# Essays on Green Bonds

Shijie Jin

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## Acknowledgements

I must acknowledge that this work represents not just individual effort but the culmination of collective support from mentors, colleagues, friends, and family who have contributed in countless ways to its completion. The intellectual journey documented in this thesis would not have been possible without their guidance, encouragement, and assistance at every stage. Their contributions, both direct and indirect, have shaped not only the content of this research but also my development as a scholar and as a person. This work stands as a testament to the power of collaborative intellectual endeavour and the generous spirit of those who invest in the next generation of researchers.

First and foremost, I am profoundly thankful to Professor Peng Zhou, whose exceptional mentorship has been the cornerstone of my doctoral experience. His unfailing enthusiasm for discovery, combined with his meticulous attention to methodological detail, challenged me to refine my ideas continuously and pursue excellence in every aspect of this research. My discussions, often stretching well beyond conventional office hours and extending into evenings and weekends, instilled in me a rigorous approach to scholarly inquiry that emphasizes both theoretical depth and empirical precision. Professor Zhou's ability to identify the most promising research directions while maintaining the highest standards of academic integrity has been truly inspiring. His guidance in navigating the complexities of sustainable finance research, from understanding market mechanisms to grappling with environmental impact measurement, has been invaluable. Beyond his academic expertise, his patience and encouragement in helping me develop as an independent researcher have made this journey not only intellectually rewarding but also personally transformative.

Meanwhile, I am equally indebted to Professor Khelifa Mazouz, whose broad vision and strategic advice helped me connect individual findings to the wider disciplinary conversation in finance and economics. Professor Mazouz's remarkable ability to see the forest while attending to the trees enabled me to understand how my specific research on green bond heterogeneity fits within the broader landscape of sustainable finance and environmental economics. His encouragement to think critically yet creatively has been instrumental in developing my academic independence and confidence as a researcher. Professor Mazouz's insights into market dynamics, institutional behaviour, and the practical implications of academic research have enriched every chapter of this thesis. His constructive feedback during our regular meetings helped me refine my arguments, strengthen my empirical strategies, and ensure that my work maintains relevance for both academic audiences and policy practitioners. The breadth of his knowledge across financial markets and his ability to identify connections between seemingly disparate phenomena have expanded my understanding of how green bonds function within the complex ecosystem of global finance.

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Yet another essential contributor was Professor Qingwei Wang, my panel reviewer, whose role extended far beyond formal evaluation to encompass genuine intellectual collaboration. His incisive questions and perceptive comments during periodic reviews prompted me to refine key arguments, strengthen theoretical foundations, and improve the overall coherence of the thesis. Professor Wang's deep understanding of financial markets and his keen eye for identifying potential weaknesses in empirical strategies helped me anticipate and address concerns that might arise from academic reviewers and policy practitioners. His suggestions for alternative approaches and his challenges to my initial assumptions forced me to think more deeply about the mechanisms underlying green bond market behaviour. The periodic review meetings became opportunities for intellectual growth that extended well beyond simple progress reporting, evolving into substantive discussions about the broader implications of my findings for sustainable finance theory and practice.

Years from now, I hope this research will contribute to the ongoing efforts to build more effective and transparent sustainable finance systems that can meaningfully address the environmental challenges facing our world. The support and guidance I have received during this doctoral journey have not only enabled the completion of this specific project but have also prepared me to continue contributing to the scholarly understanding of sustainable finance and its role in addressing global environmental challenges. To all who have supported this journey, I offer my heartfelt thanks and the commitment to carry forward the values of rigorous scholarship, intellectual curiosity, and collaborative inquiry that they have exemplified.

## Statement for Chapter 3

This chapter contains material that has been published as a peer-reviewed journal article. The chapter is based on the following publication:

Zhou, P., Jin, S., Mazouz, K., Ding, W. 2025. Choices and effects of different green labels in the EU bond market. J. Bus. Ethics 200. https://doi.org/10.1007/s10551-024-05847-0

In accordance with the University's policies on the inclusion of published work in thesis, I hereby provide a statement of authorship and contribution:

- I declare that I am one of the authors of this published paper.
- All of my supervisors (co-authers) have verified my contribution and support the inclusion of this paper in the thesis.
- My contribution to this publication includs the development of research ideas, the formulation of research questions, and the design of methodological approaches. I also managed revisions in response to peer-review comments and prepared the final submitted version of the paper.

## Abstract

This thesis examines the heterogeneous nature of green bonds in the European Union (EU) financial market, with a particular focus on how the credibility of environmental labelling shapes their financial and risk-related properties. While green bonds are often treated as a homogeneous asset class, this research demonstrates that substantial differences exist depending on whether bonds are self-labelled or externally certified.

The thesis consists of three interconnected studies. First, a systematic literature review of 206 peer-reviewed articles identifies three main research areas: asset pricing, corporate finance, and environmental impact. The review documents a clear shift in the literature from a focus on financial characteristics toward increasing attention to environmental credibility and sustainability outcomes.

Second, the thesis investigates how different labelling approaches affect bond pricing and investor attention. Using an endogenous treatment effect model and a hand-collected dataset of EU green bonds, the results show that externally labelled bonds exhibit significantly lower yields and attract greater investor attention compared to self-labelled bonds. This suggests that credible certification enhances both signalling effects and investor preferences for sustainability.

Third, the thesis explores the role of green bonds as hedging instruments during periods of extreme market stress, such as the COVID-19 pandemic and the Russia–Ukraine war. The findings reveal that only externally labelled green bonds provide meaningful hedging benefits under tail-risk scenarios, while self-labelled bonds behave similarly to conventional assets.

Overall, the thesis highlights the critical importance of label credibility in shaping the economic value of green bonds. By moving beyond a binary classification of green versus non-green assets, it provides new insights into how credibility influences pricing, investor behaviour, and risk management in sustainable finance markets.

