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The pricing mechanism of green bonds and the determinants of the green bond premium.

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ABSTRACT:

Investors have been reallocating their capital toward sustainable investments and green assets as a new investment strategy. However, a fundamental question still remains: are fixed-income investors willing to accept lower returns when investing in green assets, and what driver this capital shift?

This report delves into the concept of "greenium" and its determinants. Using post-issuance data from the European corporate bond markets spanning from January 2018 to October 2023, I empirically investigate the presence of green bond premia and the factors driving this premium, with a specific focus on external reviews and the dynamics of Use of Proceeds. The findings reveal that, on average, green bonds exhibit an 8.1 basis points lower yield compared to their matched non-green counterparts. Moreover, reviewed green bonds demonstrate a pricing advantage over standard green bonds. Additionally, green bonds allocated towards Climate Change Adaptation and Eligible Green projects display more pronounced green bond premia, indicating investor preference for bonds financing these environmentally impactful initiatives.

Keywords: Green Finance, Green Bonds, Green Bond Premium, Green Bond Pricing, External Reviews, Use of Proceeds.

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Abbreviations:

Bps: Basis points

CB: Conventional Bonds

CBI: Climate Bonds Initiative

EU: European Union

ECB: European Central Bank

GB: Green Bonds

GBP: Green Bond Principles

ICMA: International Capital Market Association

NPV: Net present value

1. Introduction

Several extreme weather events in the recent decade have impacted the lives of people and the world's economy. These past occurrences require embracing sustainable solutions. With the aim of saving as many natural resources and reducing climate change as soon as possible, companies and manufacturers have actively committed to unwavering measures to minimize their ecological footprint and use renewable forms of energy. Additionally, in the recent past, the Russian-Ukrainian conflict expanded, and drawn-out enmity forced energy prices to rise, thus pressing European countries to develop alternatives for gas and oil (Goldman Sachs, 2023). However, it may necessitate a considerable investment to finance decarbonization projects as well as economic transformation. The European Commission's 2019 prediction argues that an annual investment of 260 billion Euros will be necessary to meet the climate and energy objectives set for 2030 (Europa, 2021). In this regard, the financial market begins to play a significant role in aggregating funds for renewable energy and new environmental science projects promoting the development of new sustainable financial products and tools (Riksbank, 2020). Thus, green bonds have proven to be the most important financial instrument for the implementation of such projects that attract investments from investors (Le Houérou, 2019).

The global green bond markets have become the innovation hub of green finance, as interest in green assets has attracted fixed-income investors who wish to finance projects that produce global environmental benefits and demand a fair financial return. However, green bond investors still have doubts about the appropriate pricing of eco-friendly investments. As a result, there is a growth in the number of academic research on the valuation of green bonds. Most of the literature on green bond valuation primarily focuses on examining the concept of a "greenium" and identifying factors influencing the pricing of these assets. Like other fixed-income investments, the primary objective of investors in green bonds is to maximize risk-adjusted returns (Goldman Sachs, 2023). Numerous studies indicate that investors can expect comparable risk-adjusted returns from green bonds compared to traditional ones (Larcker and Watts, 2020; Baker et al., 2022; Goldman Sachs, 2023). While some experts argue for the existence of a green bond premium, or "greenium" (Ehlers & Packer, 2017, Hachenberg & Schiereck, 2018, Zerbib, 2019, Kapraun et al., 2021, the European

Central Bank, 2022), these findings suggest that fixed-income investors prioritize sustainable and climate-related risks and may accept lower returns in exchange for societal benefits.

This thesis aims to scrutinize the green bond pricing mechanism. More precisely, it seeks to assess the implications for asset pricing of investment instruments specially designed for climate investment initiatives. The considered market is the European corporate bond market post-issuance, and more specifically, the author reflects on the influence of several characteristics of a green bond on the green bond premium. To shed light on the green bond pricing mechanism, this report aims to answer three research questions. They are the following: (1) Do green bonds have a lower yield compared to their matched conventional peers? (2) Will green bonds reviewed by a third party have a pricing advantage with respect to normal green bonds? (3) Will green bonds earmarked by different eligible green projects affect differently on the green bond premium? The assessment is carried out through the lens of the green bond premium, commonly referred to as the "greenium." This term denotes the negative disparity between the yields of paired green bonds and their conventional counterparts. The analytical approach expands upon the methodological framework employed in earlier relevant work introduced by Zerbib (2019) and incorporates a direct matching approach, specifically targeting bonds after issuance.

Drawing from empirical tests conducted on a sample of 51 matched bond pairs, spanning from 2018 to October 2023, the results from the experiment indicate that fixed-income investors, on average, exhibit a willingness to forego 8.1 basis points in returns to incorporate green assets into their portfolios. Additionally, the findings reveal that green bonds subject to external review command higher premia compared to their non-reviewed counterparts. Furthermore, the distinct investors' choices are identified, with the most pronounced green bond premium belonging to initiatives related to Climate Change Adaptation and Eligible Green projects. This discovery demonstrates that investors are even more eager to align their capital with projects that address environmental issues, particularly those contributing to climate change adaptation and sustainability.

As a detailed experiment on the green bond premium and its determinants, the Thesis gives an in-depth analysis of how the greenness credibility and the Use of Proceeds impact the green bond premia. This report also seeks to provide insight into green bond pricing to investors, eventually, they will have better investment strategies when adding green assets into their portfolios. Moreover, with the rising demand for green finance, the suggestion can go further to encourage global authorities and governments to standardize the frameworks and requirements for these instruments.

The remainder of this paper is structured as follows: First, a summary of the literature resources in green bonds, green finance, green bond markets, and bond pricing. This is followed by a section on an overview of the Dataset being used in this report. Then Section 4 describes the report's methodology. After that, the results from the empirical analysis are presented in section 5, and finally, section 6 is the conclusion part of the report.

2. Literature Reviews and Hypothesis

2.1 The background of green bonds

2.1.1 Green Finance

Green financing is the interaction between financial activities and the environment, which is based on the principle that for sustainable growth, finance activities must consider the environment (Spinaci, 2021, ISO, 2022). In some countries, they have adopted different definitions to assess green finance (UNEP, 2016):

People's Bank of China (2016): Green finance encompasses a range of financial instruments such as loans, private equity, bonds, stocks, and insurance to facilitate green investments.

Government of Germany (2011): Green finance is an innovative measure aimed at integrating the financial segment into the economic transformation that contributes to the reduction of carbon footprint and the development of energy efficiency.

Banglades Bank (2011): Green finance is defined as one segment of green banking. Besides, green finance can foster a low-carbon economy by utilizing efficient energy.

Broadly defined, green Finance encompasses structured financial activities, products, or services explicitly designed to contribute to improved environmental outcomes Wang and Zhi (2016). This encompasses diverse financial instruments such as loans, debt mechanisms, and investments, all strategically employed to foster the growth of eco-friendly initiatives or mitigate the environmental impact associated with conventional projects. While other scholarly sources argue that green finance is sustainable finance (Migliorelli and Dessertine, 2019). The essence of green Finance lies in its ability to catalyze positive environmental change through a multifaceted approach, ultimately aligning financial efforts with sustainable and climate-conscious objectives (World Economic Forum, 2020).

In recent years, several innovative financing mechanisms have emerged to boost green projects forward. These include the advent of financial instruments such as climate bonds and green bonds, the establishment of green banks, and the formation of green funds. Green banks and green bonds, in particular, exhibit substantial potential for supporting enduring environmental initiatives. Green banks not only extend favorable credit terms for clean energy development projects but also pioneer inventive financial products that bolster the realm of green finance (Sachs et al., 2019).

The shift in capital allocation toward green finance has transcended its initial role as a risk management strategy, evolving into a catalyst for innovation and a wellspring of new opportunities that generate lasting value for both businesses and society. Despite this transformative trend, the mobilization of capital for green investments encounters impediments, primarily within the regulatory framework governing the financing system. A critical hurdle involves the absence of a standardized definition of "green" and a comprehensive taxonomy of green activities. This absence hampers investors in efficiently directing capital and making informed decisions. Therefore, establishing a clear definition of green finance is imperative for transparency, guarding against the misleading practice of "greenwashing" and ensuring that capital is allocated judiciously to initiatives with genuine environmental impacts.

The surge in green bond markets has unfortunately given rise to the phenomenon of greenwashing, presenting a significant trust issue (de Freitas Netto et al., 2020). As the occurrence of environmentally friendly claims grows, investors face challenges in distinguishing genuine green initiatives from misleading or insincere ones. Greenwashing is characterized by the strategic disclosure of positive details regarding a company's environmental or social performance, coupled with the intentional omission of any unfavorable information in these domains (Lyon and Maxwell, 2011, Delmas and Burbano, 2011), therefore can create an overly positive image for a company. This escalating trend of greenwashing is characterized by an increasing number of firms spreading misleading information to stakeholders and investors regarding their environmental performance or the actual benefits of environmental projects (Laufer, 2003, Shahrin et al., 2017). Due to its prevalence, the broad effects of greenwashing cause far-reaching consequences, including the weakening of trust and confidence of investors in green products. However, the effects of greenwashing are more severe than mere skepticism. Delmas and Burbano (2011) warn of the dangers of genuine loss of markets for green finance products and services. As a result, the need to address and neutralize greenwashing is critical not only to maintain the integrity of sustainable initiatives but also to foster a genuine and resilient green finance ecosystem.

2.1.2 Green bond definition

The European Parliament (2022) argues that green bonds are a type of fixed-income security aimed at supporting action against climate change. These perspectives have dominated the field of green finance. However, issuers have the freedom to spend the proceeds of traditional bonds as they see fit, while the issuer of the green bond must dedicate all or a portion of the proceeds to projects named "green". These “green” projects are the lower or less pollution ways to avoid crossing a temperature limit of 2 degrees Celsius (OECD, 2021).

A clearer definition of what qualifies as "green" and the set of global standards for these financial tools has materialized through voluntary frameworks such as the Green Bond Principles (GBP) from the International Capital Market Association (ICMA) and the Climate Bond Standard from the Climate Bonds Initiative (CBI). These guidelines assist both issuers and investors in gaining better insights and supporting their financing in environmental and sustainable projects that promote a net-zero emissions economy and environmental protection. Moreover, several other organizations including the European Union (EU), the People's Bank of China (PBoC), and the Association of Southeast Asian Nations (ASEAN), also introduced the Green Bond Standards. These institutions have developed green bond principles and provided frameworks for promoting environmentally responsible investment practices while ensuring consistency, transparency, and credibility within the issuance and evaluation of green bonds in their local markets. This step can be seen as particularly beneficial for the global sustainability agenda.

According to GBP, green bonds are defined as any form of bond instruments whose funds were raised to be dedicated exclusively to the financing or refinancing, either partially or in full, of qualified green projects. These projects must also adhere to the four essential elements outlined by the GBP (ICMA, 2022), including (1) Use of Proceeds, (2) Process for project evaluation and selection, (3) Management of Proceeds, and (4) Reporting (Table 1).

The more stringent criteria introduced by the Climate Bonds Initiative (CBI) are incorporated into the Climate Bond Standard, which encompasses a taxonomy with screening criteria for the classification of environmentally friendly economic activities. Additionally, green bonds are mandated to undergo certification by approved external assessors as a result, which has led to a reduction in their user base.

Intending to establish regulations for green bonds, the European Parliament emphasized the necessity of an EU green bond standard in its resolution on the Sustainable Europe Investment Plan in 2020. This framework mandates the verification and oversight of green bonds by public authorities, and it also calls for regular reporting on the environmental impact of the underlying assets (European Parliament, 2022).

The recently adopted framework, EUGBS (the European Green Bond Standard) introduced by The European Parliament and the Council on Europen, strives to establish a common language for the Use of Proceeds. The criteria encompass only those green bonds that align with the four fundamental elements of the ICMA green bond principles, hold a certification from the CBI, or are self-labeled as green bonds without requiring adherence to ICMA principles or certified by the CBI (European Environment Agency, 2023).

Table 1: ***Summary of Green Bond Principles' core components, source ICMA (2022)***

Principle	**Description of Issuer's responsibilities**
Use of Proceeds	The proceeds of green bonds are used to finance eligible green projects, which should be described in the security's legal documentation. Moreover, these eligible green projects should provide clear environmental benefits, such as energy efficiency/renewable projects, clean transportation, sustainable waste management, green building, sustainable land use, biodiversity, and clean water.
Process for Project Evaluation and Selection	Explain the procedure involved in selecting a project in detail to investors

Management of Proceeds	Manage the net proceeds of the green bonds, reallocate the bond proceeds to be solely utilized for projects with an environmental focus
Reporting	Provide both qualitative and quantitative information on the use of proceeds

2.1.3 Green bond markets

The green bond market has rapidly grown since the first issuance of the climate awareness bond by the European Investment Bank in 2017. Indeed, the remarkable growth of green bond markets is presented in Figure 1 which shows an average annual growth rate of 55% from 2013 to 2023 (source: Refenitiv as of October 2023). Europe has consistently led the way in promoting the green bond market, followed by various markets from around the globe following suit. The notable contributors to the green bond market development consist of the United States, China, France, and Germany. The prominence of Europe in this market is evident in the prevalence of euro-denominated green bonds, constituting 51.9% of the market share as of October 2023 (Refinitiv, 2023). Meanwhile, dollar-denominated bonds issued by corporates and local authorities in the US and other issuers worldwide were a distant second at 18.3% of the market, although this share is increasing.

In nations with developing economies like China, government initiatives are demonstrating a strong commitment to revising green bond standards to better align with international principles. These proactive measures aim to bolster transparency within the green bond market, a move anticipated to draw increased interest from international investors. As a result, this concerted effort is poised to not only attract more foreign investment but also stimulate further growth within the market.

A 2023 report from the European Environment Agency highlights a remarkable surge in the issuance of green bonds in EU nations, from 0.6% in 2014 to 8.9% in 2022. This positive trend is expected to continue, driven by the European Union’s ambitious plan, in which the EU will issue green bonds in the amount of up to 250 billion euros to finance its Next Generation EU program by the end of 2023 (Goldman Sachs, 2023). The proceeds from this issuance will go to support the economic recovery of the EU Member States after the COVID-19 crisis and channel into green development.

Figure 2 presents the growth of green bond issuance by different issuers, including government, corporate, supranational bodies, and subnational entities. Throughout the period spanning from 2014 to 2022, the issuance rates of these issuers all increased, although each of them has a different growth rate. Moreover, the amount of green bond issuance by corporates across this period was rapidly growing, and eventually, in 2022, corporates culminated in their dominance as green bond issuers. This underscores the important role that corporations are poised to play in driving the growth of the green bond market.

