low) factor represents the excess return of high book-to-market ratio stocks over low book-to-market ratio stocks. These factors are part of the Fama-French Three-Factor Model. From the work of Carhart (1997), I used the WML (Winner Minus Loser) factor to gauge the excess return of past winners over past losers. This factor extends the Fama-French Three-Factor Model to include momentum.

Table 8. Correlation of GMB factor with Fama-French 5 factors and Momentum.

	GMB-RF	*Mkt-RF*	*SMB*	*HML*	*RMW*	*CMA*	*WML*
GMB-RF	1.00						
Mkt-RF	-0.30	1.00					
SMB	0.17	0.07	1.00				
HML	-0.60	0.37	-0.04	1.00			
RMW	0.44	-0.27	-0.04	-0.80	1.00		
CMA	-0.35	-0.24	-0.26	0.53	-0.44	1.00	
WML	0.28	-0.49	-0.04	-0.53	0.39	0.04	1.00

This table represents correlation results for the model using Scope 1, 2 & 3 Total emissions. The table examines the sample period from January 2007 to December 2022.

	GMB-RF	*Mkt-RF*	*SMB*	*HML*	*RMW*	*CMA*	*WML*
GMB-RF	1.00						
Mkt-RF	-0.45	1.00					
SMB	0.05	0.07	1.00				
HML	-0.44	0.37	-0.04	1.00			
RMW	0.34	-0.27	-0.04	-0.80	1.00		
CMA	-0.05	-0.24	-0.26	0.53	-0.44	1.00	
WML	0.34	-0.49	-0.04	-0.53	0.39	0.04	1.00

This table represents correlation results for the model using Scope 1, 2 & 3 emissions intensity.The table examines the sample period from January 2007 to December 2022.

	GMB-RF	*Mkt-RF*	*SMB*	*HML*	*RMW*	*CMA*	*WML*
GMB-RF	1.00						
Mkt-RF	-0.25	1.00					
SMB	0.09	0.07	1.00				
HML	-0.49	0.37	-0.04	1.00			
RMW	0.37	-0.27	-0.04	-0.80	1.00		
CMA	-0.28	-0.24	-0.26	0.53	-0.44	1.00	
WML	0.30	-0.49	-0.04	-0.53	0.39	0.04	1.00

This table represents correlation results for the model using Scope 1 & 2 emissions intensity. The table examines the sample period from January 2007 to December 2022.

From the Fama-French Five-Factor Model (2015), I have included the RMW and CMA Factors: the RMW (Robust Minus Weak) factor measures the excess return of firms with robust profitability over firms with weak profitability, while the CMA (Conservative Minus

Aggressive) factor represents the excess return of firms with conservative investment policies over firms with aggressive investment policies. Finally, the GMB Factor, which is the newly proposed factor in this study, the GMB (Greeners Minus Brown) factor accounts for the exposure of companies to climate change and transition risks based on their CO2 emissions. The results of the regression analysis are summarised in Tables 1, 2 and 3 .

The findings from this study align with previous research, as they show a negative correlation between the GMB spread returns and the HML (value) factor. The correlation is particularly strong (60%) when taking into account all Scope 1, 2 and 3 unscaled emissions This implies that more polluted companies tend to exhibit stronger characteristics of value stocks. The opposite is true for green firms, which are more environmentally friendly, and therefore are more likely to resemble growth stocks.

Huij et al. (2021) also reported a positive correlation between the returns of their brown minus green portfolio and the HML factor. They observed that the most polluting firms tend to be classified as value firms, while cleaner firms are more likely to be categorised as growth firms. Similarly, Pastor et al. (2022) mentioned a negative correlation between their green factor and the HML factor. This indicates that value stocks are more often associated with brown characteristics (higher polluters) than with green characteristics (lower polluters). Value stocks often include companies that operate in traditional and mature industries, which may have higher environmental footprints due to historical practices and reliance on fossil fuels. These industries can include energy, manufacturing, and certain segments of the materials sector, which are more likely to be associated with brown characteristics.

The consistent negative correlation between GMB spread returns and the HML factor, observed on these tables and supported by previous research, highlights the relationship between environmental performance (brown or green) and investment styles (value or growth).

4.4 GMB factor explained by other factors and key metrics

Having obtained the GMB (Green Minus Brown) factor, my analysis proceed to assess its relevance in comparison to other commonly used factors in the financial literature, such as SMB (Small Minus Big), HML (High Minus Low), WML (Winners Minus Losers), RMW (Robust Minus Weak), and CMA (Conservative Minus Aggressive). The aim is to determine whether the GMB factor provides unique information that is not already accounted for by these existing factors. As further evidence of the low correlation between GMB and the existing factors, I proceed to perform a regression analysis where it regresses the log return of GMP on the log returns of the other factors. The results are summarised in Table 8.

Table 9. Regression of the GMB factors on the other market factors

	Scope 1,2 Intensity	Scope 1,2,3 Intensity	Scope 1,2,3 Total
Constant	-0.240 (0.230)	-0.195 (0.188)	-0.254 (0.172)
MKT	-0.061 (0.042)	-0.143*** (0.040)	-0.079** (0.036)
SMB	0.081 (0.105)	0.122 (0.099)	0.203 (0.091)
HML	-0.398*** (0.144)	-0.376*** (0.136)	-0.601*** (0.124)
WML	0.044 (0.062)	-0.009 (0.058)	0.140 (0.161)
RMW	-0.079 (0.187)	0.022 (0.176)	-0.112 (0.156)
CMA	-0.203 (0.180)	0.190 (0.170)	-0.058 (0.053)
# observations	193	193	192
R2 adjusted	0.235	0.272	0.383

Note: Regression of the log return of the GMB factor on the log returns of the other market factors (i.e., MKT (market excess return); the Fama & French (1993) SMB (small minus big) and HML (high minus low); the Carhart (1997) WML (winners minus losers); the Fama and French (2015) RMW (robust minus weak) and the CMA (conservative minus aggressive). Robust standard errors in parenthesis. ***, **., * is the 1%, 5% and 10% significance level,

As per Table 9 above shows, with the exception of the HML factor, the GMB factor is minimally correlated with other common risk factors pointed to the fact that it could have unique return influencing characteristics. However the alpha (negative) is not significant. This alpha shows a negative association with stock returns with a coefficient of (-0.240, -0.195, -0.245) indicating that Brown firms have higher returns. The GMB factor shows a consistent negative relationship which is significant at the 1% level with the HML factor for all the different methodologies to rank portfolios using Scope 1, 2 and 3 emissions. This would indicate that the GMB factor can be explained by the Growth factor, as it is to be representative of the "glamour" stocks[12]. This result is expected as the Green portfolio is

[12] Robert Engle´s comments during speech at the ICADE Climate Finance conference in Madrid, May 2023.

made of a combination of companies representing the Technology and Healthcare sectors, which are by design “Growth”stocks. Interestingly, for portfolios including Scope 3 emissions, the GMB is statistically negative with respect to the market, indicating that the GMB factor has hedging characteristics, that is a market neutral or risk-minimising strategy.

Table 10. GMB Factor Key metrics

	Mean	Stdev	Sharpe	Max	Min	Skew	Kurtosis
Scope 1, 2 Intensity	-1.60	9.96	-0.16	9.72	-9.31	-0.30	1.35
Scope 1,2,3 Intensity	-1.41	9.66	-0.15	6.60	-7.84	-0.14	-0.12
Scope 1,2,3 Total	-2.59	9.56	-0.27	6.39	-9.99	-0.31	0.57

Table 10 shows the key metrics for the GMB factor (Green-Minus-Brown) for Scope 1,2 Intensity and Scope 1, 2, 3 Intensity and Total emissions for the sample period from 2007 to 2022.

Looking at the risk metrics, Table 10 shows that the mean returns for the GMB factor is negative for all the portfolios, independently on whether this is calculated using scaled or unscaled emissions and whether Scope 3 emissions are included or not. The biggest underperformance at -2.59% annually is for the Scope 1,2,3 Total Emissions portfolios. Also it is important to look at the Sharpe ratios which are all negative. This would lead us to conclude that this GMB factor has failed to provide alpha in the past 15 years, and in fact it has been rather a contributor to negative performance.

In terms of other metrics, Scope 1, 2 Intensity shows a higher volatility which is a surprise, as one would intuitively expect that higher volatility would be assigned to those portfolios which include for Scope 3 emissions. The values for asymmetry and kurtosis between -2 and +2 are considered acceptable in order to prove normal univariate distribution (George &

Mallery, 2010). Scope 1, 2 Intensity portfolio has higher kurtosis and higher standard deviation.

4.5 The asset pricing models

If an asset pricing model completely captures expected returns, the intercept is indistinguishable from zero in a regression of an asset's excess returns on the model's factor returns (FF, 2005). Therefore, If the exposures to the 7 factors (MKTi, SMB, HML, WML, RMW, CMA and GMB) capture all variation in expected returns, the intercept $\alpha\mathbf{i}$ is zero for all securities and portfolios i.