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# Chapter 1. General Introduction

## 1.1. Background and Motivation

In the past two decades, the escalating urgency of addressing climate change has catalysed a profound transformation across global policy agendas and capital markets. The ambitious goals set forth in international accords, such as the Paris Agreement, underscore the colossal scale of investment required to facilitate the transition toward a sustainable, low-carbon economy. Within this context, financial instruments that explicitly integrate environmental objectives have emerged as indispensable tools for mobilizing the necessary capital. Among the innovations in this burgeoning field of sustainable finance, green bonds have achieved particular prominence. These debt instruments are uniquely defined by their earmarking of proceeds for environmentally beneficial projects, such as renewable energy, energy efficiency, and clean transportation.

Since the inaugural issuance by the European Investment Bank in 2007, the green bond market has experienced exponential growth, surpassing one trillion U.S. dollars in cumulative issuance globally and involving issuers from over 100 countries. The European Union (EU) has firmly established itself as the vanguard of this movement, cultivating a vibrant and rapidly expanding green bond market underpinned by progressive regulatory initiatives such as the EU Green Bond Standard (EU GBS) and the EU Taxonomy for Sustainable Activities, robust institutional frameworks, and strong, sustained investor demand. This leadership role makes the EU a critical and compelling setting for in-depth empirical investigation.

Despite green bonds' surging popularity and central role in climate finance, fundamental questions about the market dynamics and financial characteristics of green bonds remain subjects of vigorous academic debate. Empirical research has yielded inconsistent and often contradictory evidence regarding the existence and magnitude of a so-called "greenium", meaning the potential yield discount that green bonds might offer relative to their conventional, non-green counterparts. While some studies find a small but significant greenium, suggesting investors are willing to pay a premium for sustainability, others report that this yield differential disappears after controlling for all relevant bond and issuer characteristics. Similarly, research into investor behaviour has produced mixed results, with some studies documenting heightened market attention and distinct investor clienteles for green bonds, while others find negligible differences from conventional debt markets. More recently, as the market has been tested by systemic crises, scholars have begun to examine the risk properties of green bonds, including their resilience and potential as hedging instruments, yet these findings also remain largely inconclusive.

A crucial, yet often overlooked, factor contributing to this landscape of inconsistent evidence is the inherent heterogeneity within green bonds. Not all green bonds are created equal: issuers can choose to self-label their bonds as green or to obtain external verification of their environmental credentials. These labelling choices reflect not only issuer preferences but also strategic considerations, credibility concerns, and resource constraints. Importantly, the credibility of a bond's label can shape investor perceptions, influence demand, and determine how the bond behaves under normal and stressed market conditions. Labelling is therefore not a neutral disclosure but an endogenous decision with potential financial consequences.

Moreover, as the market matures, questions arise about the long-term sustainability of the green bond premium, the credibility of environmental claims, and the extent to which these instruments deliver on their promises.The growing attention to "greenwashing", referring to the risk that issuers overstate the environmental benefits of their bonds, underscores the importance of understanding how label credibility affects market outcomes. Investigating these dynamics is crucial for both theory and practice, providing insights for investors seeking to construct credible sustainable portfolios, for issuers determining their labelling strategies, and for regulators tasked with ensuring transparency and trust in the market.

This thesis addresses these challenges through a multi-layered analytical approach that progresses from comprehensive literature synthesis to targeted empirical investigations at both micro and macro levels. By examining green bonds through complementary lenses, first mapping the intellectual landscape, then analysing firm-level strategic decisions, and finally assessing market-level risk dynamics, this research provides a holistic understanding of how heterogeneity within green bonds shapes their financial characteristics and policy effectiveness.

## 1.2. Research Objectives and Questions

To advance the understanding of green bond markets by systematically dissecting this heterogeneity, this thesis focusing specifically on the pivotal role of labelling in shaping financial and risk outcomes in the EU. Moving beyond the simplistic binary distinction between "green" and "non-green" bonds, this research offers a more nuanced perspective that accounts for the varying degrees of credibility conveyed through different labelling choices. The investigation is structured around three overarching and interconnected research questions:

1. How has the academic literature on green bonds evolved? This question probes the intellectual development of the field, seeking to understand its predominant research themes, theoretical underpinnings, and methodological approaches. Identifying the major thematic clusters and remaining research gaps is essential

for situating the present study and guiding future inquiry in this rapidly expanding area.

2. What drives an issuer's choice between self-labelling and external labelling, and what are the consequences for bond yields and investor attention? This question strikes at the heart of the economic incentives and market mechanisms at play. It explores the determinants of this key strategic decision and its direct impact on two critical market outcomes: the cost of debt (the "greenium") and market visibility (investor attention), thereby linking label credibility to tangible financial value.
3. Do externally- and self-labelled green bonds exhibit different hedging performance during systemic oil price shocks? This question addresses the risk dimension of green bonds, examining their utility as portfolio diversifiers and safe-haven assets during periods of extreme market stress, such as those triggered by the COVID-19 pandemic and geopolitical conflicts. This is of immense practical importance for risk management and asset allocation in an increasingly uncertain world.

These questions are strategically sequenced to build understanding progressively. The first question establishes the knowledge foundation and identifies where the literature points toward unresolved issues. The second question applies these insights at the micro level, examining corporate finance decisions and their immediate market consequences. The third question extends the analysis to the macro level, investigating how heterogeneity influences systemic risk properties and portfolio dynamics during market-wide crises.

### 1.3. Methodology and Data

I address the above issues through three independents but connected studies. The following three chapters are connected by a common focus on green bond heterogeneity, particularly in how labelling affects financial outcomes and investor responses. I first offer a conceptual and methodological synthesis of the literature, then the third and fourth chapters develop empirical strategies to assess the pricing and risk-related implications of label type, taking its endogenous nature explicitly into account. Each chapter adopts a distinct empirical design aligned with its objective, namely reviewing existing literature, analysing label selection and pricing effects, and evaluating risk performance under market stress.