*Figure 1: **Green bond issuance across the world as of Oct 2023, source: Refinitiv***

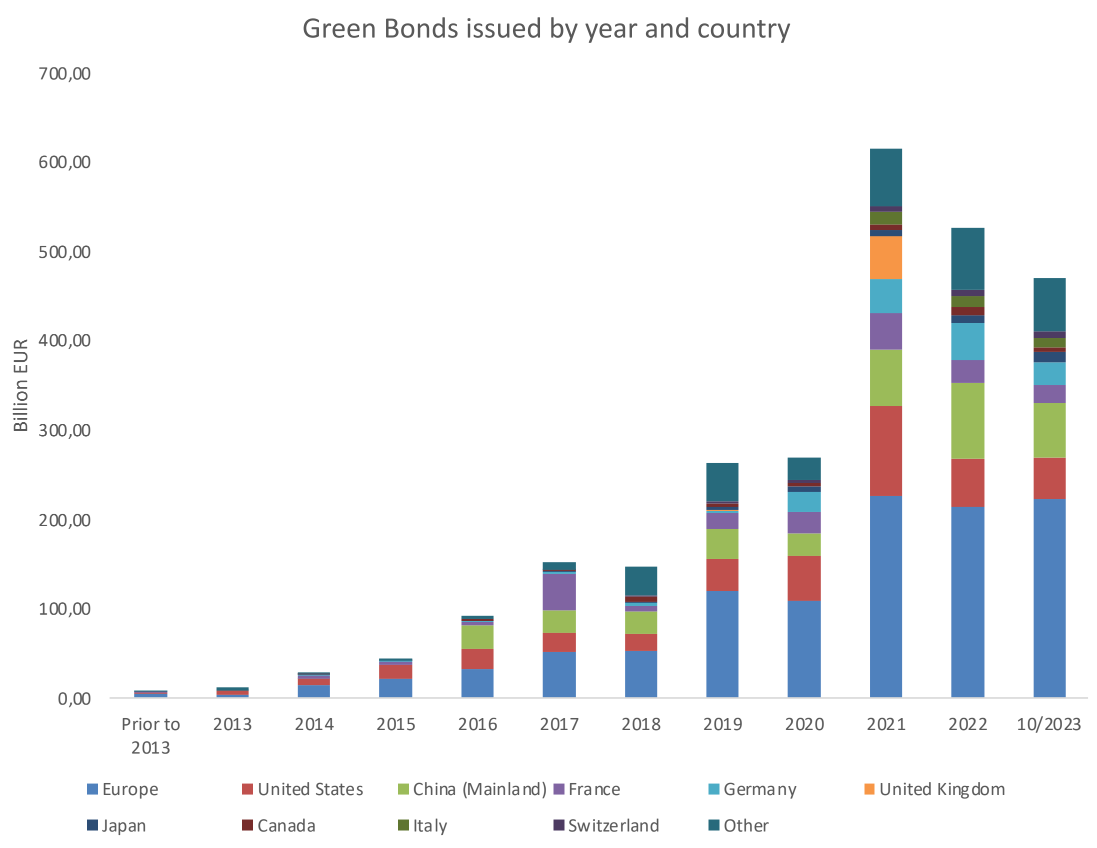


Figure 2: ***Proportions of green bond issuance over the total bond issuance by all and each type of issuers in the EU, 2014-2022, source: European Environment Agency, 2023***

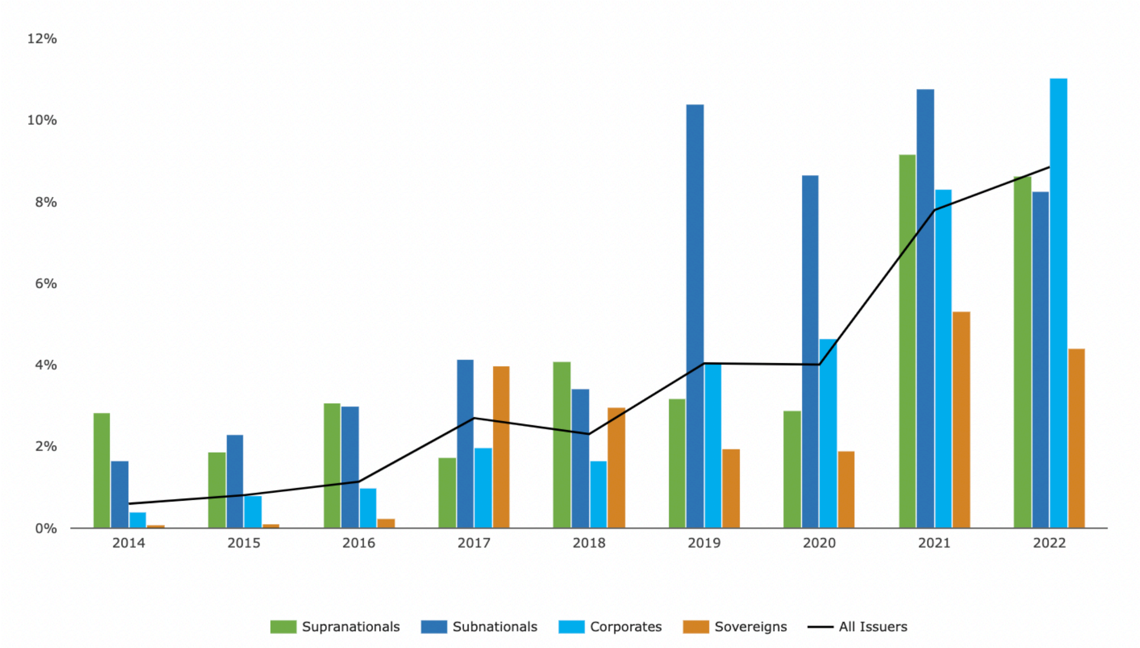
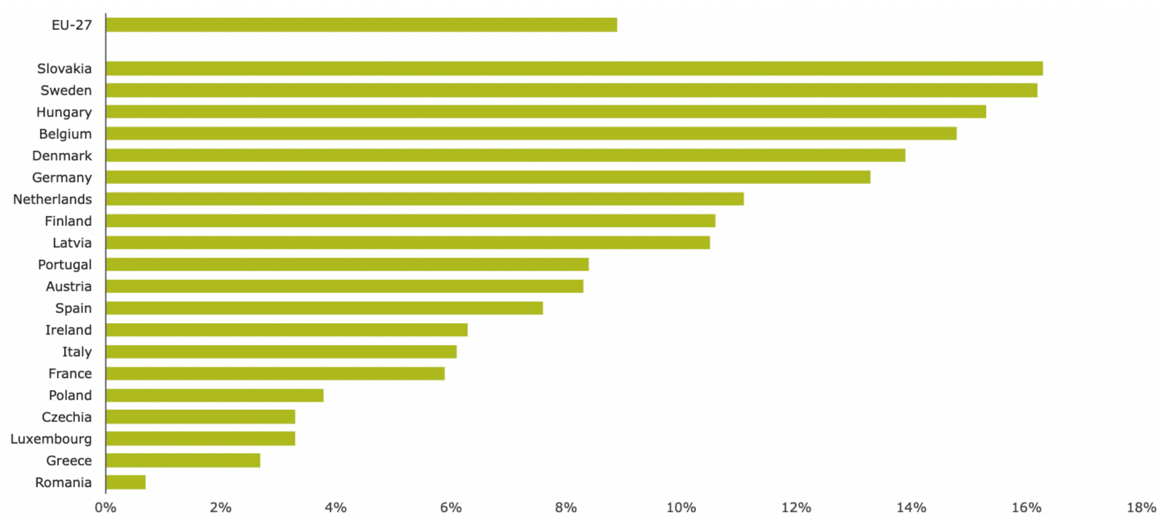


Figure 3: ***Green bond issuance by corporations and Sovereign Governments, by the EU Member State, 2022. Source: European Environment Agency***



Across the EU Member States, the leading countries with the highest shares of green bonds were Slovakia, Sweden, and Hungary in 2022 (Figure 3).

With the expansion of the Green bond market and growing investor interest, there has been a push to establish benchmarks and reference indices for measuring Green bond performance

(OECD, 2016). In 2014, various banks, rating agencies, and service providers introduced Green bond indices, which became accessible by 2015.

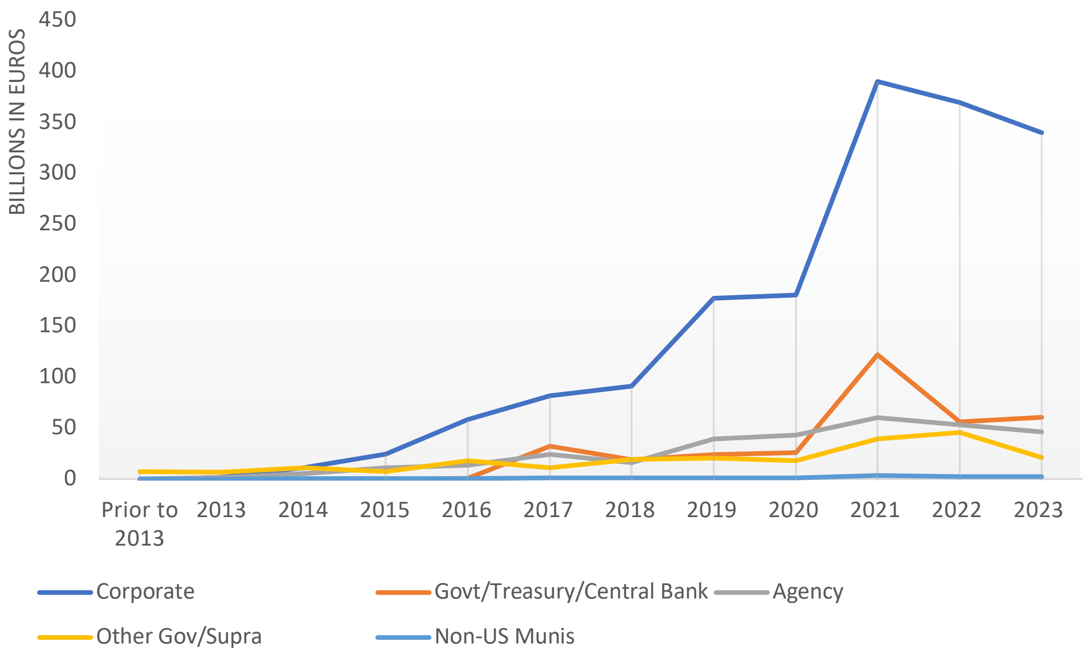
- Bank of America Merrill Lynch Green Bond Index
- Barclays MSCI Green Bond Index
- S&P Green Bond Index and Green Project Bond Index
- Solactive Green Bond Index

2.1.4 Corporate green bonds

The issuance of green bonds by corporations has experienced a noteworthy surge in popularity, as evidenced by the increasing prevalence in the green bond markets over recent years (see Figure 4). For example, Apple, whose green bond program was established in 2016, has managed to raise 4.7 billion US dollars since. Notably, the funds raised through the green securities are dedicated to innovative projects to develop carbon-neutral and clean energy projects (ESG Today, 2022). This development is an aspect of ESG commitment, whereas another example is Mitsubishi Electric Corporation which announced the first issuance of green bonds intended for supporting the decarbonization project to be ready by. All of the examples underscore the growing trend among corporations to leverage green bonds as a financial instrument to fund and propel environmentally responsible projects.

Flammer (2021) outlines three compelling rationales behind the issuance of corporate green bonds: (1) Credible environmental commitment: green bonds serve as a credible signal of a firm’s commitment to environmental sustainability. More specifically, by choosing to issue green bonds, companies can actively communicate to their stakeholders that they are dedicated to participating in environmentally responsible practices. (2) Demonstration of green initiatives: companies who issue green bonds can showcase their dedication to investing in environmentally friendly projects and making tangible strides in improving their overall environmental footprint. (3) Access to cost-effective capital: issuing green bonds provides companies with an avenue to raise capital at a potentially lower cost. Investors, recognizing the societal benefits associated with green finance, may be willing to accept a trade-off between financial returns and social, and environmental advantages.

*Figure 4: **The boom of corporate green bonds in the green bond markets, source: Refinitiv as of 31 Oct 2023***



2.2 Bond valuation

Bond valuation is a process to determine the fair value or the present value of a bond, and this procedure is often described as "valuing" or "pricing" asset in financial terminology. Bond pricing is based on the application of the discounted cash flow (DCF) model, a robust method for estimating an investment's value based on its expected future cash flows. A study conducted by Kaplan and Rubanck (1995) underscores the credibility of discounted cash flow valuation techniques in gauging an asset's market value. The traditional valuation approach incorporates the utilization of a single market discount rate, often referred to as the yield to maturity if a bond is held until its maturity day, within the time value of money framework. This rate plays a pivotal role in the calculation, leading to the determination of the bond's price.

Therefore, the price of fixed-income securities can be precisely ascertained by applying the following formula:

$$PV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + \frac{FV}{(1+r)^n}$$

In which: $PV = price\ of\ a\ bond\ at\ time\ t$

$C_t = coupon\ payment\ per\ period$

$FV = face\ value$

$r = market\ discount\ yield\ or\ yield\ to\ marturity\ (ytm)$

$n = number\ of\ evenly\ coupon\ payments$

$t = time\ when\ the\ payment\ is\ received$

Kritzman (1993) posits that the conventional valuation methodology exhibits a fundamental limitation by treating each security as an identical composite of cash flows. A more nuanced perspective suggests that the cash flows associated with a bond ought to be construed as a package of individual zero-coupon bonds, thereby preventing market participants from exploiting arbitrage opportunities (Fabozzi, 2009). This valuation framework is commonly denoted as the "arbitrage-free approach." Consequently, the execution of the arbitrage-free methodology necessitates the mapping of interest rates corresponding to their respective maturities and a determination of the interplay between these rates. Kritzman (1993), Martellini, Priaulet, and Priaulet (2003) expound upon the concept that the connection between the yield of an investment and its time to maturity is encapsulated by the financial theory commonly referred to as the "*Term Structure of Interest Rates*". The outstanding hypothesis cited to explain the Term Structure of Interest Rates is the liquidity premium theory, which postulates that forward rates solely encapsulate the market participants' demand for a risk premium to retain longer-term bonds.

In addition, a few key studies have fundamentally shaped the way financial economists think about corporate bond pricing. Merton (1974) examines the risk structure of interest rates, Black and Cox (1976) introduce three aspects of bond indentures that affect the value of corporate bonds, including "*safety covenants, subordination arrangements, and restrictions on the financing of interest and dividend payments*".

An investor can expect more return if he assumes more risk on an investment (Tobin, 1958). There is broad consensus in the profession that the default risk premium must be related to the risk of the differential in credit rating assigned by external rating agencies, such as Moody’s, Standard & Poor’s Corporation, and Fitch Ratings (Fabozzi, 2009, Elton et al., 2004).