The results of the GMB quintile analysis are shown in Tables 11, 12 and 13 on the next pages.

Table 11. Results for 3 Factors Fama-French model with and without GMB factor

	Scope 1,2 Intensity				*Scope 1,2,3 Intensity*				*Scope 1,2,3 Total*			
	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio
Constant	0.149 (0.164)	0.181 (0.268)	0.076 (0.222)	0.243 (0.187)	0.161 (0.164)	0.171 (0.165)	0.011 (0.195)	0.087 (0.182)	0.161 (0.164)	0.191 (0.166)	0.021 (0.195)	0.202 (0.265)
MKT-Rf	0.688*** (0.031)	0.694*** (0.031)	0.734*** (0.042)	0.764*** (0.035)	0.686*** (0.031)	0.696*** (0.033)	0.664*** (0.037)	0.736*** (0.036)	0.686*** (0.031)	0.690*** (0.031)	0.718*** (0.037)	0.744*** (0.034)
SMB	-0.278*** (0.088)	-0.293*** (0.088)	0.187 (0.119)	0.113 (0.100)	-0.274*** (0.090)	-0.279*** (0.090)	0.127 (0.107)	0.088 (0.100)	-0.273*** (0.090)	-0.293*** (0.092)	0.228** (0.107)	0.108 (0.100)
HML	-0.023 (0.037)	0.035 (0.069)	-0.231*** (0.085)	0.076 (0.079)	-0.004 (0.062)	0.014 (0.066)	-0.038 (0.074)	0.093 (0.073)	-0.005 (0.062)	0.041 (0.075)	-0.265*** (0.074)	0.012 (0.081)
GMB	n/a	0.130** (0.065)	n/a	0.671*** (0.074)	n/a	0.061 (0.069)	n/a	0.430*** (0.076)	n/a	0.085 (0.075)	n/a	0.509*** (0.082)
# Observations	193	193	193	193	193	193	193	193	193	193	193	193
R2 adjusted	0.744	0.749	0.628	0.739	0.744	0.743	0.656	0.704	0.743	0.744	0.675	0.729

The table presents results for the model where the dependent variable are the stock returns, and the explanatory variables are the beta of the excess returns of each company to the market factors (MKT, SMB, HML, as well as GMB). In Columns 2, 5, 9 regressions use the initial MSCI Europe full index and Columns 4, 8 and 12, use the Green portfolios are built using the 20% firms with less emissions. In Columns 3, 5, 7, 9 ,11, 13 regressions do not include the GMB factor. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance level.

Table 12. Results for Carhart model with and without GMB factor

	Scope 1,2 Intensity				*Scope 1,2,3 Intensity*				*Scope 1,2,3 Total*			
	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio
Constant	0.234 (0.166)	0.270 (0.166)	0.233 (0.223)	0.415** (0.185)	0.247 (0.167)	0.258 (0.167)	0.185 (0.194)	0.264 (0.179)	0.247 (0.167)	0.269 (0.169)	0.230 (0.190)	0.375** (0.176)
MKT-Rf	0.660*** (0.033)	0.666*** (0.033)	0.683*** (0.044)	0.710*** (0.036)	0.658*** (0.033)	0.669*** (0.035)	0.608*** (0.038)	0.680*** (0.037)	0.658*** (0.033)	0.663*** (0.033)	0.650*** (0.038)	0.683*** (0.035)
SMB	-0.286*** (0.087)	-0.301*** (0.087)	0.173 (0.117)	0.097 (0.096)	-0.282*** (0.089)	-0.288*** (0.089)	0.109 (0.103)	0.070 (0.095)	-0.282*** (0.089)	-0.298*** (0.091)	0.207 (0.101)	0.097 (0.095)
HML	-0.090 (0.069)	-0.030 (0.074)	-0.354*** (0.092)	-0.051 (0.082)	-0.070 (0.068)	-0.051 (0.071)	-0.172** (0.079)	-0.041 (0.076)	-0.071 (0.068)	-0.030 (0.081)	-0.426*** (0.078)	-0.149* (0.085)
WML	-0.116** (0.052)	-0.119** (0.052)	-0.216*** (0.070)	-0.232*** (0.057)	-0.166** (0.052)	-0.117** (0.052)	-0.236*** (0.060)	-0.241*** (0.056)	-0.117** (0.052)	-0.112** (0.052)	-0.285*** (0.059)	-0.253*** (0.055)
GMB	n/a	0.134** (0.064)	n/a	0.679*** (0.071)	n/a	0.063 (0.069)	n/a	0.435*** (0.073)	n/a	0.069 (0.075)	n/a	0.473*** (0.078)
# Observations	193	193	193	193	193	193	193	193	193	193	193	193
R2 adjusted	0.750	0.754	0.644	0.758	0.749	0.749	0.680	0.729	0.749	0.749	0.709	0.755

The table presents results for the model where the dependent variable are the stock returns, and the explanatory variables are the beta of the excess returns of each company to the market factors (MKT, SMB, HML, WML, as well as GMB). In Columns 2, 5, 9 regressions use the initial MSCI Europe full index and Columns 4, 8 and 12, use the Green portfolios are built using the 20% firms with less emissions. In Columns 3, 5, 7, 9 ,11, 13 regressions do not include the GMB factor. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance level.

Table 13. Results for 5 Factor Fama-French with and without GMB factor

	Scope 1,2 Intensity				***Scope 1,2,3 Intensity***				***Scope 1,2,3 Total***			
	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio	MSCI Europe Index	MSCI Europe Index	Green Portfolio	Green Portfolio
Constant	0.029 (0.170)	0.044 (0.170)	-0.108 (0.226)	0,028 (0.187)	0.029 (0.170)	0.044 (0.170)	-0.222 (0.199)	-0.133 (0.183)	0.030 (0.170)	0.055 (0.171)	-0.146 (0.198)	0.003 (0.180)
MKT-Rf	0.638*** (0.036)	0.649*** (0.037)	0.651*** (0.048)	0.695*** (0.040)	0.638*** (0.036)	0,649*** (0.037)	0.619*** (0.043)	0.682*** (0.040)	0.639*** (0.036)	0.645*** (0.037)	0.638*** (0.042)	0.675*** (0.039)
SMB	-0.294*** (0.091)	-0.303*** (0.092)	0.149 (0.121)	0.099 (0.099)	-0.294*** (0.091)	-0.303*** (0.092)	0.132 (0.107)	0.079 (0.099)	-0.293*** (0.092)	-0.311*** (0.093)	0.181* (0.107)	0.079 (0.098)
HML	0.344*** (0.113)	0.370*** (0.092)	0.317** (0.151)	0.607*** (0.128)	0.344*** (0.113)	0.370*** (0.116)	0.429*** (0.133)	0.591*** (0.125)	0.342*** (0.113)	0.389*** (0.120)	0.254* (0.132)	0.532*** (0.126)
RMW	0.478*** (0.163)	0.477*** (0.163)	0.702*** (0.218)	0.757*** (0.179)	0.478*** (0.163)	0.477*** (0.163)	0.766*** (0.191)	0.756*** (0.175)	0.477*** (0.163)	0.489*** (0.163)	0.652*** (0.189)	0.720*** (0.171)
CMA	-0.306** (0.149)	-0.319** (0.150)	-0.549*** (0.200)	-0.440*** (0.165)	-0.306** (0.149)	-0.319** (0.150)	-0.262 (0.175)	-0.342** (0.161)	-0.304** (0.149)	-0.290* (0.150)	-0.532*** (0.174)	-0.447*** (0.158)
GMB	n/a	0.071 (0.067)	n/a	0.667*** (0.070)	n/a	0.071 (0.067)	n/a	0.441*** (0.073)	n/a	0.086 (0.074)	n/a	0.510*** (0.077)
# Observations	193	193	193	193	193	193	193	193	193	193	193	193
R2 adjusted	0.758	0.758	0.658	0.768	0.758	0.758	0.684	0.735	0.758	0.758	0.706	0.760

This table presents the results for the model where the dependent variable are the stock returns, and the explanatory variables are the beta of the excess returns of each company to the market factors (MKT, SMB, HML, RMW, CMA as well as GMB). In Columns 2, 5, 9 regressions use the initial MSCI Europe full index and Columns 4, 8 and 12, use the Green portfolios are built using the 20% firms with less emissions. In Columns 3, 5, 7, 9 ,11, 13 regressions do not include the GMB factor. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance level.

Although the alphas in each of the models are higher when adding the GMB factor, the alphas are not significant. Therefore, I find no evidence of a green factor in Europe, as the alphas (constants) are statistically not significant, for any of the portfolios using the three different methodologies, Fama French 3 and 5 factors and Carhart models. This is a similar result to that found by Gorgen (2020) where there was no evidence of a risk premium associated with carbon risk. This may be due to a number of reasons. First, carbon risk may not be priced because investors are unable to adequately predict or quantify carbon risk (Gorgen, 2020), or because investors are not fully aware of the financial risks associated with it.