The next chapter conducts a systematic review of 206 peer-reviewed articles on green bonds. Using bibliographic coupling and thematic analysis, the literature is grouped into three major clusters: asset pricing, issuance determinants, and sustainability outcomes.I document how the research focus has shifted from instrumental aspects, such as yield and liquidity, toward intrinsic concerns, including environmental credibility and sustainability impact. This chapter introduces a  conceptual len to position existing studies along this spectrum and summarizes the identification strategies used in empirical work. It concludes by outlining directions for future research, particularly in addressing endogeneity and integrating financial and environmental objectives.

The third chapter examines both the determinants of green bond label choice and its financial implications. While many prior studies treat green bonds as a homogeneous category without distinguishing between label types (e.g., Mokni et al., 2022; Su et al., 2023), issuers in the EU choose between self-labelling and external labelling. Using manually collected data from 2012 to 2021, I apply the endogenous treatment effect model to address selection bias in labelling decisions, and use difference in differences models to estimate changes in investor attention. The results suggest that externally labelled green bonds are associated with lower yields and attract more short-term investor attention compared to self-labelled bonds. These findings support both the signalling theory (Riley, 1979) and the taste-based framework (e.g., Du et al., 2017; Fatica et al., 2021).

In the fourth chapter I investigate whether green bonds with different label types exhibit heterogeneous hedging performance during oil price shocks. The analysis constructs four asset classes, namely brown, neutral, self-labelled green, and externally labelled green, to reflect variation in environmental labelling. Using SVAR decomposition, copula, wavelet coherence, and connectedness analysis, I find that externally labelled green bonds can consistently provide hedge benefits to oil investors under tail-risk scenarios, such as those observed during the COVID-19 pandemic and the Russia-Ukraine war. In contrast, self-labelled green bonds do not offer significant hedging benefits relative to conventional debt. This chapter highlights the importance of distinguishing among green bond subtypes when evaluating their role in risk mitigation.

Taken together, the three main chapters contribute to the literature on green finance by documenting the empirical relevance of labelling choices. They show that financial effects associated with green bonds, including bond yield, investor attention, and hedging properties, are not uniform but depend on the credibility and type of label adopted by the issuer. The findings underscore the need to move beyond binary comparisons of green and non-green bonds and to incorporate labelling heterogeneity into the analysis of sustainable financial instruments.

## 1.4. Thesis Contributions

This thesis makes theoretical, methodological, and empirical contributions that deepen the understanding of heterogeneity in the green bond market, with particular emphasis on the credibility of environmental labelling. While each chapter constitutes an independent study, they are conceptually connected and methodologically complementary, forming a coherent structure that links the evolution of research knowledge, firm-level mechanisms, and market-level implications.

First, at the theoretical level, the thesis develops a conceptual lens that connects the instrumental and intrinsic value continuum in sustainable finance with the credibility of environmental labelling. It demonstrates that the financial and environmental functions of green bonds cannot be fully understood without recognising their internal heterogeneity. By embedding label credibility within this value continuum, the thesis reconciles fragmented perspectives in existing research and provides a unified way to interpret the dual nature of green bonds as both financial instruments and environmental policy tools.

Second, at the methodological level, the thesis refines empirical strategies for addressing endogeneity in labelling and performance evaluation. Chapter 2 introduces a transparent systematic review protocol that synthesises 206 peer-reviewed studies through bibliometric and content analysis. Chapter 3 applies an endogenous treatment effect model to account for the strategic nature of labelling decisions, while Chapter 4 integrates several time, frequency, and dependence-based econometric techniques, including SVAR decomposition, copula modelling, and wavelet coherence, to evaluate hedging dynamics under extreme market stress. These approaches collectively enhance causal interpretation and improve the robustness of sustainable finance research.

Third, at the empirical level, the thesis provides multi-scalar evidence of how labelling heterogeneity affects both financial and risk outcomes.

1. Chapter 2 delivers the most comprehensive synthesis of the green bond literature to date, identifying three main thematic clusters covering asset pricing, corporate finance, and environmental impact, and documenting a clear shift from financial attributes to environmental credibility. It introduces the conceptual lens that links existing theories such as signalling, taste-based, and liquidity frameworks along the instrumental and intrinsic value continuum.
2. Chapter 3 offers novel micro-level evidence on labelling choices and their financial implications in the EU bond market. Using manually collected data from 2012 to 2021 and addressing selection bias through an endogenous treatment effect model, it shows that externally certified green bonds command significantly lower yields and attract greater investor attention than self-labelled bonds, confirming the joint influence of signalling and taste-based mechanisms.
3. Chapter 4 extends the analysis to the macro-financial level, showing that only externally labelled green bonds maintain effective hedging properties during systemic oil price shocks such as the COVID-19 crisis and the Russia–Ukraine war. In contrast,

self-labelled bonds behave similarly to conventional debt, providing little protection. This chapter provides the first comprehensive evidence that credibility-based heterogeneity drives the resilience of sustainable assets under severe market stress.

Finally, at the integrative level, the three essays together establish the originality and coherence of the thesis. Chapter 2 identifies a fundamental research gap, namely the neglect of within-category heterogeneity, while Chapters 3 and 4 empirically address this gap by demonstrating how credibility differences shape both firm-level financing outcomes and system-wide risk behaviour. The sequential design, progressing from conceptual synthesis to micro-level mechanisms and then to macro-level implications, ensures theoretical consistency and cumulative contribution. As a whole, the thesis provides a coherent explanation of how environmental credibility underpins both the financial performance and the sustainability integrity of the green bond market, contributing to academic understanding and to the development of more credible green finance frameworks.

### 1.5. Structure of the Thesis

The thesis is organised into five chapters that progress from a review of existing knowledge to empirical investigations at both the micro and macro levels. This structure allows a systematic examination of green bond heterogeneity from different analytical perspectives while maintaining clarity and consistency throughout.

Chapter 1 introduces the background, motivation, and research questions of the study. It outlines the methodological approach and establishes the central focus on the credibility of environmental labelling, which serves as the conceptual thread connecting the subsequent chapters.