2.3 Review previous literature on green bonds

2.3.1 Evidence of the green bond premium

The pricing of green bonds has emerged as a rapidly evolving topic within the realm of green finance literature. The majority of studies have concentrated on the valuation of these financial instruments based on their conventional counterparts. A central question in this domain pertains to whether eco-friendly investments carry added value for investors, extending beyond the anticipated risk and return characteristics of a security. For instance, in a scenario where two bonds, one green-labeled and the other not, exhibit identical risk and return profiles, would investors be willing to pay a premium for the environmentally responsible aspect? Despite conventional no-arbitrage postulations suggesting that these securities should be priced equivalently, empirical findings regarding the yield differential between green and traditional bonds remain inconclusive.

The concept of green bond premium (“greenium”) has become a prevalent topic when investors switch their interest to more sustainable investments. According to Bachelet et al. (2019), Hyun et al. (2020), Kapraun et al. (2021), Fatica et al. (2021), green premia is the reduced costs of issuers when they issue green bonds compared to traditional bonds with the same characteristics. A broader definition of green premium is the difference in yield between green bonds and their matched non-green bonds (Huang, Dekker, and Christopoulos, (2023)). Another explanation proposed by Karpf and Mandel (2018), Hachenberg and Schiereck (2018), Zerbib (2019), Larcker and Watts (2020), Flammer (2021), and Simeth (2022) imply that green premium is an unweighted average yield difference between green bonds and their traditional peers.

HSBC (2016) and Tang and Zhang (2020) conduct their own research and find no evidence of green bond premium. Similarly, Larcker and Watts (2020) analyse 640 pairs of green and non-green bonds with similar characteristics and conclude that there is no significant yield difference in 85% of the cases. Additionally, Baker et al. (2022) investigate 3,983 green U.S municipal bonds issued between 2013 and 2018 and find no significant premium over conventional bonds with similar attributes. These findings from previous research suggest that investors are not willing to compromise on their financial returns to support environmentally friendly projects.

In contrast, some theoretical perspectives argue that investors may be willing to accept lower yields for investments in environmentally friendly projects. This view is backed by the findings of several studies. Ehlers and Packer (2017) analyze 21 pairs of bonds issued between 2014 and 2017 and discover that green bond issuers were able to borrow at a lower rate of 18 basis points than when they issued traditional bonds in the primary market, however, in the secondary market analysis they do not witness any premium. In another research, Hachenberg and Schiereck (2018) examine a sample of 63 green bonds traded on the secondary market and observe that green bonds traded at a slightly tighter spread than non-green bonds. Zerbib (2019) and the European Central Bank (ECB, 2022) employ a matching method to examine the yield spread between pairs of green bonds and non-green bonds issued by the same entities. In their analysis, a negative premium of 2 basis points (bps) is identified across a sample dataset spanning from 2013 to 2017 (Zerbib, 2019). Similarly, the ECB's findings reveal a 4 basis points negative premium over the entire sample period in the euro area, covering the years 2016 to 2021 (ECB, 2022). A large “greenium” in the Chinese corporate green bond market is reported in a study by Hu, Zhong, and Cao (2022), with 20-26 basis points in the secondary market.

2.3.2 Determinants of green bond premium

The studies of Karpf and Mandel (2018), and Bachelet et al. (2019) underscore that, on average, conventional bonds tend to outperform green bonds in terms of returns, a disparity primarily attributed to inherent bond characteristics, for example, the credit rating (Arat, Hachenberg, Kiesel, and Schiereck (2023)). In contrast, the research by Martin and Moser (2016), and MacAskill et al. (2021) present a compelling argument, demonstrating that the social and environmental benefits associated with green investments exert a discernible influence on asset prices. Similarly, the findings of Koziol et al. (2022) indicate that the higher sustainability awareness, the larger the green premium. This alignment with the broader asset pricing literature, as established by Geczy et al. (2005), highlights the nuanced relationship between environmental sustainability and market dynamics. Furthermore, MacAskill et al.

(2021) also emphasize the significance of bond governance characteristics in shaping the green premium. They posit that factors, such as a commitment to recognized green bond standards, having a certification, and the engagement of a third-party reviewer to authenticate and transparently report on the utilization of green bond proceeds are pivotal determinants driving the observed green premium.

It is crucial to acknowledge the role of liquidity concerns among investors in shaping the liquidity premium on green bond yield spreads (Febi et al., 2018, Huang, Dekker, and Christopoulos, 2023). These concerns are further exacerbated by the absence of robust fiscal incentives for green investments, a point emphasized by Zerbib (2017). Additionally, the lack of an official and universally accepted classification system for green bonds, particularly one in alignment with a market-based framework, as articulated by Cochu et al. (2016), contributes to inconsistencies in defining green bond projects. This lack of a standardized framework necessitates additional transaction costs, such as external reviewers when issuing new debts, which can render the yield at the issuance of green bonds less appealing than that of conventional bonds, a phenomenon observed by Sangiorgi and Schpohl (2021). However, Hachenberg and Schiereck (2018) posit that to receive a green bond verification from an independent party, it needs more costs to issue the bonds. Furthermore, the interplay between supply and demand in the green bond market, exacerbated by investors' growing need to fulfill ESG (Environmental, Social, and Governance) and SRI (Socially Responsible Investment) mandates, allows issuers to offer green bonds at more competitive yields compared to the broader bond market (Preclaw and Bakshi, 2015).

On the other hand, Baker et al. (2018), Bachelet et al. (2019), Simeth (2022), and ECB (2022) postulate that green securities with positive environmental scores and external certificates have lower expected returns. Hu, Zhong, and Cao (2022) find that when the air pollution level increases, green bonds will be valued at a higher price. Furthermore, research by Fatica, Panzica, and Rancan (2021) reveals the presence of a premium for green bonds issued by supranational institutions and non-financial corporates, whereas such a premium is notably absent in the case of issuances by financial institutions. This result shows that there is a difference in green bond pricing at issuance by different issuer types. This complex interplay of factors underscores the multifaceted nature of the green bond market and its intricate relationship with investor sentiment, societal benefits, liquidity dynamics, and regulatory frameworks.

While the literature on green bonds has advanced significantly, a notable gap exists in understanding the specific impact of how the funds raised from green bonds will be used or the use of proceeds on the premium. Although prior studies, such as Hu, Zhong, and Cao (2022) have shed light on the influence of the environmental condition on “greenium”, the distinct role of the allocation and utilization of funds raised from green bonds remains underexplored. Furthermore, while Baker et al. (2018), Bachelet et al. (2019), and Simeth (2022) work has examined the role of external certifications, it is potential and warrants an insight to incorporate this factor with the “Use of Proceeds” in the context of the green bond premium. This research aims to bridge this gap by incorporating the “Use of Proceeds” and external certificates into Zerbib’s model, providing a comprehensive analysis of the determinants of the green bond premium, with a focus on the specific application of raised funds.

2.3.3 Hypothesis

The results of prior research have been conflicting, leading to concerns about whether climate-related investments offer intrinsic value to investors beyond the typical risk and return associated with financial securities. Furthermore, an enduring inquiry persists concerning the multifaceted factors that contribute to the yield spread, especially in the context of green bonds. Within this framework, the credibility of green bonds and their respective issuers emerges as a pivotal point of examination, influencing the magnitude of the observed "greenium" across different bond types and issuers.

The ongoing apprehension over greenwashing risks is unambiguous, as market participants are concerned with the authenticity of environmental claims made by issuers. However, one potential avenue for mitigating greenwashing risks lies in the deployment of third-party certifications, such as external assessments verifying compliance with the Green Bond Principles (GBP) of the International Capital Market Association (ICMA) or the Climate Bond Standard of the Climate Bonds Initiative (CBI).

Moreover, the individual risk appetites of issuers in the context of deploying funds for sustainable and environmental investments may significantly shape the yield dynamics of green bonds. In this regard, this section posits hypotheses aimed at rigorously testing whether the presence of external certifications exerts a dampening effect on green bond yields and whether a heightened commitment to green projects translates into reduced funding costs for the bonds. Therefore, this Thesis is going to test three hypotheses:

(1) *There is a green bond premium between a green bond and its conventional correspondent.*
(2) *Green bonds with external verification offer lower yields*
(3) *Green bonds' proceeds financed to different environmentally eligible projects will have different effects on the green bond premium.*

3. Data

3.1 Data overview

This paper concentrates on labeled green bonds, referring to bonds officially designated as "green" by the issuer, indicating a commitment to allocating the bond proceeds to support environmental projects. The prevailing standards for identifying securities as "green" are outlined in the Green Bond Principles (GBP), initially introduced in early 2014 by the International Capital Market Association (ICMA). Labeled green bonds are collected by utilizing the database by Refinitiv, named Datastream, and selected by the "Green Bond Guide". The green bond database received approval from the Climate Bond Initiative. For a security to be identified as "green" on Refinitiv, it must satisfy four obligatory requirements:

- Labeling: The issuer should classify the security as green.
- Framework: There should be a framework on which the security is issued, ICMA green bond principles.
- Reporting: The issuer is obligated to provide periodic reports (quarterly, semi-annual, or annual) detailing the utilization of proceeds for as long as the instrument remains outstanding.
- UoP framework: The issuer should have a clear framework on how to utilize the proceeds from the offering.

Central to the data collection process is the unwavering compliance with the GBP's prerequisite, mandating that 100% of the use of proceeds be channeled into activities that resonate with the principles' green objectives (ICMA, 2017).

The decision to concentrate on the European market stands as a compelling choice, underpinned by several persuasive considerations. Firstly, Europe has not only pioneered the development of green bonds but has also cultivated a highly mature and well-established green bond market. Secondly, this leadership role provides an ideal backdrop for an in-depth exploration of green bond principles and their real-world impact. Its proactive stance towards sustainability, highlighted by initiatives like the EU Green Bond Standard, demonstrates a strong commitment to environmental responsibility. Furthermore, the European corporate bond market, characterized by its diverse range of issuers, offers a rich and extensive dataset for meticulous research, facilitating comprehensive analysis and meaningful insights. By centering on the European corporate bond market, this study has the privilege of immersing itself in a well-entrenched green bond landscape, thereby affording a comprehensive understanding of how green finance intersects with diverse corporate practices.

To construct the dataset, the first step involves downloading all issued corporate green bonds listed on Refinitiv between 2018 and October 2023, which are issued in the European area. 890 green bonds align with the ICMA principles and clarify whether the ICMA framework's first principle, the Use of Proceeds, is fulfilled. From the comprehensive list of bond issuers generated from the universe of green bonds, 13.787 potential conventional bonds are collected. From the Matching technique described in the following section, 62 bond couples are identified, corresponding to 122 different bonds.

Refinitiv offers daily observation of bid and ask prices for bonds, as a result, bid yield and ask yield bonds are acquired by a net present value (NPV) of the future cash flows. The dataset of the daily yields covers the period from January 1, 2018 to October 31, 2023. This dataset allows for a comparative analysis between green and non-green bonds with similar properties traded on the same day. These bonds exhibit identical credit risk, bond characteristics, and exposure to concurrent market fluctuations. Consequently, any disparities in their yields cannot be attributed to differences in credit risk, tax considerations, or market-related risks. Any bonds with missing data are removed from the datasets. Eventually, the dataset includes 51 bond pairs, with 110 different bonds.

For the bond’s characteristics, the following information is obtained: (1) Issuer, (2) Ticker, (3) Preferred RIC, (4) Principal currency, (5) Coupon, (6) Coupon type, (7) Issue date, (8) Maturity date, (9) Country of issue, (10) issued amount in USD, (11) Sector, (12) Collateral, (13) Bond structure, (14) Bond rating, (15) Seniority, (16) External review, and (17) Use of Proceeds.

3.2 Matching Method

Various matching techniques have been employed in studies comparing green bonds with their non-green counterparts. The initial set of methods involves pairing green and non-green bonds using the propensity score matching technique, particularly when dealing with numerous variables. This approach is frequently applied, as seen in studies by Wamser (2014), Gianfrate and Peri (2019), and Hu, Zhong, and Cao (2022). Alternatively, other matching techniques involve pairing two types of bonds based solely on observed characteristics. However, it is important to note that these methods might not account for unobserved characteristics, potentially leading to a spurious relationship between the prices of green bonds and traditional bonds, as discussed by Flammer (2021).

In comparing the prices of green bonds and traditional bonds to assess the impact of their environmental characteristics, it is crucial to mitigate issuer-based influences on pricing. The distinction in issuers between these bonds may introduce variations, as green bond issuers could exhibit heightened awareness of climate-related risks, possess lower emissions, and demonstrate overall greater resilience to climate shocks (Flammer, 2021). To ensure a meaningful analysis of the impact of greenness on prices, controlling for issuer-related factors becomes imperative (ECB, 2022).

This study employs a matching method, which involves pairing two securities with identical characteristics, except for the single property of interest which is consistent with Zerbib's (2019) method. This method is well-established in financial literature and widely used to assess the impact of liquidity on corporate bond spreads, as noted by Helwege et al. (2014) and Dick-Nielsen et al. (2012). To achieve this, a green-labeled bond is paired with the nearest conventional bond, which shares identical attributes. This approach facilitates an examination of yield spreads between green bonds and their closest non-green counterparts.

To analyze the yield spreads between the two categories of bonds, firstly, green bonds are matched with their closely resembled counterparts which are non-green, sharing key attributes such as (1) issuer, (2) credit rating (utilizing S&P rating or, when unavailable, Moody's rating), (3) bond structure, (4) seniority, (5) collateral, (6) coupon type (zero-coupon bonds are excluded in this paper), (7) maturity, (8) currency, and (9) sector. By facilitating the matching of this paired set of securities with identical characteristics, the aim is to effectively control and mitigate bond-specific characteristics, and credit risk, which can influence yield differentials. Secondly, out of the remaining candidates, given the impossibility of finding two bonds with exactly the same characteristics, several matching thresholds are applied in order to find a brown bond that is as similar as possible to its closest green bond correspondent. For the issuance date, a maximum one-year lead/lag is allowed. With the coupon rate, the accepted values are at most 0,25 higher or lower than the green bonds' rates (Bachelet et al., 2019).

Furthermore, it is worth noting that the issue amount of bonds can serve as a proxy for their liquidity and can have a discernible impact on yield levels (Elton et al., 2004). In light of this, to maintain equitable and rigorous matching of the two bond types, certain constraints are imposed on the issue amounts of conventional bonds. Specifically, these constraints dictate that the issue amounts of conventional bonds must fall within a range of less than four times and greater than one-quarter of the issue amount of the corresponding green bond, in line with Zerbib's methodology in 2019.

These carefully designed limitations about the issue amount, the coupon rate, and the issue date play a pivotal role in enabling the control of any residual liquidity bias that may influence the estimation of the green bond premium. By enforcing these constraints, the study seeks to ensure that the comparison between green bonds and their conventional counterparts remains meticulous and impartial, accounting for factors that could otherwise introduce confounding variables.