I would proceed to analyse the results of the betas of the factors. The market betas (MKT) are significant and close to 0.7 for all the portfolios, as this is the most significant factor to explain returns. The beta of the GMB factor is positive but much higher for the green portfolio than for the index. The GMB betas are all positive and the magnitude is lower for the MSCI Europe index at 0.1 than for the green portfolios at 0.5-0.6. It is important to highlight that the GMB in itself is statistically significant, showing that it is relevant to explain variation in returns, however this is not priced in my sample period through any alpha in the models.

The beta of the SMB factor is negative which makes sense as the MSCI Europe index is formed by large and medium companies, and SMB is an explanatory factor for small companies behaviour. The coefficient of the momentum factor (MOM) on Table 9, indicates a negative relationship between returns and the factor across the board. This negative momentum is increased as Scope 3 emissions are added, reaching a coefficient of -0.25 for portfolios ranked with Scope 1, 2 and 3 unscaled emissions. Finally, on Table 10, I expand the regression to other factors using the Fama French 5 factors model. The factors showing significance which is consistent across all the portfolios are MKT, HML & RMW factors.

The SMB and GMB are significant only for some of the portfolios but do not explain returns for all of them.

Taking all the 3 regression models together, I can draw some conclusions about patterns. My analysis finds that the MKT factor has a significantly higher relevance in explaining the excess return compared to the other factors. This is not surprising, as the MKT factor is essentially the market return itself and represents the overall market movement. As a result, the MKT factor captures a substantial portion of the variability in excess returns across different companies.

In terms of which asset pricing model works best, the Five-factor model outperforms the FF three- factor model on all metrics, followed by the four-factor model. The p-value for the intercept is >0.05 for all the portfolios under the Fama French 3 and 5 factors which means that the explanatory power of the intercept is not significant. As the p-value is not significant, the null hypothesis is not rejected, concluding that there is no green factor priced in European stocks.

However, as mentioned in the footnote in the 4 factor model using Momentum, the intercept shows significance for all portfolios using Scope 1, 2 and 3 Total emissions. This may be because aggregated emissions have an economic rationale for investors in the case of a potential carbon tax which would affect the largest emitters, while companies sorted by intensity are not affected (Bolton, 2020).

Table 11, 12 and 13 show, not surprisingly, that the excess returns on the market portfolio of stocks Rm-Rf, captures more common variation in stocks return than the other factors (Fama, 1993). In the context of asset pricing models, the Rm-Rf factor represents the excess return of the overall market portfolio (Rm) above the risk-free rate (Rf). It serves as a broad indicator of the general market movement and captures the systematic or common risk shared by most assets. This factor is particularly important because it reflects the performance of the entire market and thus includes a significant portion of the overall stock return variation. While other factors, such as size, value, and momentum, provide valuable insights into specific risk factors, the Rm-Rf factor captures the overarching systematic component that affects most stocks. Among the factors to show significance are also the SMB for the index portfolios. This could be because the size of the emissions and therefore the ranking under which the portfolios have been built, represents for the most part large companies in the case of brown portfolios. It is expected that for the biggest polluters, the larger the size of the company, the bigger the reported emissions. Next in relevance are the RMW and also the Momentum factor. Finally, in the case of the Fama French 5 factor model, the HML factor shows to be very significant to explain the returns.

I proceed to analyse the betas or the slopes coefficients to assess volatility to check for trends. In almost all the cases under the study using Scope 1,2 intensity or Scope 1.2,3 intensity and total, there is evidence that the brown portfolio has a slightly higher market beta (0.637; t=14.53 or 0.684; t=16.6 or 0.677; t=17.2), which means it is more risky than the green portfolio. This is also due to the fact that the green portfolio is more market neutral.

Also, there is another interesting fact as the market beta is larger for Scope 1,2 and 3 portfolios, both intensity and unscaled, than for Scope 1,2 Intensity stocks. As Scope 3 emissions account for the majority of a company's total carbon footprint, it makes sense that by including these emissions, a more accurate picture of the company's overall environmental impact is obtained, and those companies can experiment higher volatility during periods when preferences take hold among investors or there is the possibility of policy changes around carbon.

A key finding is that all the regressions regardless of the methodology used generates strong average slopes for the GMB factor but in opposite directions, the beta is positive if the portfolio is green (0.426; t= 7.62) and the beta is negative (-0.569; t=-10.3) if the portfolio is brown. In both cases the GMB has been found to be significant at the 1% level. A positive beta for a green portfolio and a negative beta for a brown portfolio can be justified by considering the growth potential, innovation, regulatory support, and changing consumer preferences in green industries, as well as the climate and regulatory risks, economic vulnerabilities, and reputational challenges faced by brown industries. These fundamental differences contribute to the varying levels of risk and return associated with each portfolio type, ultimately impacting their beta values.

Other factors showing evidence of strong coefficients with a positive sign are the RMW (0.724; t=4.18) and the HML (0.538; t=4.20) and with a negative sign the CMA (-0.480; t=-2.74) under the FF Five factor model. The RMW factor represents the difference in returns between companies with strong profitability (robust) and those with weak profitability. The positive coefficient for RMW indicates that companies with strong profitability have a positive impact on portfolio returns. This might be because well-managed and profitable companies are likely to generate better performance over time.

The HML factor reflects the difference in returns between companies with high book-to-market ratios (value stocks) and those with low book-to-market ratios (growth stocks). A positive coefficient suggests that value stocks tend to have higher returns. The positive coefficient for HML implies that investing in value stocks contributes positively to portfolio returns compared to growth stocks.

The CMA factor captures the difference in returns between companies with conservative investment policies and those with aggressive investment policies. The negative coefficient for CMA suggests that aggressive investment policies lead to better portfolio performance compared to conservative policies. The statistically significant t-values indicate that these relationships are likely not due to random chance and provide evidence for the model's explanatory power. Finally, the alphas are not statistically significant at conventional significance levels under the Fama French 3 and 5 factor models, and they tend to have low values in any case.

4.6 Results using different time periods

I have intended to test the influence of the period of study on the results, and I show the standard metrics of the Green and Brown portfolios using different time periods. On Table 13, the time period ends in December 2020 which is a date used in several academic papers to test for a Green Factor. On Table 14, I expand the analysis to include monthly returns for the European stock market until the end of 2022.

According to the table above and for the period until 2020, the Brown portfolio has a slightly lower sharpe ratio than the Green portfolio, as it exhibits higher returns but also higher volatility.

Table 14. Green and Brown Portfolios standard metrics for period 2007-2020

	Scope 1, 2 Intensity	Scope 1,2,3 Intensity	Scope 1,2, 3 Total
Green Ptf Mean returns annual	4.58%	3.24%	4.33%
Green Ptf Standard Deviation	1.45	1.34	1.34
Green Ptf Sharpe Ratio	0.032	0.024	0.032
Brown Ptf Mean Returns annual	4.55%	3.48%	4.81%
Brown Standard Deviation	1.58	1.69	1.57
Brown Sharpe Ratio	0.029	0.021	0.031

Table 14 shows the key metrics for the period 2007-2020 for the Green and Brown Portfolios built using the 20% firms with less emissions (and 20% with more emissions) respectively, Columns 2, 3, 4 show the results under for portfolios ranked using the Scope 1,2 Intensity and Scope 1,2,3 Intensity and Total emissions.

As we can see, the evidence gives us different results. The green portfolios have higher Sharpe ratios than brown ones until the end of 2020, and this is in alignment with most academic research. However, when I expand the period of analysis to cover returns until the end of 2022, the brown portfolios have higher Sharpe ratios than the green portfolios for all the methodologies.

Table 15. Green and Brown Portfolios standard metrics for period 2007-2022

	Scope 1, 2 Intensity	Scope 1,2,3 Intensity	Scope 1,2, 3 Total
Green Ptf Mean returns annual	3.65%	2.72%	3.27%
Green Ptf Standard Deviation	1.45	1.33	1.36
Green Ptf Sharpe Ratio	0.025	0.021	0.024
Brown Ptf Mean Returns annual	5.17%	3.70%	5.07%
Brown Standard Deviation	1.56	1.67	1.56
Brown Sharpe Ratio	0.033	0.022	0.032

This table shows the key metrics for the period 2007-2022 for the Green and Brown Portfolios built using the 20% firms with less emissions (and 20% with more emissions) respectively, Columns 2, 3, 4 show the results under for portfolios ranked using the Scope 1,2 Intensity and Scope 1,2,3 Intensity and Total emissions.