Chapter 2 provides a comprehensive systematic review of 206 peer-reviewed studies on green bonds. It identifies three main thematic clusters (asset pricing, corporate finance, and environmental impact) and traces the evolution of the literature from instrumental financial characteristics to intrinsic environmental credibility. The chapter also develops the conceptual lens that links theories such as signalling, taste-based, and liquidity frameworks along the instrumental and intrinsic value continuum, establishing the theoretical foundation for the empirical analyses that follow.

Chapter 3 investigates the determinants and consequences of labelling choices in the EU bond market. Using a manually collected dataset for the period 2012-2021 and an endogenous treatment effect model, the study examines how issuers decide between self-labelling and external certification, and how these choices influence bond yields and investor attention. The analysis provides micro-level evidence that externally certified bonds enjoy lower yields and greater investor interest, highlighting the combined effects of signalling and taste-based mechanisms.

Chapter 4 extends the analysis to the macro-financial level by examining the risk and hedging properties of green bonds with different label types during major oil price shocks, including the COVID-19 crisis and the Russia-Ukraine war. Applying a multi-method framework that combines SVAR decomposition, copula modelling, and wavelet coherence, the chapter demonstrates that only externally labelled green bonds provide consistent hedging benefits under systemic stress, whereas self-labelled bonds behave similarly to conventional debt.

Chapter 5 concludes the thesis by synthesising the results across all analytical levels. It summarises how the progression from literature mapping to firm-level mechanisms and to market-level dynamics provides an integrated understanding of green bond heterogeneity and credibility. Together, these chapters form a continuous analytical narrative that connects theoretical development, corporate decision-making, and financial market behaviour.

Together, these chapters form a continuous analytical narrative that connects theoretical development, corporate decision-making, and financial market behaviour. This structure, moving from intellectual foundations through micro-level corporate finance to macro-level financial markets, allows the thesis to bridge traditionally separate strands of literature while maintaining coherence through the unifying theme of heterogeneity and its implications across different analytical scales.

# Chapter 2. From Instrumental to Intrinsic: A Review of Green Bond Studies

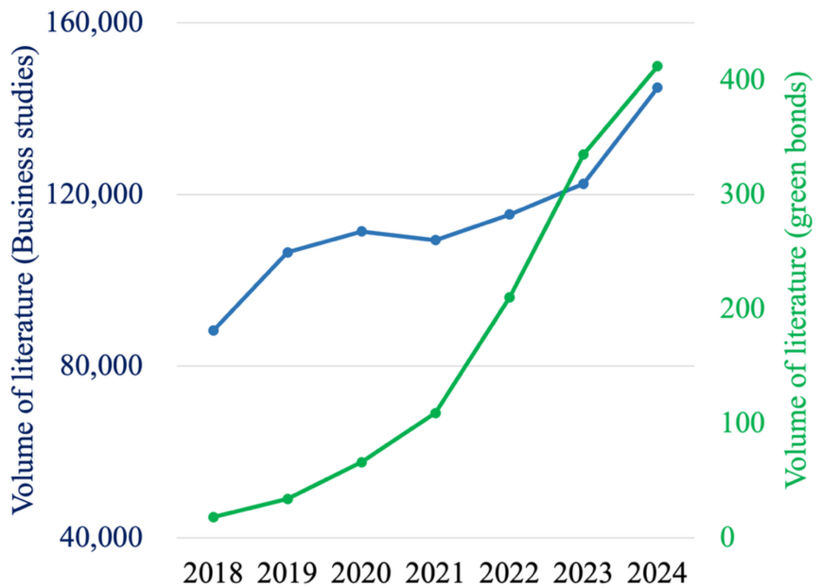
**Abstract:** This systematic review synthesizes evidence from 206 peer-reviewed studies on green bonds, a financial instrument created to direct capital toward environmental objectives. Employing bibliometric methods, we organize the literature into three clusters: (i) asset pricing research on green bonds, (ii) corporate finance research on the determinants of green bonds, and (iii) corporate finance research on their effects. Early studies concentrated on pricing and other financial attributes of green bonds, while recent research attention has shifted toward their intrinsic value, such as sustainability performance and environmental impact. This review aims to integrate these perspectives into a unified framework. Theoretically, we map green bond studies onto a spectrum from instrumental to intrinsic value. Methodologically, we summarize a menu of identification strategies to address endogeneity. Finally, we propose a research agenda that highlights underexplored questions and promising empirical approaches. Collectively, these elements provide a structured foundation for advancing green bond research and informing climate finance practice.

**Keywords:** Green Bonds; Systematic Literature Review; Bibliometric Analysis; Sustainability

## 2.1. Introduction

A defining feature of green bonds, in contrast to conventional bonds, is their dedicated use of proceeds for environmentally friendly projects, a requirement formalized through frameworks such as the Green Bond Principles (Zhou, Jin, et al., 2025). The global transition toward sustainable development has driven rapid growth in the green bond market since the European Investment Bank's inaugural issuance in 2007. By 2024, the cumulative value of green bonds reached $818 billion, with participation spanning supranational entities and 112 countries[1]. Parallel to this market expansion, academic research on green bonds has also grown rapidly (**Figure 2.1**).

**Figure 2.1.** The volume of literature on green bonds.




Source: Scopus, business studies (e.g., accounting, finance, and economics) published in ABS 3/4 journals.

However, the growth of the green bond market has been accompanied by heightened scrutiny over its environmental integrity, particularly concerning the risk of "greenwashing" (e.g., Berrone et al., 2015; Shi et al., 2023). Such practices undermine the credibility of issuers by creating misalignments between stated sustainability goals and actual environmental impacts, which can distort pricing mechanisms and erode investor trust in green instruments (Henide, 2022). This review is a timely contribution amid rising policy and investor emphasis on climate finance and the pressing need to evaluate the credibility and performance of green financial instruments.