*Table 2: **Matching criteria***

Matching criteria	
Characteristic	Matched conventional bonds' criateria
Issued amount	Less than four times and greater than one-quarter of the issued amount of corresponding green bonds
Issuance date	1 year lead or lag
Coupon rate	Not higher or lower than 0.25% the corresponding green bonds' coupon rate
Year to maturity	Same
Currency	Same
Issuer	Same
Rating	Same
Coupon type	Same
Seniority	Same
bond structure	Same
Collateral	Same

3.3 Descriptive statistics of data

The final dataset is an unbalanced panel data consisting of 51 matched bonds, 51 green bonds, and 51 conventional bonds, with 26320 daily yield observations ranging from January 1, 2018 to October 31, 2023. The data comprises the following series.

Cross-section and period identifiers:

Date: the identifier of periods

Ticker: the identifier of bonds

The data in Table 3 shows that green bonds have lower yields than their corresponding conventional peers, with 0.5 basis points (bps) on average, while their bid-ask spreads are quietly comparable.

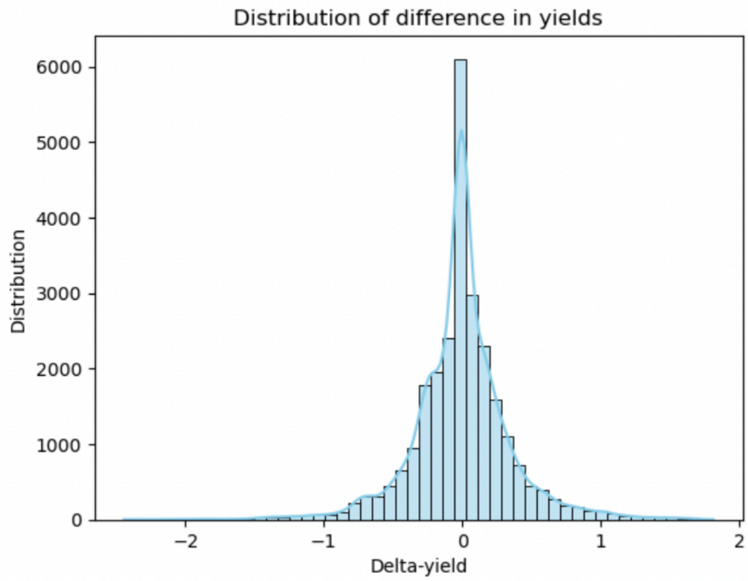
Table 3: ***Statistic description of the entire sample.***

The bid yield of GB, the ask yield of GB are the bid yields, and ask yields of green bonds. Bid yield of CB and ask yield of CB are the bid and ask yields of conventional bonds. Delta yield is the difference in ask yields of green bonds and their conventional peers.

	Sample						
	Min	25 %	Median	Mean	75 %	Max	Count
Bid yield of GB	0.122	2.009	4.204	3.537	4.965	10.683	26320
Ask yield of GB	0.122	2.001	4.193	3.520	4.949	9.934	26320
Bid yield of CB	0.123	2.064	4.226	3.540	4.975	9.159	26320
Ask yield of CB	0.121	2.054	4.215	3.524	4.959	9.155	26320
Delta_yield	-2.444	-0.170	-0.001	-0.005	0.152	1.814	26320
BA spread of GB	0.000	0.006	0.011	0.016	0.016	0.749	26320
BA spread of CB	0.000	0.006	0.010	0.015	0.015	0.512	26320
Liquidity premium	-0.365	-0.002	0.000	0.002	0.003	0.745	26320
Maturity	3.0	5.0	5.0	7.2	10.0	31.00	26320
Issued amount (billion)	0.0184	0.0454	0.05514	0.16587	0.1391	1.0729	26320

The distribution of the yield differences (Delta_yield) appears to have a slight leftward skewness and heavier tails, indicating the distribution of the Delta_yield tends to be negative and the presence of extreme values in the dataset (Figure 5).

*Figure 5: **The distribution of bonds' yield difference***



Upon subdividing the dataset based on the Use of Proceeds, distinct patterns of distribution in delta yield emerge among the matched pairs (Appendix 2). Notably, the most substantial difference in yield is observed in green bonds earmarked for Environmental protection projects, exhibiting an average Delta_yield 17.8 basis points lower than their corresponding traditional bonds.

Conversely, green-labeled bonds directed towards Eligible Green Projects display an average Delta_yield 5 basis points higher than their conventional counterparts.

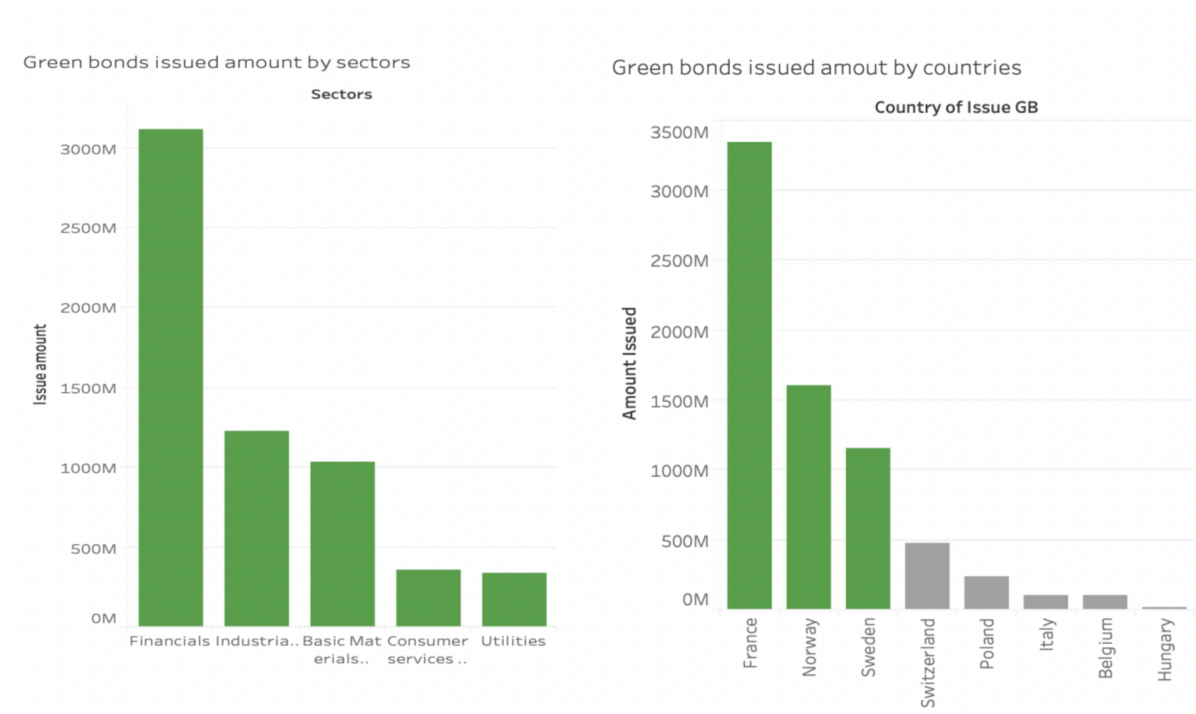
*Table 4: **Yield differences by the use of proceed subgroups***

	Sample		
UoP	**Min**	**Mean**	**Max**
Clean Transport	-2.104	0.001	1.301
Access to Essential Services	-0.347	0.044	0.432
Aquatic Biodiversity Conservation	-1.524	-0.145	1.221
Climate Change Adaptation	-0.943	-0.063	0.229

Eligible Green Projects	-1.364	0.052	1.813
Energy Efficiency/Renewable Projects	-2.444	-0.019	1.304
Environmental Protection Projects	-2.196	-0.178	1.146
Green Construction/buildings	0.782	-0.008	0.845

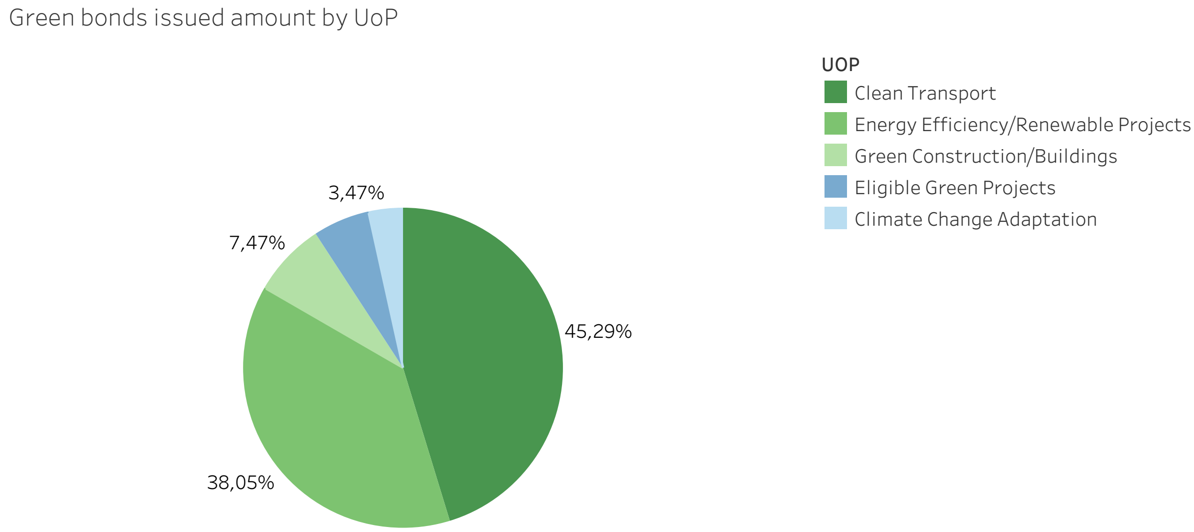
In the studied dataset, France leads the pack as the top issuer by volume, with Norway securing the second position and Sweden in third. Notably, the Financial sector stands out as the predominant contributor to the green bond outstanding amount, with over 3 billion USD (Figure 6), followed by the Industrials segment.

*Figure 6: **Country and sector of the issued amount***



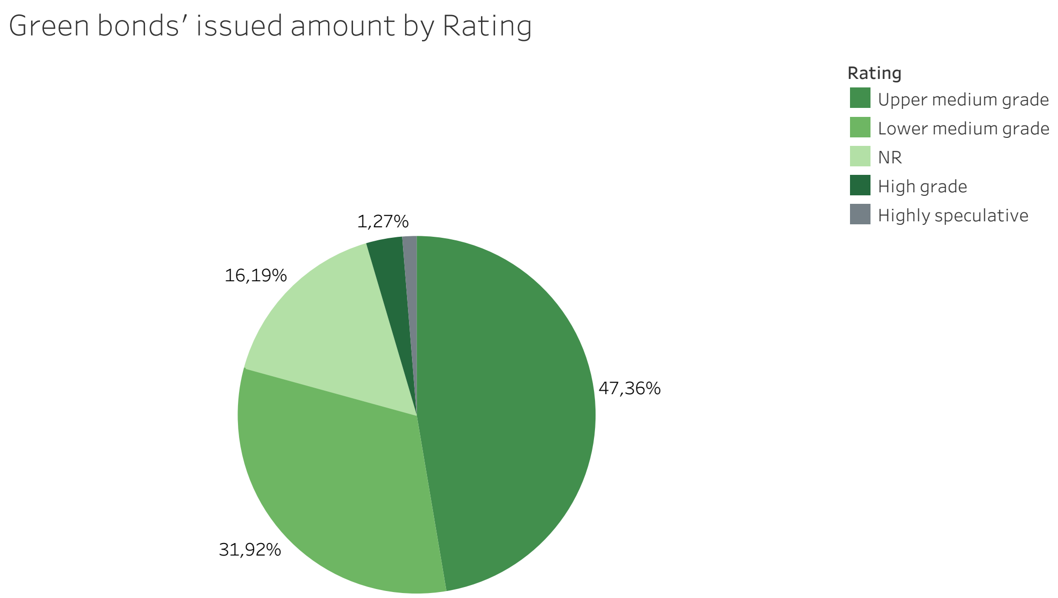
The Green bonds in the dataset are issued to finance four green-eligible projects (Figure 7). Clean Transport and Energy Efficiency/Renewable projects are the areas with the highest issued amount, with more than 45% and 38%, respectively. Green Construction/Buildings constitute 7.47% equally in the total of the green bonds in the dataset, followed by Eligible Green Projects.

Figure 7: ***Green bonds issued amounts categorized by Use of Proceeds***



% of Total Issue amount. Color shows details about UOP. Size shows sum of Issue amount. The marks are labeled by % of Total Issue amount.

Figure 8: ***Green bonds' issued amount categorized by Rating***



In terms of rating, the majority of Green bonds in the data analysed are rated at upper and lower medium grades, only 1.27% of the total amount of bonds issued is graded at a high grade (Figure 8).

4. Methodology

This analysis aims to ascertain the existence of a greenium, a comparison between the yields of green bonds and their conventional counterparts is essential. This study adopts a methodology employed by Zerbib (2019) in the context of corporate green bonds issued in the European area, with certain modifications tailored to the specific focus of this investigation. The model is a two-step regression methodology. The initial step is designed to mitigate any residual disparities in liquidity between the two bonds within each pair and estimate the green bond premium. Subsequently, in the second step of the analysis, the study delves into the various determinants of the green bond premium, shedding light on the complex interplay of factors that contribute to this phenomenon.

4.1 The existence of green bond premium

In the pursuit of understanding the presence of a "greenium", the first step is set up to estimate the green bond premium.

Step 1: Estimation of green bond premium

$$\Delta yield_{i,t} = g_i + \beta\ Liquidity\ premium_{i,t} + \varepsilon_{i,t}\ (1)$$

The panel data is set up in the regression model (1), a pair of bonds i is observed at time t. The dependent variable, represented as $\Delta yield_{i,t}$, serves as the metric to quantify the yield differential between a specific green bond i and its corresponding traditional bond i at time t, in which $\Delta yield_{i,t} = y_{i,t}^{GB} - y_{i,t}^{CB}$. It is worth noting that the delta yield is the difference between the green bond's ask yield and the conventional bond's ask yield. The ask yield is presented for the analysis as this paper focuses on the demand and sentiment of investors on green investments, which proxies for the investors' willingness for environment-related investments. The delta yield variable is regressed on a constant and liquidity premium variable.

The constant g_i is the green bond premium, which is estimated to unveil the latent factors that contribute to the observed "greenium" in the subsequent analytical stage. As delineated in Equation (1), the difference in yield of two bond categories can be explicitly attributed to the combined influence of the liquidity differential and the green bond premium, after controlling bonds' characteristics.