The Chow test allows us to test for whether or not the regression coefficients of each regression line are equal. If the test determines that the coefficients are not equal between the regression lines, this means there is significant evidence that a structural break exists in the data. In other words, the pattern in the data is significantly different before and after that structural break point. I split my sample data into two groups based on the Paris agreement date as a break point and fit the following standard linear regression models to each group. The standard F-test for the null hypothesis in the model is Ho: $\Delta\beta = 0$.

$$y_i = \alpha_i + \beta_i X_i + \ldots + \beta_k X_k + \varepsilon_i \; ; \; t = 1, \ldots, T$$

If I fail to reject the null hypothesis, it means that I do not have sufficient evidence to say that there is a structural break point in the data. In this case, the regression lines can be “pooled” into a single regression line that represents the pattern in the data sufficiently well. If the p-value associated with this test statistic is less than the 5% significance level, we can reject the null hypothesis and conclude that there is a structural break point in the data.

Table 16. Chow Test for split data sets: Before and after Paris agreement

Chow test statistic	P-value
Scope 1,2 Intensity	0.000
Scope 1,2,3 Intensity	0.439
Scope 1,2, 3 Total	0.034

This table shows the P-Values for the regressions for the two different data sets using Scope 1,2 Intensity and Scope 1,2,3 Intensity and Total emissions portfolios for the periods running from January 2007 until December 2015 and after from December 2015 until December 2022.

The results prove to be inconclusive. The p-value is below 0.05 for the Scope 1, 2 Intensity and Scope 1, 2 and 3 Total emissions portfolios, however it is above 0.05 for the portfolios sorted using Scope 1, 2 and 3 Intensity. Therefore, the evidence shows that it can not be implied that there is a breakpoint in the data, and the data set can be represented with a single regression line.

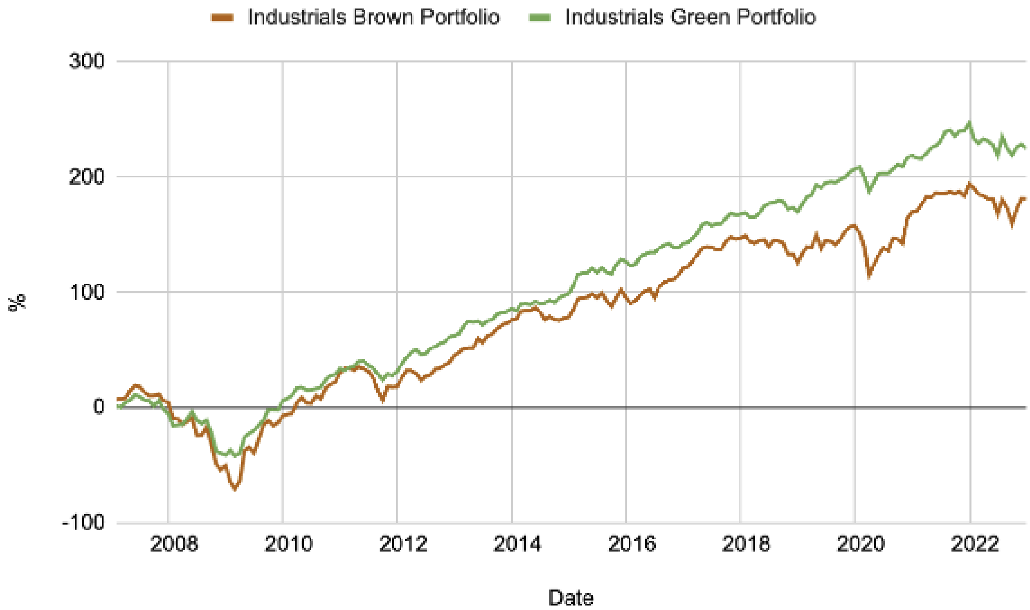
4.7 Robustness test: Industry analysis of the green factor

When analysing factors like the Green Minus Brown (GMB) factor, it's essential to consider potential variables that might explain the observed differences in returns, apart from the intended environmental factor (GHG emissions in this case). The observed difference in returns might be driven by the differing industry characteristics of green companies and polluter companies rather than their actual environmental practices. Certain industries might inherently perform differently due to market conditions, technological changes, or regulatory environments, regardless of their environmental impact. Some Industries with cyclical or counter-cyclical tendencies can significantly impact returns. If the green companies are concentrated in sectors that respond differently to economic cycles compared to polluter companies, this could drive the return differences.

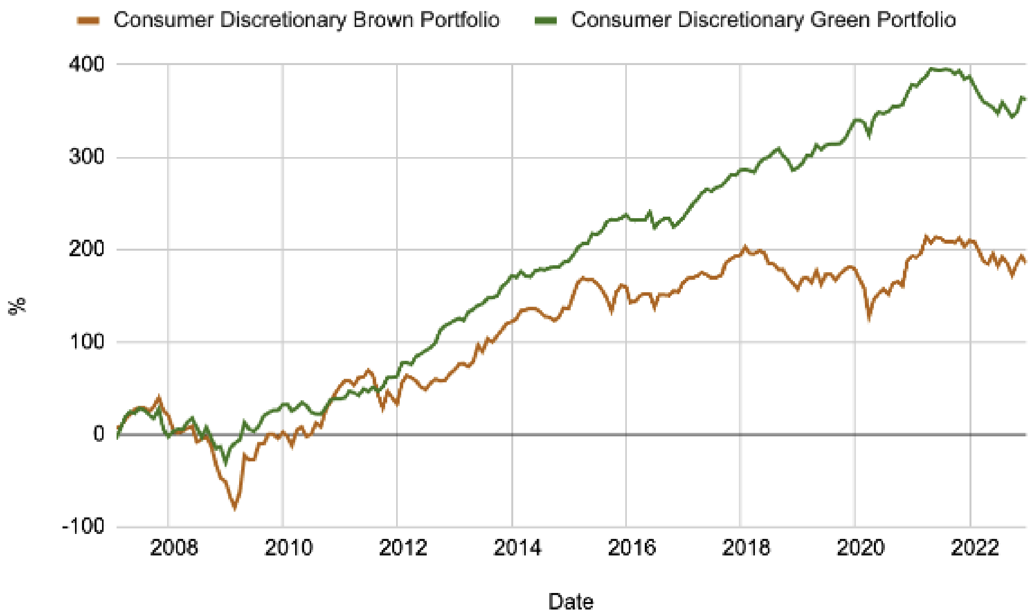
My selection of these two industries is because they are impacted differently by the inclusion of Scope 3 emissions. In the case of the Consumer Discretionary Sector, because the Autos sub sector has a very high ratio of Scope 3 emissions. However, this is not the case of the Industrial sector, which has a higher proportion of Scope 1 & 2 emissions. I expect that in industries where climate change is going to be a more material financial issue, that this would show increased pressure by consumers and investors to lower their carbon emissions because of upcoming climate regulation. The logic is that I should find evidence of a green premium for the low carbon emitters vs the more polluted peers within the same sector.

In order to perform this analysis, I build brown and green portfolios for both the industrial and for the Consumer discretionary sectors ranked by quintiles, using the latest level of carbon emissions available as of December 2021. Then, for each sector, I take the quintile formed by the lowest emission companies to build the green portfolios and the quintile with the highest emitters to create the brown portfolios. It is important to highlight that for this analysis, and similar to other studies (Gimeno, 2022), the companies of the portfolio do not change each year based on their emissions, and the portfolios´ constituents remain static during the 15 year period. In the case of the Industry sector, the Brown and Green portfolios are formed by 15 and 16 companies respectively. For the Consumer Discretionary sector, there are 10 companies for the Brown and Green portfolios each.

Figure 8. Returns on Green and Brown Sector Portfolios on Scope 1, 2, 3 Total



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 224.60 and 181.31, implying green stocks outperformed brown by (224.60-181.31) × 100 = 43.29 percentage points over this period.



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 62.7 and 85.31, implying brown stocks outperformed green by (85.31− 62.7) × 100 = 22.61 percentage points over this period.

In the following tables, I perform a correlation analysis of the GMB factor against the other factors. Table 17 reports a strong negative correlation with the HML factor proposed by Fama French for the industrial sector at -0-62 and for the consumer discretionary sector a bit lower at -0.48. This is an interesting result, as it indicates that the GMB factor has a strong opposite relationship with the value factor. This is not surprising since greener companies often embrace innovation and develop new technologies or solutions to address environmental challenges. In my empirical study, most of the companies in the green portfolios are technology companies, and tech stocks are the flagship growth stocks. The GMB factor also shows a positive moderate correlation with the momentum factor at 0.52. Media attention on climate-related issues and growing investor focus on sustainability has contributed to heightened demand for green stocks, which explains the correlation between the GMB and MOM factors during the period of my study.

Table 17. Correlation coefficients for the Industrial sector

	GMB-RF	*Mkt-RF*	*SMB*	*HML*	*RMW*	*CMA*	*WML*
GMB-RF	1.00						
Mkt-RF	-0.52	1.00					
SMB	0.04	0.07	1.00				
HML	-0.62	0.37	-0.04	1.00			
RMW	0.43	-0.27	-0.04	-0.80	1.00		
CMA	-0.20	-0.24	-0.26	0.53	-0.44	1.00	
WML	0.52	-0.49	-0.04	-0.53	0.39	0.04	1.00

Correlations of GMB factor for the Industrial sector for Scope 1, 2 & 3 Total emissions portfolios. The table examines the sample period from January 2007 to December 2022.