[1] For more information about the state of the global sustainable debt market, please see: https://www.climatebonds.net/files/reports/cbi_mr_q3_2024_01c.pdf.

The existing literature on green bonds remains fragmented across disciplines, including economics, finance, and environmental sciences. Prior reviews have focused narrowly on the financial aspects (e.g., Cestau et al., 2019; Bhutta et al., 2022; Tao et al., 2022) of green bonds. While studies on issuers' environmental performance have received limited attention. Integration across these dimensions remains limited, with insufficient emphasis on the theoretical basis and methodological rigor. This systematic literature review (SLR) aims to fill this gap with a unified framework. Reflecting the dual nature of the term "green bonds", I assess both the "green" or sustainability dimension (e.g., measurable carbon reductions, project-level accountability) and the "bond" or financial dimension (e.g., risk-return profiles, liquidity) of the existing literature. To achieve this aim, I answer three related research questions (RQs):

- RQ1: What are the predominant themes in green bond research?
- RQ2: What theoretical frameworks and empirical approaches are used in these themes?
- RQ3: How has research attention to these themes evolved over time?

Using bibliographic coupling, I classify the existing literature on green bonds into three main thematic clusters (RQ1). Cluster 1 belongs to asset pricing, primarily analysing the connectedness between green bonds and other assets, while Clusters 2 and 3 fall under corporate finance, examining antecedents (e.g., issuance decisions) and consequences (e.g., environmental effects) of green bonds. Work in Cluster 3 lags behind that of Clusters 1 and 2, but recent studies show burgeoning interest in the sustainability attributes of green bonds.

Recognizing that each thematic cluster rests on distinct theoretical foundations and empirical methods (RQ2) is essential for understanding how literature has evolved (RQ3). Cluster 1 relies on high-frequency financial market data. Therefore, little theoretical foundation is involved since there is plenty of data to provide evidence-based explanations. As a result, sophisticated empirical approaches such as various connectedness and GARCH models are essential to identify empirical patterns in this strand of literature. In contrast to the "let data speak" philosophy, Clusters 2 and 3 ask research questions related to corporate finance based on low-frequency firm-level data. Thus, theory is critical for developing hypotheses and justifying identification strategies (e.g., Benlemlih et al., 2023; Jia, 2023). Nevertheless, theories can be partial, only capturing a specific aspect of green bonds. For example, taste-based theory emphasizes the *intrinsic* value of green bonds (Tang and Zhang, 2020), while signalling theory underscores the *instrumental* value of green bonds (Flammer, 2021). Debates can only be resolved by evidence, which is limited by available data at the firm level. The effect of data availability on literature development is documented in recent systematic reviews as "directed research attention" (e.g., Zhang et al., 2024; Zhou, Gai, et al., 2025).

My systematic review aims to make three novel contributions. Theoretically, I synthesize fragmented perspectives by outlining a  conceptual len that distinguishes between instrumental and intrinsic values of green bonds. I show how existing theories, such as taste-based, signalling, and liquidity theories, map onto this value spectrum, offering a unified lens for understanding green bonds' dual financial and environmental functions. Methodologically, I provide a comprehensive empirical toolbox to address endogeneity, a challenge largely overlooked in prior green finance reviews (e.g., Bhutta et al., 2022; Tao et al., 2022; Singhania et al., 2023). This equips future researchers with tools to better assess the credibility and impact of green bonds. Practically, I identify emerging research opportunities and propose a structured research agenda that integrates theoretical basis and empirical rigor. This roadmap is designed to support academic research and to inform practitioners and policymakers working in climate finance.

The remainder of this paper proceeds as follows. Section 2.2 presents the screening process of the SLR. Section 2.3 reports identified research clusters on green bonds. Section 2.4 summarizes prevailing theoretical frameworks and empirical strategies, discusses the evolution of the literature, and proposes a future research agenda. Section 2.5 concludes.

## 2.2. Methods

To ensure transparency and replicability, and to address the fragmented state of green bond research, I adopt the three-stage SLR framework proposed by Tranfield et al. (2003), comprising planning, conducting, and reporting. This protocol-driven approach, widely applied in recent SLRs in management (Zhang et al., 2024) and economics (e.g., Zhang et al., 2024; Zhou, Gai, et al., 2025), offers a structured process that minimizes bias and facilitates reproducibility. **Table 2.1** summarizes the three-stage SLR framework adapted to the context of green bond research. To mitigate the biases identified by (Castañer and Oliveira, 2020), including retrieval bias in the search phase, selection bias during screening, and expectancy bias in analysis, I have carefully calibrated every parameter of the SLR.

**Table 2.1.** Procedures of the three-stage SLR.

**Stage 1: Planning**

- From the review panel and establish the review protocol.
- Conduct an exploratory pilot review.
- Define research scope: green bonds.
  - Inclusion Criteria:
    - Include studies on green bonds.
    - Include studies on green bonds using alternative names like climate bonds.
  - Exclusion Criteria:
    - Exclude studies focusing on other green finance instruments like green loans.
    - Exclude studies focusing on other assets.