Concurrently, the variable, $Liquidity\ premium_{i,t}$, holds a pivotal role as it is designed to act as a control mechanism for any residual disparities in liquidity that might influence the yield difference. Specifically, this variable captures the difference in liquidity between both bonds of a pair.

$$Liquidity\ premium_{i,t} = Liquidity_{i,t}^{GB} - Liquidity_{i,t}^{CB} \quad (2)$$

In this model, the quoted bid-ask spread is used as a proxy of the liquidity. Febi et al. (2018) findings show a high correlation between bid-ask spread and liquidity premium. This liquidity-related measure is also widely used in financial research by Beber et al. (2019), and Dick-Nielsen et al. (2012). Indeed, an essential factor influencing bond yields is the market liquidity of bonds. The ease with which bonds can be bought or sold in the market plays a significant role in determining their yields. Higher market liquidity generally corresponds to lower yields, as it implies lower transaction costs and increased ease of trading. Conversely, lower market liquidity tends to result in higher yields, reflecting the associated challenges and costs in buying or selling bonds in the market. Thus, market liquidity is a critical consideration when assessing and understanding the dynamics of bond yields (Longstaff et al., 2005, Han and Zhou, 2016, Bao et al., 2011).

Consequently, the proxy for the Liquidity premium in the equation (2) is:

$$\Delta BA\ spread_{i,t} = BA\ spread_{i,t}^{GB} - \ BA\ spread_{i,t}^{CB}$$

The possibility of selecting an inappropriate regression model introduces the potential for additional errors in the analysis. In order to mitigate these errors and enhance the accuracy of model selection, statistical tests such as the F-test and the Hausman test are employed in regression analysis. In particular, the tests serve to assess the goodness-of-fit among different models, namely pooled OLS, fixed-effect (FE), and random-effect (RE) models. Specifically, the F-test evaluates the significance of fixed effects by comparing the pooled OLS model with the fixed-effect model. This test aids in determining the most appropriate regression model for the given data and minimizing the likelihood of errors associated with an unsuitable model choice. The overarching goal is to ensure a robust and accurate regression analysis. The test statistic for the F-test is calculated as follows:

$$F - statistic = \frac{\frac{(RSS_{OLS} - RSS_{FE})}{(k_2 - k_1)}}{\frac{RSS_{FE}}{(N - k_2)}}$$

Where:

RSS_{OLS}: the sum of squares of residual errors of the pooled OLS model

RSS_{FE}: the sum of squares of residual errors of the fixed-effect model

k_1: degrees of freedom of the pooled OLS model

k_2: degrees of freedom of the fixed-effect model

N: number of data samples.

Meanwhile, the idea behind the Hausman test is to compare the consistency and efficiency between the fixed and random effect models. The Hausman test statistic can be calculated as:

$$\xi_H = \left(\widehat{\beta_{FE}} - \widehat{\beta_{RE}}\right)' [\hat{V}\{\hat{\beta}\}_{FE} - \hat{V}\{\hat{\beta}_{FE}\}]^{-1} (\widehat{\beta_{FE}} - \widehat{\beta_{RE}})$$

Where $\hat{V}$ is denoted as estimates of covariance metric of the estimators. The Hausman test statistic follows a Chi-squared distribution with k degrees of freedom.

The final results show that the fixed effect model is preferred over the other models. Additionally, it is noteworthy that the fixed-effect model effectively manages all time-invariant disparities among the entities under consideration. As a result, the estimated coefficients derived from the fixed-effect model remain unbiased, as it adequately addresses any potential bias stemming from omitted time-invariant characteristics of bonds. Therefore, a fixed effect model is run to test the existence of green a bond premium based on Equation 1.

4.2 Step 2: The green bond premium's drivers

In this stage, the estimated green bond premia are regressed on a set of factors to identify its determinants since these factors vary across bonds. Then, a Least Squares Dummy Variable Estimator (LSDV) estimation with robustness is embraced to estimate the relationship between green bond premia and the green bond premium's drivers.

4.2.1 Green bond with an external review offers lower yields

To test the second Hypothesis, examining whether green bonds, subject to external verification, exhibit a lower yield compared to non-reviewed green bonds, the paper utilizes a multiple regression model that contains a dummy variable denoting external review (ER) and indicator variables to code information about the bonds' Rating, Sector (see Table 5 for variable definition). The external review (ER) variable, as outlined in the regression model (3), is a binary dummy variable assigned a value of 1 if the bond i has been certified by a third party. It is 0 for all other bonds. Thus, the coefficient β_1 measures the difference in pricing between non-reviewed and reviewed green bonds. Additionally, the logarithm of the issued amount for green bonds is employed to linearize the variable, facilitating interpretation through an exponential function. The construction of other independent variables aligns with the details outlined in Table 5. Although this section just only focuses on the Dummy variable external review predictor, the methods and concepts extend into other categorical variables to determine which factors contribute to the green bond premium. The specified Model (3) encompasses φ_i is the error term.

$$\hat{g}_i = \alpha + \beta_1 ER_i + \sum_{j=1}^{N_{rating}-1} \beta_{2,rating_j} 1_{rating_j} + \sum_{j=1}^{N_{sector}-1} \beta_{3,sector_j} 1_{sector_j} + \boldsymbol{\beta_4} \log(amt)_{\boldsymbol{i}} + \beta_5 Tenor_i + \varphi_i \quad (3)$$

Model (3) employs the Least Squares Dummy Variable Estimator (LSDV) to derive the coefficient estimates for the independent variables. In this approach, dummy variables such as 1_{rating_j} (1_{sector_j}) are utilized, taking the value of 1 for rating j (sector j), and zero elsewhere, and so on. The inclusion of the intercept term α is essential, with the omission of one dummy variable to mitigate multicollinearity. Additionally, as an alternative approach to illustrate the impact of rating and external review on the premium, this study incorporates dummy variables capturing interactions between rating and external review.

4.2.2 The premia of green bonds that fund different environmental projects are expected to vary

To assess the third Hypothesis, which posits that the allocation of green bond proceeds to various environmentally eligible projects will yield different effects on the green bond premium, a comprehensive analysis is conducted. Model (4) is employed to scrutinize the intricate relationship between the nature of the use of proceeds and their impact on the green bond premium. Model (4) is set up as follows:

$$\hat{g}_i = \alpha + \sum_{j=1}^{N_{UOP}-1} \beta_{1,UOP_j} 1_{UOP_j} + \sum_{j=1}^{N_{rating}-1} \beta_{2,rating_j} 1_{rating_j} + \beta_3 \log(amt)_i + \beta_4 Tenor_i + \varphi_i \quad (4)$$

An indicator variable for coding the categorical variable of the Use of Proceeds is added to Model (4) to discern the nuanced influence of distinct green-eligible projects on the overall performance of the green bond, which is described in Table 5. Similar to Model (3), Model (4) employs the Least Squares Dummy Variable Estimator (LSDV) to derive the coefficient estimates for the independent variables. In this approach, dummy variables such as 1_{UOP_j} (1_{rating_j}) are utilized, taking the value of 1 for UOP j (rating j), and zero elsewhere, and so on. Moreover, the interaction between the rating and the use of proceed is added to the Model for further understanding the drivers of green bond premium.

In Models (3) and (4), an LSDV estimation is employed to meticulously assess the factors influencing the green bond premium. This method hinges on the least squares assumptions, crucial for attaining unbiased and consistent estimators. To ensure the robustness of our analysis, this thesis rigorously adheres to three pivotal assumptions. Firstly, we assert that the conditional mean (or forecast error) is zero, signifying the independence and homogeneity of explanatory variables from the residual. Secondly, we demand homoscedastic errors and non-multicollinearity, fostering reliability and precision in our estimations. Lastly, we insist that explanatory variables exhibit no perfect correlation or multicollinearity. The meticulous examination of these assumptions, detailed in the subsequent section, bolsters the credibility and persuasiveness of our regression model.

Table 5: ***Variable definition.***

This table shows the explanatory variables and their construction.

Variable	Type	Description
UOP: Used of Proceeds	Category variable	The proceeds from bond sales are invested in generating environmental benefits, 9 categories are included in this sample: Clean Transport, Green Construction/Building, Energy Efficiency/Renewable Projects, Eligible Green Projects, Environmental Protection Projects, Climate Change Adaption, Aquatic Biodiversity Conservation, Access to Essential Services, and Renewable Energy Projects. These categories, then are encoded in no specific order.
ER: External Review	Dummy variable	A dummy binary is created for the external review factor, in which ER = 1 if green bonds possess a certificate from a third party, otherwise ER = 0. An issuer can have its Green Bond verified by qualified parties, such as auditors. This external review is proxied by the "Second opinions".
Rating	Ordinal variable	The green bond's rating is rated by different agencies (Moody's, Fitch, and S&P), in the collected sample. To analyze with a universal rating designation, the rating codes are translated to the S&P scales (such as AAA, AA+, BBB+, BB, CCC+, and NR or non-rated). After that, the ratings are grouped into different groups based on their investment grade: High grade, Upper medium grade, lower medium grade, Non-investment grade speculative

		and NR. Eventually, these groups are encoded from 1 to 5, with the highest grade is 1 and the lowest grade is 5 (Appendix)
Sector	Category variable	The Thomson Reuters Business Classification (TRBC) system for industry classification is used, in the case of the present sample, the category consists of: Financials, Industrials, Basic Materials and Energy, Consumer services and Retail, Utilities.
Tenor	Continuous variable	The year to maturity of the green bonds, measured on yearly basic .
Log_(amt)	Continuous variable	The logarithm of the issued amount of green bonds

5. Empirical results

This section is divided into two parts for clarity in presenting empirical results. The first part focuses on evaluating the impact of green characteristics on bond yields, differentiating between unlabeled and labeled green bonds. The second part is dedicated to discerning the determinants of the green bond premium.

5.1 There is an existence of green bond premium

Building on the research questions guiding this thesis, the initial hypothesis asserts that green bonds exhibit lower yields when compared with their corresponding conventional bonds. The quantification of the green bond premium is represented as g_i in the regression model (1), as described in the preceding section:

$$\Delta yield_{i,t} = g_i + \beta\ Liquidity\ premium_{i,t} + \varepsilon_{i,t}$$

Prior to conducting a regression analysis aimed at estimating the green bond premium, essential diagnostic tests are administered. Specifically, both a Breusch-Pagan test and an F-test are executed to assess the presence of heterogeneous effects, with the results corroborating the existence of heteroskedasticity. Furthermore, a test that follows Drukker's (2003) procedure and both a Durbin-Watson test are employed to ascertain the presence of autocorrelation within the time series data. Lastly, as discussed in the Methodology section, a Hausman test's result and F-test show that a fixed-effect estimator (FE) is more efficient than the random-effect estimator (RE) and Pooled-OLS estimator.

To account for both autocorrelation and heteroskedasticity effects in residuals, a fixed-effect estimation within robust standard errors is run (Hoechle, 2007). Moreover, the paper also conducts a fixed-effect regression using clustered standard errors, which is proved to show more consistency when estimating mean-differenced data (Kezdi, 2003).

Table 6 presents the outcomes of the first step regression, as outlined in Equation (1). The positive and statistically significant coefficient for the bid-ask spread difference in all three models indicates that the liquidity premium is positively correlated with a noteworthy alteration in the yield difference between bond pairs. Specifically, a 1 basis point (bp) increases in the percentage yield bid-ask spread differential corresponds to a 2.288 basis point (bp) increase in Delta yield. This finding diverges from Zerbib's (2019) results, and the author speculates that this disparity may stem from variations in the chosen data analysis methods, coupled with the impact of the COVID-19 pandemic on the yields of both green and brown bonds. Cui, Suleman, and Zhang (2022) assert that green bonds are more severely affected compared to conventional bonds during the pandemic.

Table 6: ***Results of first step regression****.*

This table shows the results of the fixed-effect estimator with robust regression.

	Dependent variable: $\Delta yield_{i,t}$		
	Default robust std.err.	Robust std. err.	Robust Cluster std.err.
$\text{Liquidity premium}_{\text{i,t}}$	2.288***	2.490***	2.288*
	(0.059)	(0.0732)	(1.312)
Constant	-0.01***	-0.01***	-0.01***
	(0.0016)	(0.002)	(0.002)
R_squared	0.042	0.042	0.042

Note: * p < 0.1; ** p < 0.05; *** p < 0.01

Absoluted values of statistics in the parentheses

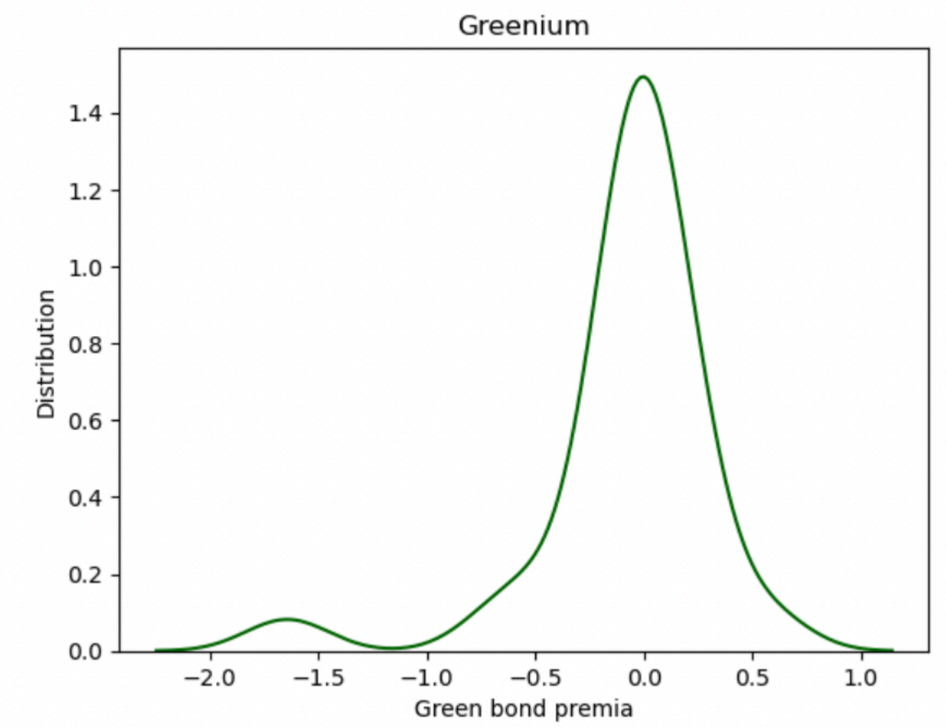
While the explanatory power of the regression is weak, as indicated by the R^2 value of 4.2%, the inclusion of bid-ask spread differences as a control variable for liquidity disparities shows statistically significant across all three standard error estimators (Table 6).

Moreover, the constant term (g_i) is statistically significant at a 1% significance level. The estimated "greenium" (g_i) for each bond couple takes precedence in this regression step. Across all three models, the results reveal a consistently negative yet modest premium. This implies that, on average, green bonds exhibit a lower yield compared to their matched conventional counterparts. The distribution of the green bond premia spans from -1,69 percentage to 0.6 percentage, with mean and median values of -0.08 bps and -0.0025 bps, respectively (Table 7). Additionally, the skewness and kurtosis values of the distribution are -2.42 and 8.2 respectively, indicating a distribution with negative skewness and leptokurtic characteristics. This suggests there are more extreme negative premia (left tail) in the premium distribution, and the extreme premia are more likely (Figure 9).