Table 18. Correlation coefficients for the Consumer Discretionary sector

	GMB-RF	*Mkt-RF*	*SMB*	*HML*	*RMW*	*CMA*	*WML*
GMB-RF	1.00						
Mkt-RF	-0.50	1.00					
SMB	0.22	0.07	1.00				
HML	-0.48	0.37	-0.04	1.00			
RMW	0.31	-0.27	-0.04	-0.80	1.00		
CMA	-0.11	-0.24	-0.26	0.53	-0.44	1.00	
WML	0.33	-0.49	-0.04	-0.53	0.39	0.04	1.00

Correlations of GMB factor for the Consumer Discretionary sector for Scope 1, 2 & 3 Total emissions portfolios. The table examines the sample period from January 2007 to December 2022.

Table 19. GMB explained by other market factors

	Constant	MKT	SMB	HML	MOM	RMW	CMA	R2
Scope 1, 2 Intensity Industrial	0.161 (0.207)	-0.056 (-1.285)	0.056 (0.514)	-0.407*** (-2.725)	0.104 (1.607)	-0.358* (-1.846)	-0.140 (-0.749)	0.200
Scope 1,2,3 Intensity Industrial	0.261 (0.234)	-0.238*** (-4.753)	-0.214* (-1.731)	-0.540*** (-3.189)	-0.015 (-0.231)	-0.463** (-2.109)	0.320 (1.506)	0.322
Scope 1,2,3 Total Industrial	0.138 (0.596)	-0.236*** (-4.776)	0.066 (0.542)	-0.657*** (-3.932)	0.184** (2.545)	-0.307 (-1.416)	-0.234 (-1.117)	0.492
Scope 1, 2 Intensity Consumer D	0.624* (0.352)	-0.250*** (-3.319)	0.038 (0.208)	-0.756*** (-2.968)	-0.269** (-2.445)	-0.521 (-1.578)	-0.268 (-0.838)	0.388
Scope 1,2,3 Intensity Consumer D	0.827* (0.426)	-0.388*** (0.091)	0.466** (0.225)	-1.470*** (0.307)	-0.246* (0.133)	-0.689* (0.399)	0.484 (0.386)	0.341
Scope 1,2,3 Total Consumer D	1.098** (0.503)	-0.545*** (-5.073)	1.049*** (3.943)	-1.399*** (-3.849)	-0.120 (-0.766)	-0.578 (-1.224)	0.340 (0.746)	0.408

Note: Regression of the log return of the GMB factor on the log returns of the other market factors (i.e., MKT (market excess return); the Fama & French (1993) SMB (small minus big) and HML (high minus low); the Carhart (1997) WML (winners minus losers); the Fama and French (2015) RMW (robust minus weak) and the CMA (conservative minus aggressive). Rows 2,3,4 represent the models for the Industrial sector using Scope1,2 Intensity and Scope 1,2, 3 Intensity and Total emissions portfolios. Rows 5,6,7 represent the models for the Consumer Discretionary sector using Scope 1,2 Intensity and Scope 1,2, 3 Intensity and Total emissions portfolios. Robust standard errors in parenthesis. ***, **., * is the 1%, 5% and 10% significance level,

As the Table 19 above shows, the constant is statistically significant only for the Consumer Discretionary sector, meaning that there is alpha, however the alpha is not significant for the Industry sector. I find that for companies within the same sector, holding other things equal, that companies with lower levels of carbon emissions tend to exhibit higher returns. This green premium is economically, as well as statistically significant, with annualised increases in stock returns for the Consumer Discretionary sector of +7.48%, +9.92% and +13.17% for Scope 1, 2 Intensity, Scope 1, 2, 3, Intensity and Scope 1, 2, 3 Total Portfolios respectively.

This large green premium cannot be observed for the European industrials sector. One of the reasons is because the industrial sector alone is responsible for over 20% of the EU emissions, and many facilities in this sector are included in the EU ETS. This suggests that there is an implied carbon price that has been steadily rising over the sample period, from nearly zero to €84 per ton, which in turn reduces their profit margin for these industrial firms (Bolton, 2022). Also the fact that the Consumer Discretionary sector is not part of the EU ETS system could be a reason for the differences. For those sectors which are already regulated, the inefficiencies in prices tend to be smaller, this is a similar experience to the behaviour of developed markets stocks vs those in emerging markets.

Finally, another highlight from the table is that the HML factor has explanatory power over the GMB factor as it is statistically significant at the 1% level across all the portfolios. The sign of the coefficient is negative which shows that the GMB factor is not related with value stocks, but with growth stocks.

Different industries have varying levels of scope 3 emissions based on their supply chain complexities, energy consumption, waste generation, and transportation practices. Even within the same sector, the intensity of scope 3 emissions can vary significantly based on factors such as production methods, geographic locations, technological advancements, and sustainability initiatives. Sectors like manufacturing, transportation, and energy are often associated with substantial scope 3 emissions due to the nature of their operations and value chains.

Companies with innovative approaches, efficient supply chains, and cleaner energy sources may have lower scope 3 emissions intensity compared to their peers. As Table 1 shows, those companies within the same industry that effectively manage scope 3 emissions better than their peers often have a competitive advantage in the market which helps to attract investors and deliver outperformance over the long term. Companies that incorporate environmental considerations into their strategies are more likely to thrive in a world where sustainable practices are becoming increasingly critical for long-term success.

For the standard deviation, the pattern shows that Scope 3 emissions add considerable volatility to each of the portfolios, and that the highest level of risk corresponds to the portfolios sorted on Scope 1,2 & 3 Total emissions. The automobiles industry within the consumer discretionary sector has a complex and extensive supply chain that involves numerous suppliers providing components, materials, and services, and often have a large scope 3 emissions footprint. The emissions from internal combustion engine vehicles release CO_2 and other pollutants directly into the atmosphere during operation. This makes vehicle usage a major contributor to scope 3 emissions.

I run a regression on the portfolios on the FF three factors for both the Industry sector and the Consumer Discretionary sector. For each of the methodologies, I find that the constants (alpha) are positive with the highest level at 0.823 and 1.232 each for the Industrial sector and Consumer Discretionary sectors, and that the constants are also significant with a t-statistic of 4.06 and 3.69 for the Green and Brown portfolio respectively ranked using Scope 1,2 and 3 Total emissions. This means that there is alpha and is statistically significant, therefore the GMB has explanatory power. This result by Sector is different to the regression done previously for the European market as a whole, as the alpha was not significant. Regarding the factor coefficients or betas, not surprisingly the market beta is again strongly positive and significant for every methodology used whether Scope 1, 2 and Scope 1,2 and 3 intensity and also by unscaled emissions, reaching a high of 0.842 and 0.916 for the brown portfolio under

Scope 1, 2 Intensity.

Following this, the GMB factor has the highest beta and is also significant for all the portfolios across the different methodologies. The t-statistic for the GMB factor is -11.01, -8.99 and -4.96 for the Industrial and -11.14, -10.12 and -5.93 for the Consumer Discretionary sector´s brown portfolios respectively, which proves that the GMB factor has strong explanatory power. The t-statistic is negative which indicates a reversal in the directionality of the GMB effect and it is higher than those for the green portfolios. The economic rationale is that the emissions have more impact on the outperformance of more polluted companies versus the less brown ones within a sector, implying a higher carbon risk premium for those companies more exposed to climate risk. Finally, the size factor also shows to be significant for all the portfolios but with less beta than the market factor and the GMB factor.

On Table 22 and 23 in the appendix, I adjust for the FF five factors and Momentum. The constant is positive and highly significant for all the portfolios at the 5% significance level, but in the case of and Scope 1,2 & 3 Total Emissions ranked portfolios, the constant shows also significance at the 1% level with t-statistics for the Green and Brown portfolios respectively are 3.56 & 3.21 in the Industry sector and 3.33 & 3.02 in the Consumer Discretionary sector.

Another interesting finding is that the value of the constant increases for the portfolios when Scope 3 is included in both sectors under analysis. In particular, the coefficient is highly positive for Scope 1, 2 and 3 Total emissions, with a value of 1.139 and 1.070 for the portfolios in the Consumer discretionary sector (there is alpha). This means that the portfolios seem to be highly and positively sensitive to Scope 3 emissions and that the companies in the

Consumer Discretionary sector are more influenced by those emissions than those companies in the Industry sector. This is in contrast with the empirical results for the dataset of the overall market in Europe which did not show significance for any of the portfolios and it was significantly lower in value. Regarding the values of the slopes of the coefficients, or the betas in the regression, there are only two factors which are significant at the 1% level for all the portfolios independent of the methodology used in the regression: the MKT factor and the GMB factor. In terms of sensitivity, portfolios have the highest sensitivity to the market beta with a value near or above 0.750 for some of the portfolios.