**Stage 2: Conducting**

**Stage 2.1: Identification**

- Search database: Web of Science; Scopus.
- Search fields: TITLE-ABS-KEY.
- Search term: “green bond*” OR “green sukuk*” OR “green municipal bond*” OR “sustainable bond*” OR “climate bond*”.
- Search restrictions:
  - Published year: 2007-2024.
  - Document type: article and review.
  - Subject area: Accounting, Finance, and Economics.
  - Language: English.
- Search queries
  - Web of Science: (TS=(“green bond*”) OR TS=(“green sukuk*”) OR TS=(“green municipal bond*”) OR TS=(“sustainable bond*”) OR TS=(“climate bond*”)) AND (PY==(“2024” OR “2023” OR “2022” OR “2021” OR “2020” OR “2019” OR “2018” OR “2017” OR “2016” OR “2015” OR “2014” OR “2012” OR “2011” OR “2010” OR “2008”) AND DT==(“ARTICLE” OR “REVIEW”) AND LA==(“ENGLISH”))
  - Scopus: (TITLE-ABS-KEY(“green bond*”) OR TITLE-ABS-KEY(“green sukuk*”) OR TITLE-ABS-KEY(“green municipal bond*”) OR TITLE-ABS-KEY(“sustainable bond*”) OR TITLE-ABS-KEY(“climate bond*”)) AND (LIMIT-TO ( PUBYEAR,2024) OR LIMIT-TO ( PUBYEAR,2023) OR LIMIT-TO ( PUBYEAR,2022) OR LIMIT-TO ( PUBYEAR,2021) OR LIMIT-TO ( PUBYEAR,2020) OR LIMIT-TO ( PUBYEAR,2019) OR LIMIT-TO ( PUBYEAR,2018) OR LIMIT-TO ( PUBYEAR,2017) OR LIMIT-TO ( PUBYEAR,2016) OR LIMIT-TO ( PUBYEAR,2015) OR LIMIT-TO ( PUBYEAR,2014) OR LIMIT-TO ( PUBYEAR,2012) OR LIMIT-TO ( PUBYEAR,2011) OR LIMIT-TO ( PUBYEAR,2010) OR LIMIT-TO ( PUBYEAR,2008) OR LIMIT-TO ( PUBYEAR,2007) ) AND ( LIMIT-TO ( DOCTYPE,“ar” ) OR LIMIT-TO ( DOCTYPE,“re” ) ) AND ( LIMIT-TO ( LANGUAGE,“English” ))

| **Stage 2: Conducting (continued)** |
|---|
| **Stage 2.2: Screening**<br>• Automated screening: publication quality (ABS 3, 4, and 4*).<br>• 1st round manual screening: based on TITLE-ABS-KEY.<br>• 2nd round manual screening: based on full text.<br>  o The results are checked by three raters independently.<br>  o Disputes are resolved by discussions and votes. |
| **Stage 2.3: Analysis**<br>• Quantitative analysis: e.g., bibliometric analysis<br>• Qualitative analysis: e.g., thematic analysis |
| **Stage 3: Reporting** |
| • PRISMA: e.g., Page et al. (2021)<br>• Synthesis: e.g., narrative, tabular, graphical, etc. (Grant & Booth, 2009) |

In the planning stage, I define the scope of the SLR as articles and reviews on green bonds published since 2007, the same year as the first green bond issuance. Given the interdisciplinary nature of green bond research, I do not restrict the subject area at the search stage[2]. Decisions regarding inclusion and exclusion are made jointly by the authors through iterative discussion to mitigate potential biases.

During the conducting stage, I carry out a comprehensive search using both Scopus and Web of Science to minimize retrieval bias. I include articles written in English and published between 2007 and 2024. To capture relevant literature, I search three fields (title, abstract, and keywords) for the following strings: “green bond*”, “green sukuk*”, “green municipal bond*”, “sustainable bond*”, “climate bond*”. It returns a total of 1,292 articles after removing duplicates and non-academic records (**Figure 2.2**).

**Figure 2.3** shows that most of these articles appear in both databases, suggesting a high degree of overlap between Scopus and Web of Science. Articles initially retrieved only from one database are typically indexed in the other within about one month, reflecting a slight delay in coverage.

[2] This restriction was necessary because the term ‘bond’ may also refer to topics in other disciplines (e.g., chemistry), which would otherwise introduce irrelevant results.

**Figure 2.2.** Article collection process.

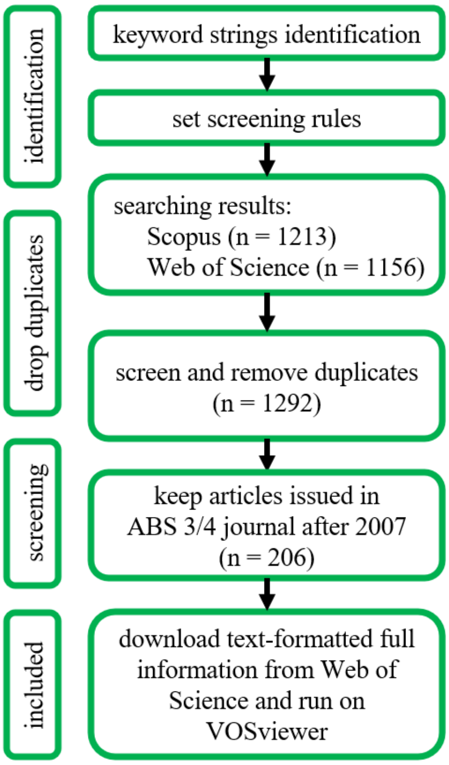
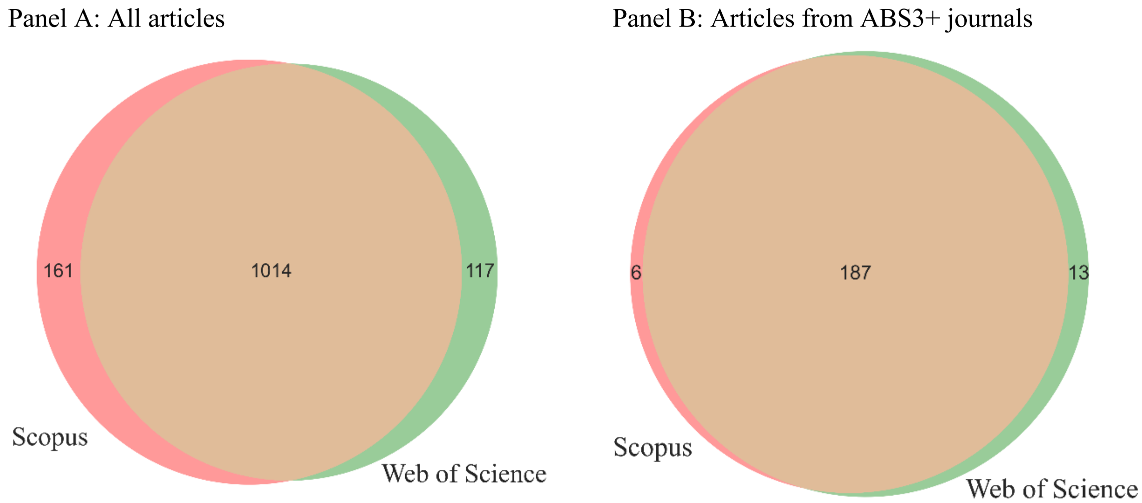