Table 7: ***Green bond premium's distribution across 51 bond couples***

$\widehat{g_\iota}$ (%)					
Min	1st Quart.	Median	Mean	3rd Quart.	Max
-1.69	-0.125	-0.0025	-0.08	0.07	0.6

Figure 9: ***The distribution of 51 bond pairs' green premium***

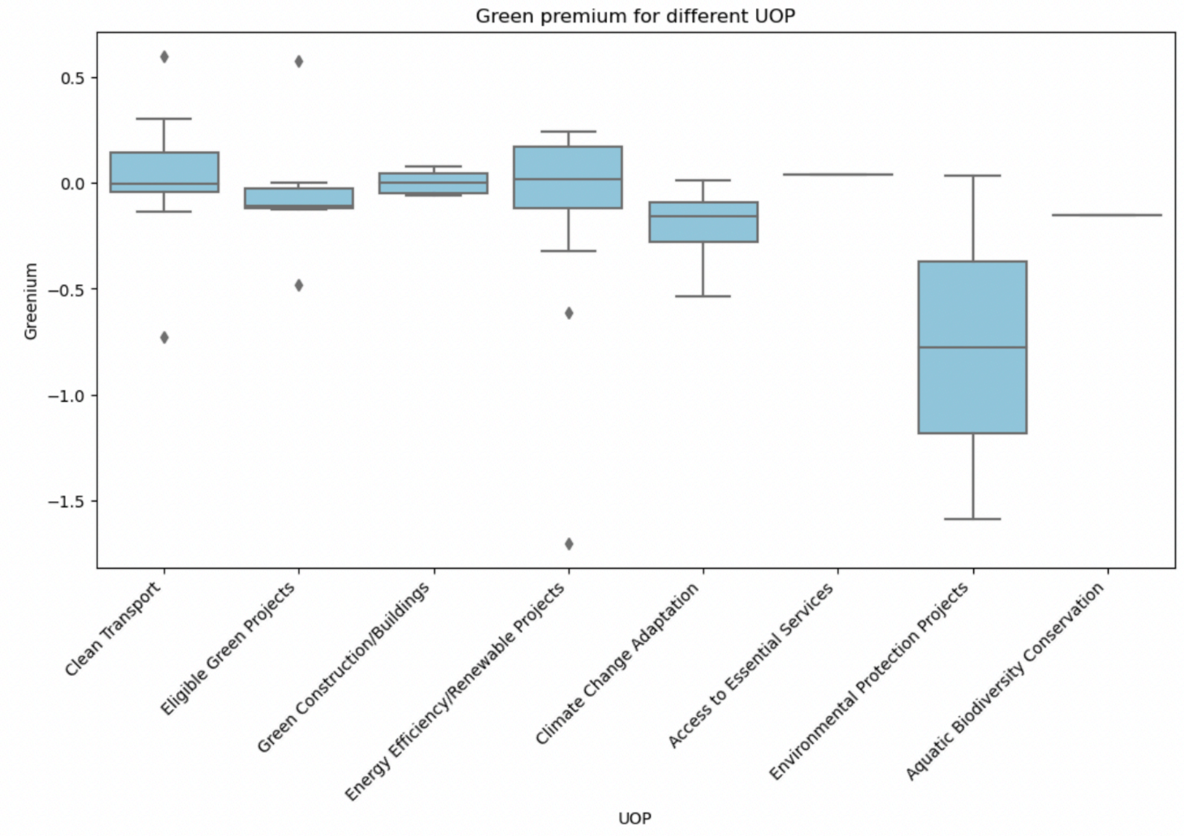


The author also observes that the cross-section means of green bond premia vary throughout the analysed period, with the most significant fluctuations occurring between 2018 and 2020 (Appendix 3).

A deeper analysis is undertaken to enhance an understanding of the green bond premium across various market segments. The author strategically dissects the analysed sample into multiple subsamples based on three key bond characteristics: Sector, Rating, and the Use of Proceeds. The calculation of the average premium for each segment is followed by a rigorous testing process to validate whether it significantly deviates from zero.

Figure 10: ***Green bond premia distribution by UOP.***

This figure shows the distribution of green bond premia of each green-eligible project. It is worth noting the most extreme value of premium appears in bonds issued to finance Environmental protection projects and Energy Efficiency/Renewable projects.



When assessing the difference in means from zero, conventional methods include the t-test or the Wilcoxon signed rank test. While the t-test is most effective with normally distributed samples, the Wilcoxon test serves as a distribution-free alternative, particularly recommended in cases where the distribution deviates from normality (Freidlin, Miao, and Gastwirth, 2003). Through a Shapiro-Wilk normality test, the normality hypothesis is rejected for various subsamples, except bonds in the Financials and Industrials sector, bonds with High grade, and bonds issued to finance Clean transport, Eligible green projects, Green construction/buildings, and Climate change adaption projects.

Figure 10 shows the distribution of bond premia categorized by the Use of Proceeds, the distributions of other subgroup premia are presented in Appendix 6&7. Accordingly, this paper opts for the Wilcoxon signed rank test to rigorously examine the disparities in premia of subgroups from zero, acknowledging its robustness in scenarios where normal distribution assumptions may not hold.

Table 8: ***Green bond premia in various market segments****.*

This table shows the mean and median of green bond premia by segments. The significance level at which the null hypothesis: H_0: $\hat{g}_i \neq 0$, and the number of green bonds in each subgroup are presented in columns 4 and 5 of the table. The Wilcoxon signed-rank test is used to test the hypothesis.

	Mean ($\hat{g}_i$)	Median ($\hat{g}_i$)	$\hat{g}_i \neq 0$	No. of GB
Full sample	-0.081	-0.003	**	51
Sector				
Basic Materials and Energy	-0.479	-0.094		4
Consumer service and Retail	-0.121	0.017		8
Financials	-0.041	-0.003	*	21
Industrials	-0.028	0.002		11
Utilities	-0.009	0.027		7
Rating				
High grade	-0.078	-0.076		6
Upper medium grade	0.0044	0.0005		11
Lower medium grade	0.145	0.002		5
Highly speculative	-0.029	-0.029		1
NR	-0.157	-0.004	**	28
Use of Proceed				
Clean Transport	0.026	-0.0026	*	15
Energy Efficiency/Renewable Projects	-0.110	0.017	***	16
Eligible Green Projects	-0.039	-0.107		6
Green Construction/Buildings	0.0014	-0.0019		6
Climate Change Adaptation	-0.209	-0.158		4
Environmental Protection Projects	-0.776	-0.776		2
Access to Essential Services	0.041	0.041		1
Aquatic Biodiversity Conservation	-0.150	-0.150		1

Note: *p<0.1; **p<0.05; ***p<0.01

Table 8 presents a comprehensive overview of average and median premia across various subsamples. In the overall sample, the average premia for 51 bond pairs is -8.1bps, demonstrating a significant deviation from zero at a 5% significance level. Financial green bonds exhibit a -4.1bps premium on average with a 10% significance level. Within the rating segment, only non-rated green bonds show a remarkable difference from zero at a 5% significance level, boasting an average premium of -15.7bps.

Moreover, green bonds allocated to Energy Efficiency/Renewable projects showcase a -11bps average premium, highly significant at a 99% level of confidence. Conversely, bonds earmarked for Clean Transport projects display a 2.6bps mean premium, achieving significance at a 90% confidence level. While other green bonds fail to register significant deviation from zero, it is noteworthy that a majority of them lean toward negative premia.

These findings present compelling evidence that participants in the European corporate bond market bear a slight negative yield premium when opting for European green bonds over their non-labeled counterparts. Notably, bondholders incur a statistically significant cost of 8.1 basis points when purchasing green bonds post-issuance. This indicates a willingness among investors to forego some interest returns in support of environmentally friendly projects. The identified green advantage aligns with similar conclusions drawn by Ehlers and Packer (2017), Hachenberg and Schiereck (2018), Kapraun et al. (2021), Zerbib (2019), Koziol et al. (2022), and ECB (2022). Consequently, these results lend robust support to Hypothesis 1, affirming that green bonds exhibit a negative yield spread compared to their matched non-green counterparts.

5.2 Green bond premium increases with external greenness valuation.

As the results in the previous section, the first regression analysis shows an average “greenium” of about -8.1bps on the entire sample. In the next step, the interest is switched to whether this “greenium” is different for bonds with and without an external review within the sample. Upon regression analysis of the entire sample, the result shows that a mean estimated error equals zero, albeit with a non-normally distributed pattern (Appendix 8). Heteroskedasticity is detected through the Breusch-Pagan test, yet the Variance Inflation Factor (VIF) calculation does not raise concerns about multicollinearity. Moreover, the variance-covariance matrix indicates no perfect correlation among independent variables

(Appendix 9). These results underscore the need for robustness of the regression model to control for the heteroskedasticity of the residuals.

Table 9: ***Results of step 2 regression in analysis of external verification.***

This table represents the results of two models based on the regression model (3): $\hat{g}_i = \alpha + \beta_1 ER_i + \sum_{j=1}^{N_{rating}-1} \beta_{2,rating_j} 1_{rating_j} + \sum_{j=1}^{N_{sector}-1} \beta_{3,sector_j} 1_{sector_j} + \beta_4 \log(amt)_i + \beta_5 Tenor_i + \varphi_i$, *in which the greenium is defined by the bonds' characteristics focusing on the credibility of the green bonds. The Rating is a categorical variable, including for groups: High grade (reference modality), Upper medium grade, Lower medium grade, and Non-rated. The Sector is a categorical variable, consisting of Financials (reference modality), Industrials, Basic Materials and Energy, Consumer Services and Retail, and Utilities.*

	Dependent variable: ($\hat{g}_i$)	
	(a)	(b)
Constant	-0.645	-0.403
	(1.164)	(1.345)
ER	-0.330**	-1.023***
	(0.159)	(0.271)
Rating		
Upper medium grade	0.280	0.262
	(0.229)	(0.167)
Lower medium grade	0.257	0.047
	(0.234)	(0.249)
Non-rated	0.016	-0.424*
	(0.219)	(0.230)
Sector		
Industrials	-0.097	-0.107
	(0.147)	(0.148)
Basic Materials and Energy	-0.544	-0.565
	(0.398)	(0.408)
Consumer services and Retail	-0.089	0.096
	(0.123)	(0.131)
Utilities	0.148	0.080
	(0.112)	(0.104)
Log_issued amount	0.034	0.041
	(0.071)	(0.075)
Tenor	-0.023*	-0.021
	(0.012)	(0.012)
RatingxER		0.273***
		(0.092)
Obs.no	44	44
R^2	33.60%	44.87%
F-statistic	F(10,33) = 2.25**	F(11,32)=3.8***
Note: *p<0.1; **p<0.05; ***p<0.01, Robust std.err in the parentheses		

Conducting multiple regression of $\hat{g}_i$ against various green bond characteristics, this analysis aims to identify whether the credibility of a green bond can be linked to a larger “greenium”. To ensure the reliability of our results, dummy variables are strategically employed in models, capturing a minimum of three observations each to prevent artificially high R^2 values. Consequently, the total number of observed premia is streamlined to 45 after eliminating dummy variables with fewer than 3 observations.

Table 9 shows two regression models with distinct specifications: (a) presents the broadest specification, aligning with the equation of model (3); (b) includes the interaction variable Rating x ER. Notably, the R^2 values exhibit a steady increase from (a) to (b), underscoring the enhanced explanatory power achieved by incorporating the interaction variable. Furthermore, the F-statistic in models (a) and (b) remains below a 5% significance level, attesting to the statistical significance of the regression model and its ability to robustly capture underlying patterns in the sample data.

Specifications (a) and (b) reveal nuanced insights into the impact on the premium concerning Financial bonds. Green bonds originating from the Industrials, Basic Materials, and Energy segments exert a more pronounced effect on the premium, while those issued by the Utility industry exhibit a comparatively lesser impact. Noteworthy distinctions arise in the influence of Consumer Services and Retail: model (a) suggests a heightened effect, which contrasts with a diminished effect in model (b) when compared with Financial segment bonds. However, it is crucial to note that these subsectors, while displaying varying effects, do not exhibit a statistically significant impact on the premium.

In contrast, the impact of the external review on the green bond premium emerges as a significant factor in both models (a) and (b), and remains negative in the two models, showing that green bonds with an external review will have a higher negative green bond premium. Notably, green bonds undergoing external verification demonstrate a notable increase in the green bond premium, with a 33bps higher than ones without a review (specification (a)). The exploration of RatingxER in the specification (b) unveils a highly statistically significant influence on the green bond premium, while the rating alone exhibits no significant impact in specification (a). Nonetheless, the analysis reveals that lower-rated bonds correspond to a downward green premium. A special case worth noting is non-rated bonds lacking external certification, showcasing a substantial -42.4 basis points (bps) effect compared to high-grade bonds. As for non-rated bonds holding an external verification, the impact on the premium is -15.1bps with respect to high-grade bonds.

In both specifications, the quantity of issued green bonds appears to correlate with a lower greenium, though this observation lacks statistical significance. Furthermore, both models indicate that an extended time to maturity correlates with a heightened green bond premium, with significance evident solely in the model (a).

These findings align with existing literature that explores the association between external greenness evaluations and premium increases. In a study conducted by Dorfleitner, Utz, and Zhang (2021), investors were observed to accept premiums of up to 5 basis points for bonds with a robust environmental agenda. Correspondingly, the ECB's (2022) research suggests that only externally reviewed green bonds exhibit a statistically significant greenium, with spreads approximately 5.3 basis points lower than conventional bonds and 15.6 basis points lower than simple green bonds.

Indeed, the outcomes of this analysis underscore that bondholders in the European market are willing to accept a 33 basis points lower yield for bonds that undergo external verification compared to simple green bonds. Notably, this effect of external validation is particularly pronounced for high-grade bonds, further emphasizing the significance of external review in influencing market dynamics.

5.3 The most pronounced premium is observed in the case of green bonds earmarked for financing Climate Change Adaptation.

In the subsequent phase, the author seeks to examine potential variations in the “greenium” of green bonds contingent upon their designated Use of Proceeds. Beyond the influence of external reviews, the nature of environment-supported projects can play a pivotal role in shaping bond pricing. Investors may prioritize projects contributing to lower greenhouse gas emissions and fostering climate-resilient development. Consequently, the formulation of Hypothesis 3 is inspired: *Green bonds’ proceeds financed to different environmentally eligible projects will have different effects on the green bond premium*.

Table 10 represents the results of three specified models: (c) performs the most general regression model based on model (4), (d) the binary variable of external review is included, and (e) presents solely the UOP x Rating cross effects.