With regards to the GMB factor with values for the coefficient around 0.628 and -0.693 for green and brown portfolios respectively, there is consistency here with the empirical results for the European overall market as green portfolios are always positively sensitive to the GMB factor, while the brown portfolios are negatively correlated to the GMB factor. A negative beta coefficient indicates that there is a negative linear relationship between the variables. The negative sign indicates that the relationship is inverse: as the GMB factor increases, the performance of the brown portfolios is expected to decrease by an amount equal to the absolute value of the beta coefficient.

The other factor to be significant in this case at the 5% level is the profitability factor (RMW) and the beta values for the coefficient move between 0.654 and 0.827 which means that the performance of all the portfolios is highly sensitive to profitability and that the relationship is positive. Stock returns being positively correlated with profitability is a fundamental principle in finance and can be justified as strong profitability reflects effective management, operational efficiency, and the ability to generate value for shareholders. Finally, the momentum factor shows significance at least at the 10% level for all the portfolios, and for some of them at the 1% significance level.

Looking at the mean returns, one sees that for both the Industrial and consumer discretionary portfolios, green stocks outperform the brown ones within each sector. The outperformance is striking for the relative performance within the Consumer Discretionary sector, and in particular when Scope 3 emissions are included on an unscaled basis with an alpha of 11.1%. Interestingly, the mean average returns increase by 74% when incorporating Scope 3 emissions. The evidence on this analysis proves that more sustainable companies within the same sector outperform their more polluted peers. The economic rationale for this is based on the assumption of higher financial costs of climate transition risk from an explicit carbon tax or an implicit "tax" resulting from increased costs of releasing CO_2 into the atmosphere.

Conclusion

5.1 Main findings of the study

As the field of Sustainable investing moves into the next stage of its evolution and adopts a more forward-looking approach, there is an increasing emphasis on determining how to measure its effects, and how to quantify their environmental impact. Investors are aiming for clearer guidance on how to prioritise metrics that are effective in assessing the progress of climate transition[13]. My primary aim in this context is to contribute to the growing research on climate finance that seeks to find the connections between stock returns and the carbon emissions of companies.

This study presents one of the first attempts to conduct a comprehensive 15-year analysis of returns on the MSCI Europe, uniquely incorporating Scope 3 emissions as a critical factor within the assessment. This has allowed me to expand the scientific knowledge of the GMB factor beyond prior studies done on Europe (Alessi, 2021; Gimeno, 2022) which focused more on Scope 1 and 2 emissions only, and also from research using other metrics to measure Greenness, such as the "E" scores from rating agencies.

In what follows, I summarise the key findings of this thesis. First, reported results demonstrate that there is currently no green factor priced in by the financial markets in Europe. I show that the GMB factor is not associated with a statistically significant monthly alpha. The period of study vastly influences the results. Previous studies only covered one cycle in the market. While the period covering 2010-2021 has been positive for sustainable

[13] "GS Sustain: ESG of the Future". 17 November 2022.

investments in Europe as other prior studies have shown, reported findings showed that there is no “green” alpha when the period of study is expanded until the end of 2022 to take into account the energy crisis, and when the analysis is done for the broader index. One possible explanation is that other explanatory variables are correlated with GMB. In the correlation analysis among factors, I report evidence showing that HML factor is moderately correlated negatively with the GMB factor. The HML factor represents the “value” style of investing, and since the sign is negative, it indicates that the GMB factor is correlated to “growth” stocks. This relationship is justified given that the green portfolios are for the most part a combination of technology and healthcare stocks which tend to do well when interest rates are low, as it has been during 2010-2021, which favoured growth stocks in detriment of value stocks.

In the aftermath of the Global Financial Crisis, the financial landscape was dominated by a monetary policy of zero interest rates, which created bubbles around certain assets. This is because extended periods of low interest rates helped growth stocks - which tend to have longer-term cash flow horizons than value stocks - to overshoot. This is what happened to the “glamour stocks"[14], while the so-called “old economy”[15] stocks performed very poorly, and those are the stocks that constituted the brown portfolios. To put in perspective, long term cash flows are now being discounted at over 5%, while before 2020 they used to be discounted below 1%.

The second finding from my research is that there is evidence of a positive relationship between a company's greenhouse emissions and perceived risk. The brown portfolios are always more volatile than the green portfolios, and interestingly the level of absolute risk

[14] Robert F. Engle, ICADE presentation, May 2023.
[15] Jeff Currie, Financial Times´s “The Revenge of the Old Economy” article. October 2021.

grows when Scope 3 emissions are included, i.e: the evidence for the largest volatility spread is found for the Scope 1,2,3 Intensity emissions ranked portfolios where the Brown portfolios exhibit a standard deviation of 20% compared to 15.9% for the Green portfolios. Therefore, we can say that the higher returns of the brown counterparts reflect also a higher risk, and the green portfolios have been slightly less volatile than the brown ones in Europe over the past 15 years on average.

This is in line with the CAPM predictions and with research about the contribution of green investments as a “hedge” in client portfolios. In theory, if green assets offer benefits such as acting as a hedge against climate risk and are seen as less risky due to their climate-resilient nature or perceived positive societal impacts, investors may be willing to accept lower expected returns for holding such assets in their portfolios. If investors demand green assets solely for environmental reasons and avoid brown assets, this could lead to a potential "carbon aversion premium” (Bauer, 2023). In other words, the increased demand for green assets would bid up their prices, reducing their expected returns. On the other hand, brown assets may carry higher risk due to factors like potential regulatory changes, or the need to transition away from carbon-intensive practices. Investors may, therefore, demand a higher expected return to compensate for the perceived higher risk associated with these assets.

As a third and important finding, the Scope 3 emissions effect in the construction of the green factor is highly relevant. The evidence shows that the regression analysis exhibits their highest explanatory capacity when they incorporate Scope 3 emissions. The adjusted R2 of GMB factor was 0.353 for Scope 1, 2 and 3 Total emissions compared to 0.235 for Scope 1, 2 Intensity and 0.272 for Scope 1, 2 and 3 Intensity. Reported findings therefore suggest that Scope 3 emissions capture a broader and more comprehensive view of a company's environmental impact, including those associated with its supply chain, customer use, and end-of-life emissions. By incorporating these emissions into the analysis, the models are better equipped to capture the full extent of a company's sustainability performance. Note that including Scope 3 emissions is going to become more relevant now as new regulatory developments and reporting standards are going to require companies to disclose Scope 3 emissions from 2024.

The fourth and most important contribution is that reported results showed that carbon premia is present in the Consumer Discretionary industry, but not in the Industrials sector in Europe. The evidence showed that the alpha is significant for the Consumer Discretionary sector when companies are selected versus their peers on a relative basis to account for their emissions. The GMB factor based on carbon emissions had very large positive and significant abnormal returns as measured by alpha at +13% for Scope 1,2,3 Total emissions in the Consumer Discretionary sector. However, that green premium was lower at +1.6% and not statistically significant for the Industrial sector.

The fact that Industrials are an important part of the EU ETS mechanism is a reason for this significant gap in alpha, suggesting that regulated sectors will see less pricing inefficiencies, and the opposite holds true too, i.e: a sudden change such as a new “carbon tax” could impose huge repricing for other sectors currently outside the EU ETS. Different industries exhibit different demand “price elasticity” as carbon emissions start to become priced, and companies have to either absorb these costs, the margin of those firms will decrease, or those companies will pass those costs to their customers, making their products more expensive and reducing their demand in the market. Based on prior research studies (Cheema-Fox, 2020), Consumer Services have a high demand price elasticity.

The following implications arise from the reported research findings. To begin, climate research studies have been focused on asking the question on whether there is “alpha” in green stocks, rather than whether they are less risky. I have shown that on average, green stocks seem to be less risky and deliver fewer risk premia than brown stocks over the past 15 years. The case for holding green investments based on their “alpha” component is not currently confirmed at the sector aggregate level, and it should be seen more as an option into the future, as the effects of climate change are difficult to capture in a backward-looking regression.

Next, these factors models have been under the assumption that there will be a change in policy by governments around the world, i.e: a carbon tax, and that by charging firms for their GHG emissions, the economy could most efficiently reallocate resources and consumption to mitigate climate change. There has been talks about carbon taxes as an efficient policy tool to solve climate issues but it is all based upon future assumptions of what is likely to happen. However, no changes in climate change policy have happened yet during this period for the impact to be visible in the financial returns. It is therefore up to the private investors and capital markets to do it on their own. What can the private sector do if the government does not act? They could be an agent of change through changes in demand, i.e: buying EV, investing in green stocks etc. The key question is at which cost for returns? Which is the right trade off?[16]

The other fundamental question is whether the EU Taxonomy is facilitating transition finance successfully for European companies and how it can further mobilise private sector engagement.

[16] Robert Engle´s presentation during the Climate Finance Conference held in ICADE. 9th May 2023.