**Figure 2.3.** Article database comparison.




Furthermore, to ensure publication quality, I keep articles published in journals rated 3-star or above in the Academic Journal Guide 2024 (ABS journal ranking), a standard quality criterion used in SLRs (Zhang et al., 2024). This screening process resulted in 206 articles, most of which are indexed by both databases (**Figure 2.3**, Panel B). Based on this result, I identify major journal outlets for green bond research in **Figure 2.4**. *Energy Economics* is the most popular source, publishing a large volume of studies nearly equal to the combined total of the next two sources, *International Review of Financial Analysis* and *Technological Forecasting and Social Change*. To date, only six studies on green bonds have been published in ABS 4-star journals (e.g., Krüger, 2015; Larcker and Watts, 2020; Tang and Zhang, 2020; Flammer, 2021; Pástor et al., 2022; Dutordoir et al., 2023).

**Figure 2.4.** Key source journals (article number >=5).


Finally, in the reporting stage, I use the bibliographic coupling method in *VOSviewer* to identify thematic clusters within the green bond literature. To capture changes in the field, I divide the articles into two subperiods because the outbreak of Covid-19 sets a structural break in both investment practices and finance research (Ferriani, 2023). As visualized in **Figure 2.5** and **Figure 2.6**, three main clusters[3] emerge: the red cluster (Cluster 1) explores the connectedness between green bonds and other assets; the blue cluster (Cluster 2) investigates the determinants of green bonds; and the green cluster (Cluster 3) examines the impacts of green bonds. The following two sections elaborate on key findings in each cluster.

[3] Yellow spots in **Figures 2.5** and **2.6** refer to the other articles, which contain reviews on municipal bond markets (Cestau et al., 2019), green bond studies (Bhutta et al., 2022), and environmental finance (Tao et al., 2022).

**Figure 2.5.** Bibliographic coupling for green bonds studies published from 2018 to 2020.

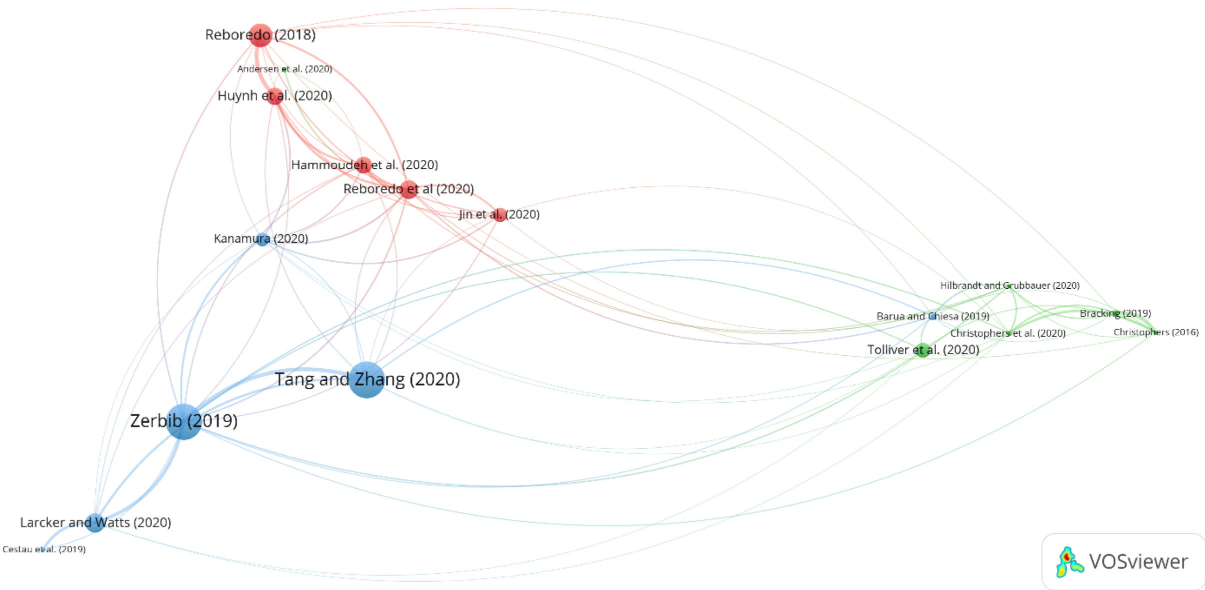
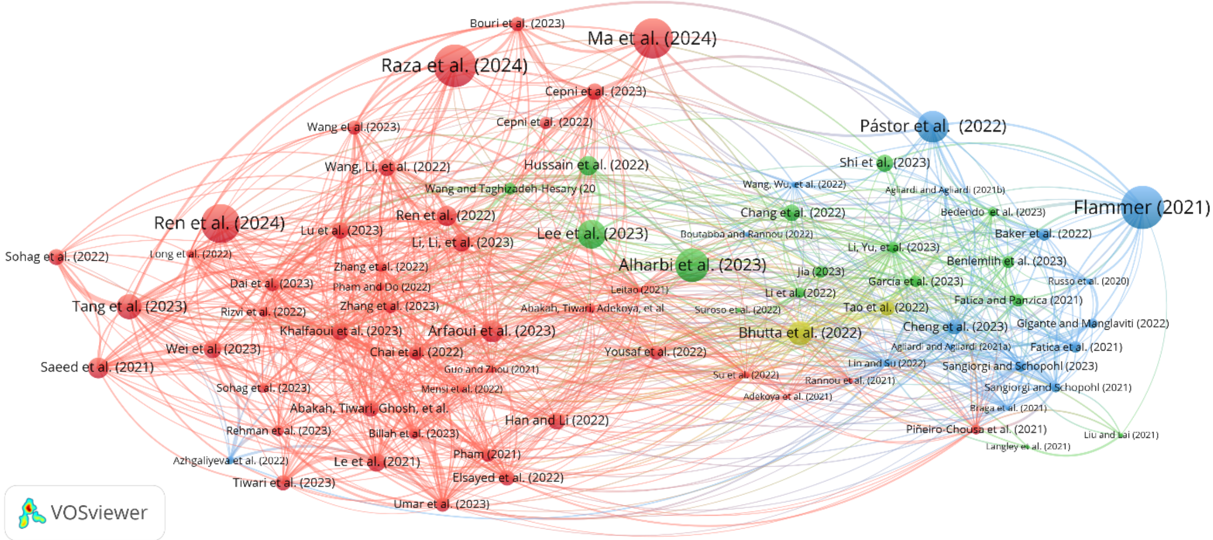