Table 10: ***Results of the step 2 regression in analysis of UOP.***

This table represents the results of three models based on the regression model (4): $\hat{g}_i = \alpha + \sum_{j=1}^{N_{UOP}-1} \beta_{1,UOP_j} 1_{UOP_j} + \sum_{j=1}^{N_{rating}-1} \beta_{2,rating_j} 1_{rating} + \beta_3 \, log(amt)_i + \beta_4 Tenor_i + \varphi_i$*, in which the greenium is defined by the bonds' characteristics focusing on the UOP of the green bonds. The Rating is a categorical variable, including for groups: High grade (reference modality), Upper medium grade, Lower medium grade, and Non-rated. The UOP is a categorical variable, consisting of Clean Transport (reference modality), Climate Change Adaptation, Eligible Green Projects, Energy Efficiency/ Renewable projects, and Green Construction/Buildings.*

	Dependent variable ($\hat{g}_i$)		
	(c)	(d)	(e)
Constant	1.028	1.165	0.111
	(0.951)	(0.896)	(1.56)
ER		-0.219**	
		(0.107)	
Rating			
Upper medium grade	0.141	0.251	
	(0.206)	(0.175)	
Lower medium grade	0.079	0.093	
	(0.192)	(0.178)	
Non-rated	-0.174	-0.106	
	(0.230)	(0.181)	
Log_issued amount	-0.047	-0.049	-0.002
	(0.048)	(0.047)	(0.091)
Tenor	-0.008	-0.009	-0.018
	(0.007)	(0.007)	(0.012)
UOP			
Climate Change Adaptation	-0.324*	-0.306**	
	(0.163)	(0.125)	
Eligible Green Projects	-0.284**	-0.279*	
	(0.117)	(0.147)	
Energy Efficiency/Renewable projects	-0.295	-0.288	
	(0.210)	(0.197)	
Green Construction/Buildings	-0.028	0.010	
	(0.099)	(0.121)	
Clean Transport x Non-rated			0.291***
			(0.033)
Climate change adaptation x High grade			-0.518***
			(0.034)
Climate change adaptation x Non-rated			-0.167***
			(0.058)

Eligible Green project x Upper medium grade			-0.275**
			(0.130)
Eligible Green project x Lower medium grade			-0.056
			(0.105)
Obs.no	44	44	44
R^2	19.25	26.19%	29.40%
F-statistic	F(9,34) = 3.75***	F(10,33) = 2.98***	F(16,27)=0.7
Note: *p<0.1; **p<0.05; ***p<0.01, Robust std.err in the parentheses			

To mitigate the potential for information overload stemming from an extensive presentation of UOP x Rating cross variables, Table 10 exclusively showcases statistically significant findings of specification (e). The complete results of specification (e) are meticulously detailed in Appendix 11 for comprehensive reference.

For each designated Use of Proceeds (UOP) category, the coefficients illuminate the influence of different utilization categories on the green bond premium. Negative coefficients imply that green bonds allocated to a specific UOP category exhibit a higher premium relative to the premium of those designated for financing Clean Transport projects, considered as the reference category. Notably, in both specifications (c) and (d), solely the Climate Change Adaptation and Eligible Green Projects categories manifest a statistically significant and negative impact on the premium. Specifically, within these two influential UOP categories: Green bonds assigned to Climate Change Adaptation projects command a 32.4 bps higher premium in comparison to the reference bond premium. Likewise, green bonds directed towards Eligible Green Projects are linked to a 28.4 bps higher premium (as indicated in the specification (c)). The external review variable added in specification (d) shows a statistical significance of a 95% level of confidence, suggesting that reviewed green bonds bear a higher premium compared to those without. This is consistent with the findings in the previous analysis.

Examining specification (e), the green bond premia can be presented in absolute terms. The exploration of Use of Proceeds (UOP) x Rating cross effects reveals a nuanced pattern wherein the level of premia varies with the rating of bonds allocated for financing specific projects, specifically, the lower the rating, the lower the premium. Illustratively, consider the following instances within this category: Bonds designated for financing Climate Change Adaptation with high grades exhibit a yield of 51.8 basis points (bps) lower than that of an equivalent conventional bond. Meanwhile, non-rated bonds within this category carry a 16.7 bps lower yield compared to their equivalent conventional bonds. These findings highlight the differential impact of Climate Change Adaptation project financing on green bond premia, emphasizing the significance of credit ratings in shaping these variations. Similarly, green bonds earmarked for supporting Eligible Green projects with upper-medium grades and lower-medium grades bear 27.5 and 5.6 bps lower yields with respect to their matched conventional bonds, respectively.

The coefficients for upper and lower medium-grade bonds (specification (c) and (d)) suggest a trend of lower green bond premiums compared to high-grade bonds, while non-rated bonds show a trend of higher green bond premiums. However, these trends are not statistically significant in the presented models, indicating that the observed differences in premiums across rating categories may not be conclusive or significant in a statistical sense.

These findings highlight that the green bond premium is particularly notable for bonds allocated to financing Climate Change Adaptation and Eligible Green projects. While there might be a gap in current studies specifically focusing on the impact of green bonds' Use of Proceeds on pricing, the observation aligns with the broader sentiment seen in sustainable finance.

Investors, motivated by a commitment to address climate change and achieve global temperature reduction goals, demonstrate a clear willingness to allocate funds toward environmentally beneficial projects (Le Houérou, 2019, Hu, Zhong, and Cao, 2022). This willingness translates into a recognition that green bonds, despite potentially yielding lower financial returns, play a crucial role in advancing sustainability objectives. Investors, thus, prioritize the broader environmental and social impacts of their investments, acknowledging the urgency of addressing climate change as a critical global priority.

6. Conclusion

The rapid expansion of the green bond market has attracted the interest of researchers, who seek to ascertain whether these instruments confer a pricing advantage over conventional bonds and to identify the premium's drivers. However, at the time of conducting this research, to the best of the author's knowledge, there is a dearth of comprehensive reporting regarding how the allocation of bond proceeds to green projects influences the pricing of green bonds.

By delving into the secondary European corporate bond markets, this Thesis identified 51 bond pairs using a rigorous matching method encompassing bonds issued between January 2018 and October 2023. This dataset comprises both green-labeled and non-green bonds. The analysis aims to gauge the green pricing effect by delineating the green bond premium, quantified as the yield spreads between green bonds and their corresponding conventional counterparts while accounting for differences in liquidity.

Based on the examined sample, this paper adopts a two-step regression methodology inspired by Zerbib's research (2019), albeit with tailored adjustments for a specific focus analysis. This approach is employed to estimate the "greenium" and its underlying determinants. Initial findings indicate that, on average, the anticipated green bond premium is negative and highly statistically significant, averaging 8.1 basis points across 51 bond pairs. Subsequently, the study identifies external review, time to maturity, and the specific allocation of proceeds from green bonds to various environmental projects as significant drivers of the green bond premium. Specifically, the negative "greenium" is more pronounced for reviewed green bonds and long-term bonds. Moreover, green bonds allocated towards Climate Change Adaptation and other eligible green projects exhibit a higher premium, particularly notable for high-grade bonds within these categories.

This study contributes valuable insights with significant practical and research implications. Firstly, the findings underscore the pivotal role of independent external reviews in shaping green bond pricing dynamics. Green bonds backed by independent external certifications exhibit a negative premium compared to their non-reviewed counterparts. This highlights investors' sensitivity to information asymmetry between issuers and investors. Enhanced transparency through independent reviews instills greater confidence in green assets, prompting fixed-income investors to accept lower returns. Consequently, it becomes imperative for issuers to consider undergoing external reviews prior to green bond issuance, as it can effectively reduce the cost of capital. Moreover, to facilitate the redirection of capital towards environmental and sustainable projects, governmental policies and regulatory authorities should establish standardized frameworks and affordable mechanisms for assessing the greenness of bonds. However, it is worth noting that conducting green liability assessments before issuance increases the costs of issuance for issuers. Consequently, issuers may adjust green bond prices upwards to compensate for these additional costs, thereby influencing pricing dynamics.

Secondly, the study identifies varying effects of different Uses of Proceeds on green bond premia, a segment that has been relatively underexplored in existing research. This finding presents a significant opportunity to stimulate further analysis and exploration into the dynamics of bond proceeds in shaping green bond pricing. By shedding light on this aspect, the study opens avenues for other researchers to delve deeper into understanding how specific applications of bond proceeds impact green bond premia, thereby enriching the comprehension of the intricacies of green finance.

However, the author acknowledges several limitations inherent in this study. The primary constraint pertains to the quality of the data, which is contingent upon the sample size. Focused solely on the European corporate bond markets post-issuance, the limited number of bond pairs and the unavailability of certain data elements may potentially compromise the accuracy and statistical significance of the regression results. Moreover, the calculation of the green bond premium, derived from the ask yields of green bonds and their matched conventional counterparts, may not fully capture the true trading prices of these bonds in the market and the sentiment of investors towards these instruments.

As a result, future research in this area could benefit from a broader dataset encompassing a larger sample size and incorporating historical trading data. Such an approach would provide a more comprehensive understanding of the dynamics influencing green bond pricing and investor behavior, thus yielding more robust and reliable insights into this burgeoning field of study.

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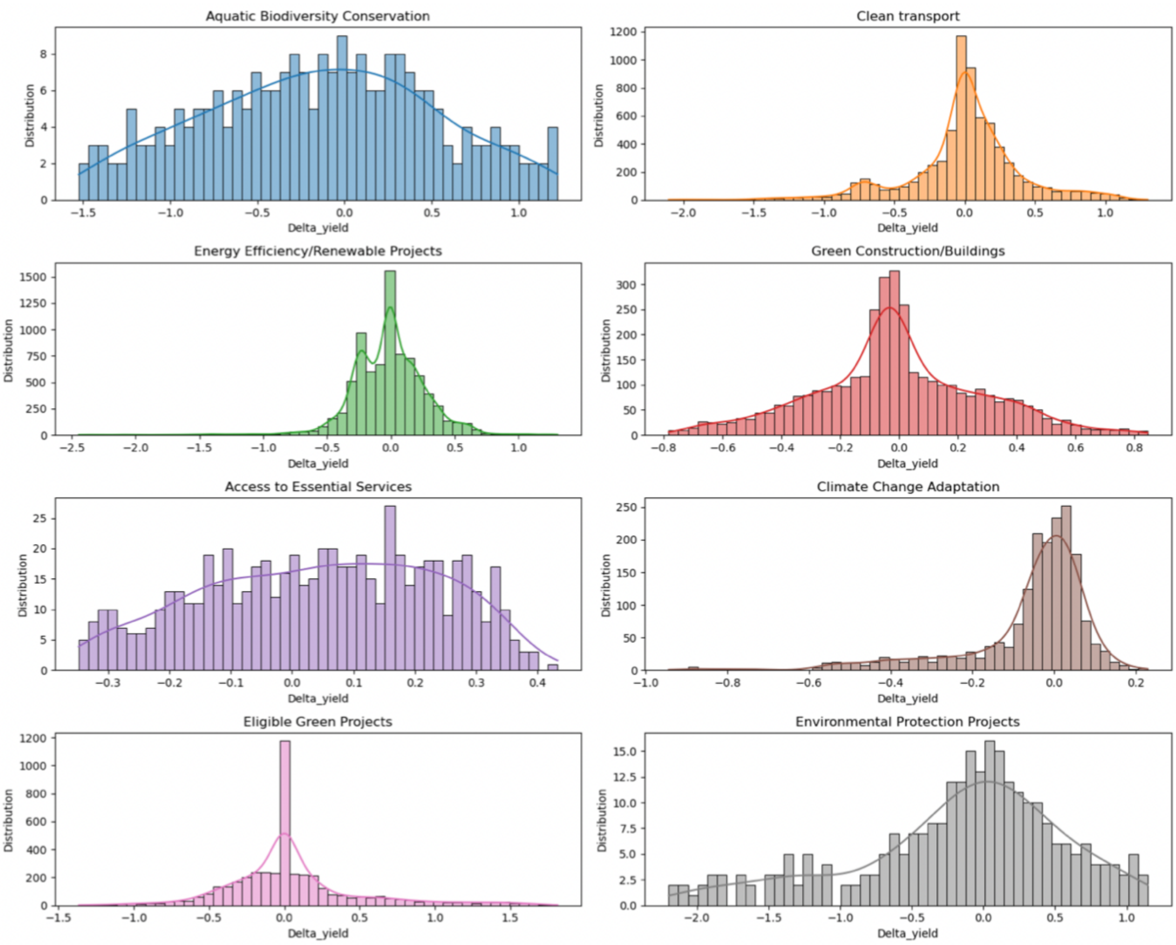
Appendices:

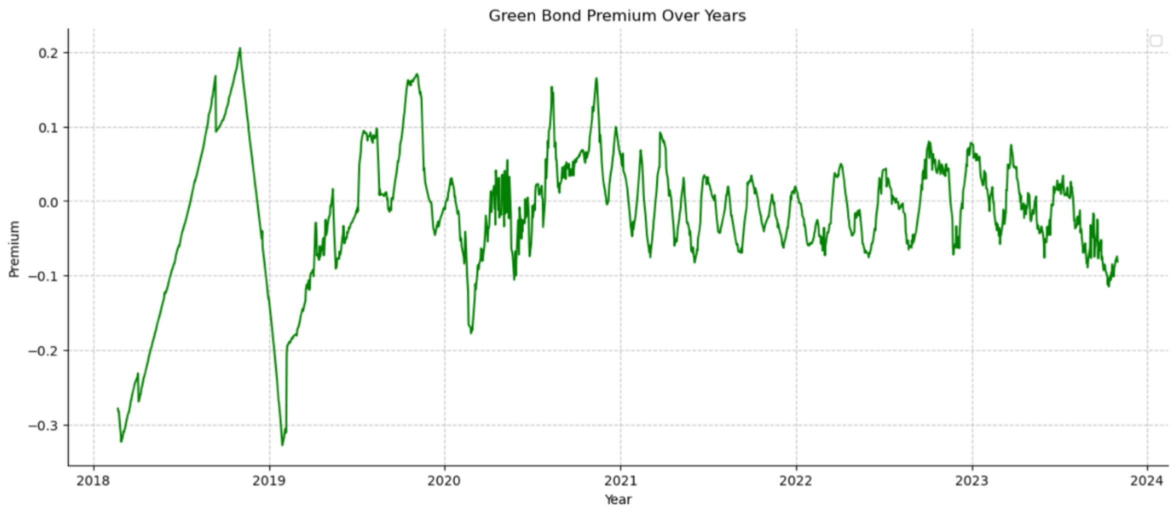
Appendix 1: ***Rating criteria***

Rating	Investment grade	Categorial variable
AA+, AA, AA-	High grade	1
A+, A, A-	Upper medium grade	2
BBB+, BBB, BBB-	Lower medium grade	3
BB+, BB, BB-	Non-investment grate speculative	4
NR	No rating	5

Appendix 2: ***distribution of bond yields' differences categorized by the use of proceeds***