The idea of "doing well by doing good" in ESG (Environmental, Social, and Governance) investing refers to the potential for achieving both financial gain and a positive social or environmental impact through investment choices. However, the combination of financial gain and a social mission can be challenging to reconcile with a simple asset pricing model. In traditional asset pricing models like the Capital Asset Pricing Model (CAPM), expected returns are determined based on the risk and return trade-off. Higher-risk assets are expected to have higher returns to compensate investors for taking on greater risk. However, financial markets are complex and influenced by various factors, including investor sentiment, market dynamics, and changes in regulatory and policy environments. Consequently, the relationship between risk and expected returns is not always straightforward. In this scenario, the traditional asset pricing model would not fully capture the complexities of investor preferences and the social mission aspect of ESG investing. The simple risk-return trade-off may not fully explain the valuation differences between green and brown assets.

From the perspective of investors, investing in firms with heavy pollution is risky because their profitability and stock prices are more negatively affected upon a regime shift from weak to strong emission regulation policy, so investors require higher expected stock returns as risk compensation. In summary, the carbon risk premium compensates investors for uncertainty about whether the strong regulation would be implemented in the future, Hsu et al (2023). As Robert Engle mentioned at the ICADE Climate Conference, the risk for fossil fuel companies is twofold: the “termination risk” may have been pushed out but it will come to an end, and they will be left only with stranded assets; and “client demand” which is currently high, but not in the future as renewables will be more important. Additionally, lowering exposure to climate risk has several implications in the future for investors. First, conservative investors will aim to reduce transition risk by hedging their exposure to it. Next, investors will request higher returns as compensation for holding this risk. Last, investors will engage with companies to persuade them to lower this risk if they are not adequately compensated for it.

For corporates on the other hand, the main consequence of transition risk management is that those with significant more exposure to climate change risk will have a higher cost of capital, implying both lower price multiples on their future earnings and higher break even rates on new investment, causing investors to reduce capital allocation to those companies and for those industries to shrink (Bolton, 2022). In conclusion, the risk management underlying theme at the core of climate finance, sets a positive relation between GHG emissions and stock returns, or in other words, it establishes a negative relation between emissions and company valuations.

Investors cannot solve this global problem on their own. The market cannot self-regulate this externality. The argument is that things will get worse without implementing carbon reduction actions. The complexity of the task lies in the fact that tackling climate change is an example of a "Tragic of the Commons" (Harding, 1968) on a global scale, and represents a global "Social Dilemma" (Kollock, 1998)[17]. This is because the costs associated with cuts in emissions are very high for countries or companies to do on their own, while the benefits are shared globally and also will materialise in the long term. Addressing climate change is a collective responsibility. No single country possesses the capacity to resolve this global challenge in isolation. Policymakers must accelerate and coordinate their efforts to ensure harmonised global incentives to reduce emissions.

[17] A defining feature of a social dilemma situation is that everyone is better off when they cooperate towards the common goal, however on an individual level, each agent on a rational level would personally benefit more by defecting from the cooperative behaviour, regardless of the choices made by others in the group. The famous "Prisoner´s Dilemma" is a classic example of this conflict of interest.

Meanwhile, according to the latest IMF update, governments provided $7 trillion of subsidies to support the use of fossil fuels in 2022 alone. These subsidies include both explicit government payments to reduce energy prices and the implicit subsidies that arise from not recognizing the damage from burning fossil fuels. These enormous subsidies reduce fossil fuel prices and lower the expected returns to low carbon investments. Decarbonization requires strong, globally harmonised, credible incentives to reduce carbon emissions. One of the solutions to decarbonizing the global economy is the rapid elimination of these fossil fuel subsidies and the institution of appropriate incentives to reduce pollution.

Given the level of noise and lack of attention to Scope 3 measurement, significant progress will have to be made over the next 3 to 5 years by companies in Europe to accurately measure these emissions. Investors are recognizing that companies with strong environmental practices are more likely to be sustainable in the long term. Such companies are better positioned to navigate changing regulations, consumer preferences, and evolving market dynamics, making them attractive investments.

Climate scientists warned us about the current climate disaster more than three decades ago. Unfortunately, the world has not made much progress towards Net Zero. While Scope 3 emissions disclosures are important, disclosing in itself is not enough if it does not incur changes in behaviour from all the stakeholders[18]. Changing norms does not necessarily change behaviour. We have to pave the way for investors to flow capital in vast amounts into sustainable investments. The market is always very forward looking, and there is currently not a strong global governance structure around climate change. Investors will not be able to solve the climate problem by themselves unless incentives to reduce emissions are created

[18] Robert B. Litterman. Personal conversation by Video Conference. 16th November 2023.

and there is enough visibility about their future stability regardless of the political party in power. Such policies are needed to attract entrepreneurs, clean-technology capital, and to dramatically scale low-carbon investments.

Given the complexity of the task ahead, we need to build a transition phase where there is a balanced view about the priorities: what has worked well and what needs to change. On the positive side, there has been more incentives in Europe to decarbonize than in any other region in the world. European green policies like the ETS and now the Carbon border adjustment is a powerful policy which will likely force other countries to follow. On the other hand, the European Financial directive has been very costly for financial firms so far to implement, and it has been seen by some as lacking clarity, mandating some exclusions and limiting asset manager flexibility. On top of the costs, financial companies have not seen demand from clients because those investments have not been profitable, as shown on this thesis, creating scepticism. Is this the right way to do it? We need incentives rather than prohibitions. As Aristotle famously said, “in the middle ground is virtue”.

5.2. Limitations of the study

The main limitations of my research are derived from the data gaps on the disclosure of emissions by companies in Europe which results in a short time period subject of analysis. Many companies have started reporting their carbon footprints only in recent years, and historical data is simply not available. This lack of historical data makes it challenging to track changes in emissions over a longer period of time. I have only been able to gather data from 2006 on emissions where at least 68% of companies were a significant number.

The implications are that it will be almost impossible for a study on carbon emissions to be earlier than the mid 2000s, as the lack of emissions data make it difficult to build portfolios ranked on that metric. Fifteen years is not enough time to establish whether a factor has explanatory power to explain the cross section of returns. Other factors like Fama French or Carhart use longer periods such as 45 years to decide whether a factor has explanatory power. The availability of emissions data is a recent development and therefore, it makes it difficult for any study to go beyond the 12 or 15 year mark. This issue is going to be resolved in the future as companies now face greater pressure to disclose and manage their emissions, leading to more comprehensive reporting. A few factors may have influenced the findings like the reference period (i.e., before the implementation of material regulations and directives in Europe) and the length of the observation period of those returns. A lot of the academic evidence in favour of low-carbon investing has been based on an incomplete sample of data spanning approximately 2012-2020, due to data availability. As new studies come out, including in the last two years, some of the relationships have started to break down. We need scope with long historic series. It is too early to conclude anything and it will be interesting to see how the academic literature evolves from here.

As we move closer to 2030, it is evident that climate change poses a large aggregate risk to the economy and the financial system (Litterman et al. 2020). Measuring carbon emissions is likely to be critical either as a basis for carbon taxes, or for regulatory efforts to rein in emissions, or for giving investors the opportunity to create a “shadow carbon price”, in which high emitters are penalised by the market. An escalating emphasis by investors may gradually result in higher valuations over the long term for companies at the forefront of corporate decarbonization, who at the same time exhibit favourable financial performance. I believe that investors will continue to look with companies with strong fundamentals but they will increasingly favour those companies within a sector with lower or declining carbon footprint metrics among their peers. Investors should consider both financial and climate metrics in seeking companies that exhibit profitability and quality business metrics, all while maintaining the lowest or most substantial reduction in environmental footprint compared to their industry counterparts.

5.3 Futures areas of research

This paper´s findings open up exciting opportunities for future research. An interesting follow up to my thesis would be to do a similar study on the fixed income market in Europe. Notably, the size of the bond markets is considerably larger than the equity market, making this investigation even more relevant and impactful. Given the recent trend from investors on "improvers", this same study could be done on the evolution of the carbon emissions by a company over the years to see whether investors are rewarding their efforts to decarbonize, and whether this is already embedded in the price. Another promising avenue is expanding research on modelling the impact of different carbon prices scenarios and their effect on different sectors of the economy. Finally, private markets have grown exponentially and this is where the action is in financial markets at present. Many companies are staying in the private domain for longer, therefore more academic research done on the topic of carbon emissions on companies owned by private market sponsors, both on the equity and the debt side, will be highly valuable as a contribution to the academic world.