Appendix 3: ***Cross-sectional green bond premium over time***



Appendix 4: ***List of green bond issuers and their average green bond premia***

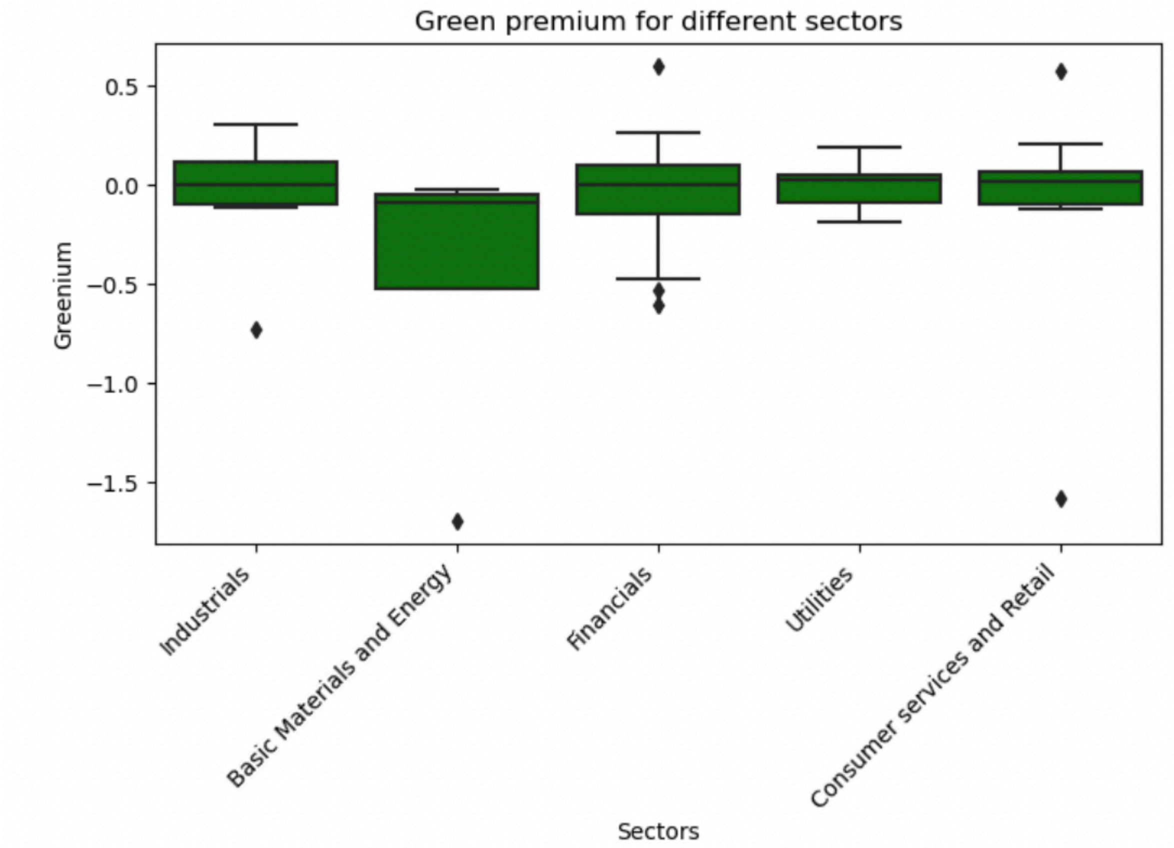
No	Issuer	RIC	**premium**
1	A Energi AS	NO1080948=	-0,05886703
2	AMAG Leasing AG	CH121171324=	0,064454613
3	Atenor SA	BE0002775568=	-0,727022987
4	Atenor SA	BE0002776574=	-0,101719269
5	Atrium Ljungberg AB	SE0013883550=	0,297769541
6	AutoWallis Nyrt	HU00360664=	0,159645898
7	Boliden AB	SE0013105251=	-0,132005873
8	Boliden AB	SE0013105269=	-1,688354782
9	Bonheur ASA	NO1089333=	0,189854239
10	Bpifrance SA	FR001400IV17=	-0,002649588
11	Brage Finans AS	NO1254957=	-0,490688732
12	Brage Finans AS	NO1284245=	-0,053933622
13	CNP Assurances SA	FR0013463775=	-0,32081226
14	Clariant AG	CH121019814=	-0,055506215
15	Cyfrowy Polsat SA	PLCFRPT00054=	0,572087899
16	Eidsiva Energi AS	NO1086661=	0,026932407
17	Eidsiva Energi AS	NO1086662=	0,049127147
18	Eidsiva Energi AS	NO1100261=	0,040941536

19	Engie SA	FR0013245859=	-0,029028177
20	Fastighets AB Balder	SE0011869825=	0,00185642
21	Ferde AS	NO1242353=	0,023473569
22	Ferde AS	NO1275143=	0,018728322
23	Ferde AS	NO1281312=	0,015271333
24	Hafslund AS	NO1096037=	-0,125025264
25	Hufvudstaden AB	SE0013883246=	0,096736513
26	Hypo Vorarlberg Bank AG	CH52515846=	0,000411294
27	ICA Gruppen AB	SE0013884137=	-1,581998085
28	ICA Gruppen AB	SE0013884145=	-0,12321403
29	Icade SA	FR0013281755=	-0,096507944
30	Nordea Bank Abp	NO1293352=	-0,611991615
31	Norske Tog AS	NO1087000=	-0,113980183
32	Samhallsbyggnadsbolaget I Norden AB	SE0012256741=	-0,033810759
33	Sparbanken Skane AB (publ)	SE0013105210=	0,243349635
34	Sparebank 1 Helgeland	NO1108954=	-0,189419052
35	Sparebank 1 Ostlandet	NO1270260=	0,602784439
36	Sparebank 1 Ostlandet	NO1294040=	0,232005895
37	Sparebank 1 Sorost-Norge	NO1117973=	0,111353261
38	Sparebanken Vest	NO1249005=	0,263303397
39	Specialfastigheter Sverige AB	SE0013884400=	-0,536021776
40	Specialfastigheter Sverige AB	SE0017780364=	-0,150803196
41	Sunnhordland Kraftlag AS	NO1096422=	-0,190712638
42	Svenska Cellulosa SCA AB	SE0013102381=	0,223290941
43	Vasakronan AB (publ)	NO1081520=	0,012848815
44	Volvofinans Bank AB	SE0013359965=	0,040835251
45	Volvofinans Bank AB	SE0013359973=	-0,030405071
46	Volvofinans Bank AB	SE0013883279=	-0,023708997
47	Volvofinans Bank AB	SE0013883485=	0,075954251
48	Volvofinans Bank AB	SE0017780265=	0,033228536
49	Volvofinans Bank AB	SE0017780273=	-0,135854128
50	Willhem AB (publ)	SE0012013001=	0,203841815
51	Willhem AB (publ)	SE0013104775=	-0,087585159

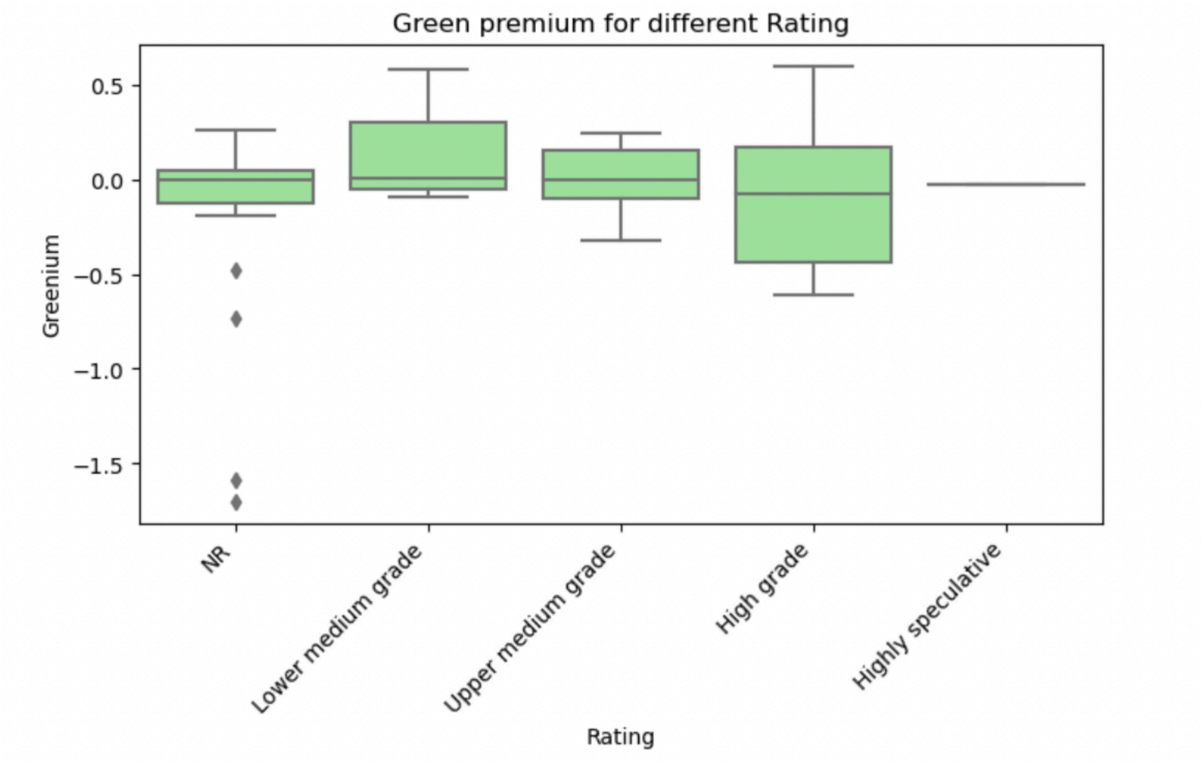
*Appendix 5: **Robustness test results of the step 1 regression**.*

	Dept			
	Test	Statistic	P-value	Conclusion
Heteroskedasticity	Breusch_pagan	961.03	0.000	Heteroskedasticity
Heteroskedasticity	F-Test	329.94	0.000	Heteroskedasticity
Serial correlation	Drukker (2003)	1.1e+05	0.000	Serial correlation
Serial correlation	Durbin Watson	0.0423517		Serial correlation
Goodness of fit	Hausman test	34.33	0.000	Fixed-effect
Goodness of fit	F-test	386.43	0.000	Fixed-effect

*Appendix 6: **Greenium distribution by Sectors***

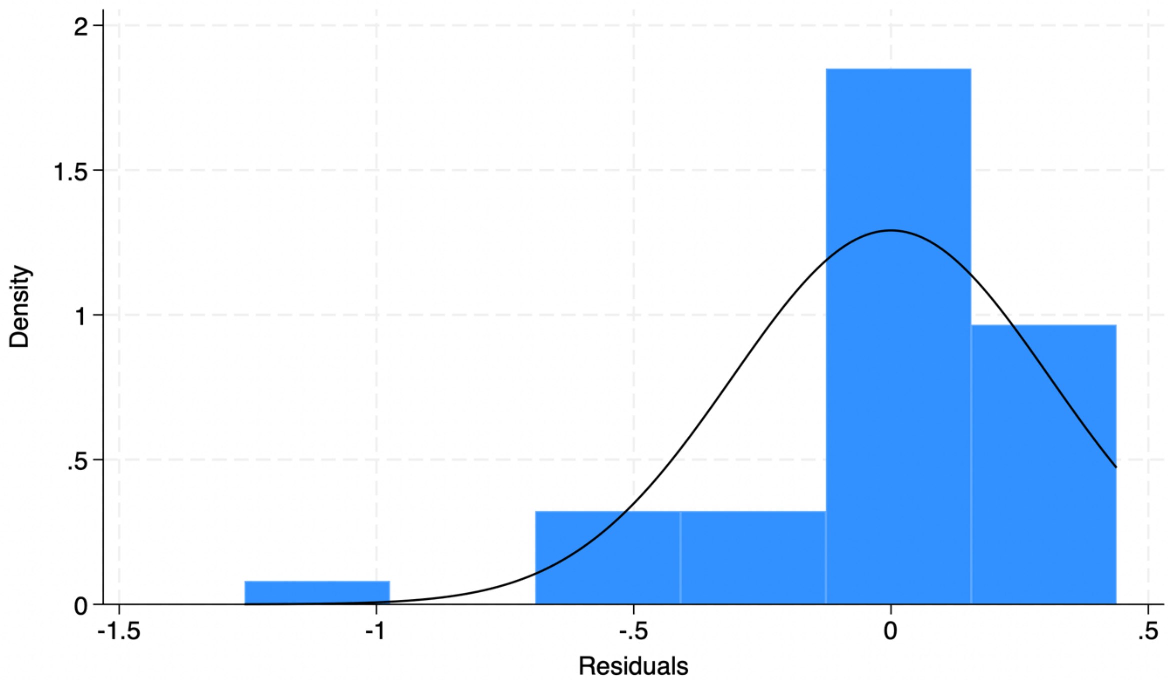


Appendix 7: ***Greenium Distribution by Rating***



Appendix 8: ***Error term's distribution****.*

This Appendix shows the distribution of the errors estimated in the step 2 regression on the entire sample. The estimated residual has mean of zero and non-normal distribution.



Appendix 9: ***Variance-covariance matrix among independent variables***

	ER	Rating	Sector	Log_amt	Tenor	UOP
ER	1					
Rating	0.0831	1				
Sector	0.3186	0.1384	1			
Log_amt	-0.1280	-0.2157	-0.1432	1		
Tenor	-0.0406	-0.2677	0.0064	0.4907	1	
UOP	0.1241	-0.0771	0.0521	-0.1290	0.0856	1

Appendix 10: ***Completed results of specification (e) in step 2 regression***

	Dependent variable ($\hat{g}_i$)
	(e)
Constant	0.111
	(1.56)
Log_issued amount	-0.002
	(0.091)
Tenor	-0.018
	(0.012)
Clean Transport x High grade	0.352
	(0.246)
Clean Transport x Upper medium grade	-0.066
	(0.212)
Clean Transport x Lower medium grade	-0.089
	(0.287)
Clean Transport x Non-rated	0.291***
	(0.033)
Climate change adaptation x High grade	-0.518***
	(0.034)
Climate change adaptation x Lower medium grade	0.017
	(0.046)
Climate change adaptation x Non-rated	-0.167***
	(0.058)
Eligible Green project x Upper medium grade	-0.275**
	(0.130)
Eligible Green project x lower mdeium grade	-0.056
	(0.105)
Energy Efficiency/Renewable x High grade	-0.179
	(0.309)
Energy Efficiency/Renewable x Upper medium grade	-0.419
	(0.247)

Energy Efficiency/Renewable x Lower medium grade	0.064
	(0.219)
Energy Efficiency/Renewable x Non-rated	-0.075
	(0.398)
Green Construction/Building x Non-rated	-0.052
	(0.433)
Obs.no	44
R^2	29.40%
F-statistic	F(16,27)=0.7
Note: *p<0.1; **p<0.05; ***p<0.01	