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APPENDIX: TABLES & GRAPHS

Table 20. Five Factors Fama French with Momentum for Industry sector

	Scope 1,2 Intensity		***Scope 1,2,3 Intensity***		***Scope 1,2,3 Total***	
	Green Ptf	Brown Ptf	Green Ptf	Brown Ptf	Green Ptf	Brown Ptf
Constant	0.592** (0.239)	0.522** (0.240)	0.662*** (0.243)	0.590** (0.244)	0.742*** (0.208)	0.672*** (0.209)
MKT-Rf	0.748*** (0.051)	0.749*** (0.051)	0.692*** (0.054)	0.695*** (0.055)	0.672*** (0.047)	0.673*** (0.047)
SMB	0.337*** (0.126)	0.347*** (0.126)	0.304** (0.129)	0.316** (0.129)	0.333*** (0.110)	0.343*** (0.110)
HML	0.260 (0.176)	0.258 (0.176)	0.118 (0.179)	0.119 (0.180)	-0.108 (0.156)	-0.109 (0.157)
GMB	0.628*** (0.084)	-0.371*** (0.085)	0.341*** (0.075)	-0.651*** (0.076)	0.304*** (0.066)	-0.693*** (0.066)
RMW	0.724*** (0.226)	0.726*** (0.226)	0.774*** (0.229)	0.779*** (0.231)	0.654*** (0.195)	0.656*** (0.197)
CMA	-0-226 (0.217)	-0.223 (0.217)	-0.284 (0.221)	-0.284 (0.222)	-0.049 (0.189)	-0.046 (0.190)
WML	-0.254*** (0.075)	-0.257*** (0.075)	-0.195** (0.075)	-0.198** (0.076)	-0.220*** (0.066)	-0.222*** (0.066)
# Observations	193	193	193	193	193	193
R2 adjusted	0.716	0.757	0.622	0.790	0.671	0.834

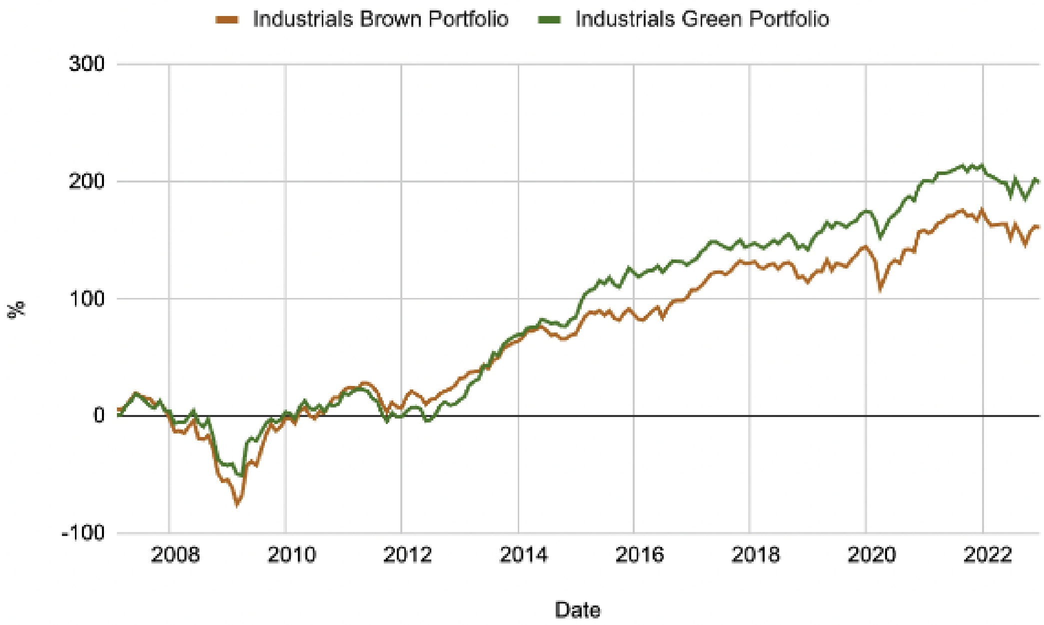
This table presents the results for the model where the dependent variable are the stock returns, and the explanatory variables are the beta of the excess returns of each company to the market factors (MKT, SMB, HML, RMW, CMA, WML as well as GMB). In Columns 2, 5, 9 regressions on the Green portfolios are built using the 20% firms with less emissions, in Columns 3, 5, 7, regressions on the Brown portfolios are built using the 20% firms with more emissions. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance level.

Table 21. Five Factors Fama French with Momentum - Consumer Discretionary sector

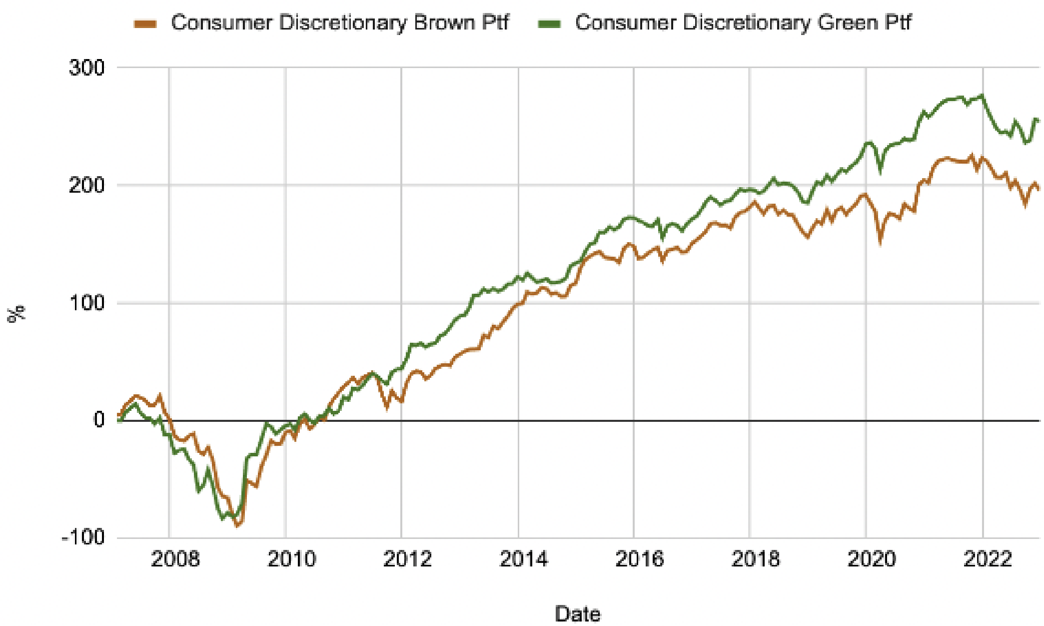
	Scope 1,2 Intensity		***Scope 1,2,3 Intensity***		***Scope 1,2,3 Total***	
	Green Ptf	Brown Ptf	Green Ptf	Brown Ptf	Green Ptf	Brown Ptf
Constant	0.944*** (0.309)	0.874*** (0.310)	0.996*** (0.332)	0.926*** (0.333)	1.139*** (0.353)	1.070*** (0.353)
MKT-Rf	0.752*** (0.067)	0.753*** (0.067)	0.702*** (0.073)	0.703*** (0.073)	0.640*** (0.079)	0.641*** (0.079)
SMB	0.432*** (0.162)	0.442*** (0.162)	0.441** (0.175)	0.451** (0.176)	0.635*** (0.191)	0.646*** (0.191)
HML	0.318 (0.226)	0.317 (0.227)	0.302 (0.251)	0.301 (0.252)	0.583** (0.261)	0.579** (0.261)
GMB	0.552** (0.063)	-0.446*** (0.064)	0.399*** (0.056)	-0.599*** (0.056)	0.420*** (0.050)	-0.580*** (0.050)
RMW	0.673** (0.289)	0.676** (0.290)	0.643** (0.310)	0.646** (0.311)	0.826** (0.328)	0.827** (0.328)
CMA	-0.421 (0.278)	-0.418 (0.279)	-0.365 (0.299)	-0.362 (0.300)	-0.764** (0.316)	-0.761** (0.316)
WML	-0.386*** (0.097)	-0.388*** (0.097)	-0.350*** (0.103)	-0.352*** (0.104)	-0.208* (0.109)	-0.211* (0.109)
# Observations	193	193	193	193	193	193
R2 adjusted	0.674	0.728	0.555	0.773	0.536	0.774

This table presents the results for the model where the dependent variable are the stock returns, and the explanatory variables are the beta of the excess returns of each company to the market factors (MKT, SMB, HML, RMW, CMA, WML as well as GMB). Columns 2, 5, 9 regressions use the initial MSCI Europe full index and Columns 4, 8 and 12, use the Green portfolios and are built using the 20% firms with less emissions. In Columns 3, 5, 7, 9 ,11, 13 regressions do not include the GMB factor. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance level.

Figure 6. Returns on Green and Brown Sector Portfolios on Scope 1, 2 Intensity



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 199.37 and 161.12, implying green stocks outperformed brown by (199.37− 162.12) × 100 = 38.25 percentage points over this period.



Note: This figure plots the green and brown portfolios' cumulative returns for the 2007-2022 period. The values of the green and brown lines at the end of 2022 are 196.32 and 255.12, implying green stocks outperformed brown by (255.12− 196.32) × 100 = 58.80 percentage points over this period.