**Figure 2.6.** Bibliographic coupling for green bonds studies published from 2021 to 2024.




## 2.3. Thematic Clusters

Based on the three main clusters identified in **Figure 2.5** and **Figure 2.6**, this section focuses on topics with debatable results in each cluster. This section answers RQ1.

### *2.3.1. Cluster 1: Asset Pricing of Green Bonds*

Cluster 1 focuses on the connectedness between green bonds and other assets, including equities, traditional bonds, commodities, and alternative investments (e.g., cryptocurrencies, AI, and FinTech). This strand of literature requires little theoretical foundation and emphasizes timely empirical analyses of green bonds' performance across various market shocks. In terms of the pairing asset, I organize studies in Cluster 1 into three panels in **Table 2.2**[4].

**Table 2.2.** Key literature on the connectedness between green bonds and different assets.

**Panel (a).** Key literature on the connectedness between green bonds and non-energy assets.

| Theme | Market | Article |
|---|---|---|
| equity | US | Yousaf et al. (2022) |
| | US; EU | Reboredo et al. (2020) |
| | US; China | Guo and Zhou (2021) |
| | US; EU; China | Long et al. (2022) |
| | China | Su et al. (2022) |
| | Global | Reboredo (2018) |
| | | Chai et al. (2022) |
| | | Elsayed et al. (2022) |
| | | Pham and Do (2022) |
| | | Zhang et al. (2022) |
| | | Sohag et al. (2023) |
| green equity | Global | Pham (2021) |
| | | Lu et al. (2023) |
| bond | US | Hammoudeh et al. (2020) |
| | | Abakah, Tiwari, Ghosh, et al. (2023) |
| | US; EU | Reboredo et al. (2020) |
| | | Han and Li (2022) |
| | US; China | Guo and Zhou (2021) |
| | China | Su et al. (2022) |
| | Global | Elsayed et al. (2022) |
| | | Reboredo (2018) |
| | | Rizvi et al. (2022) |
| | | Abakah, Tiwari, Ghosh, et al. (2023) |
| | | Billah et al. (2023) |
| green bond | Global | Long et al. (2022) |
| | | Mensi et al. (2022) |
| gold | Global | Rizvi et al. (2022) |
| | | Yousaf et al. (2022) |

**Table 2.2 (a)** presents studies on the connectedness between green bonds and non-energy assets. This strand of literature generally suggests that green bonds offer diversification benefits to equity investors, but their safe-haven feature is weaker than gold. Early studies in equity markets show that green bonds act as a net receiver of the spillover effect from the stock market (e.g., Reboredo, 2018; Pham, 2021; Zhang et al., 2022). The directional relationship evolves over time, but green bonds' role as the net receiver becomes stronger in extreme events (e.g., Reboredo et al., 2020; Guo and Zhou, 2021). Similarly, studies on bond markets also reveal that green bonds receive more but transmit less volatility to treasury bonds (Hammoudeh et al., 2020). Furthermore, as green bonds bring sizeable benefits to both stock and bond investors, further comparisons have been made between green bonds and traditional safe-haven assets. Han and Li (2022) show that portfolios with green bonds bring higher risk-adjusted returns than portfolios with conventional bonds in both the US and EU

[4] More detailed **Table 2.2**, **2.3**, and **2.4** with article data source can be found from Appendix **Table A 3.1** to **Table A 3.3**.

markets, while Rizvi et al. (2022) document that gold overperforms green bonds under bearish or extremely volatile periods. Accordingly, green bonds bring diversification benefits to equity and bond investors, but their safe-haven feature is still weaker than gold (Yousaf et al., 2022). Only a few studies consider the connectedness within green bonds or with other green equities (e.g., Long et al., 2022; Mensi et al., 2022).

**Table 2.2 (b)** compares the literature on the connectedness between green bonds and energy-related assets. It reports more mixed findings, with results varying across countries and over time. For example, Leitao et al. (2021) find that green bonds have positive effects on the EU carbon market, at odds with Li, Li, et al. (2023), who identify a significant negative impact on China's carbon emission trading price. Moreover, mixed results across countries are also found in the connectedness with oil markets. Saeed et al. (2021) document that spillovers among clean energy stocks, green bonds, crude oil, and energy ETFs in lower and upper quantiles are stronger than those in the middle quantile. This finding is further complicated by Long et al. (2022), where US green bonds act as net transmitters while China's green bonds primarily function as net receivers. Similarly, studies on traditional energy and clean energy markets confirm green bonds' long-term diversification benefits for investors (e.g., Reboredo, 2018; Elsayed et al., 2022; Arfaoui et al., 2023), and also highlight the time-varying nature of such benefits (e.g., Reboredo et al., 2020; Saeed et al., 2021; Pham and Do, 2022). However, as summarized in **Table 2.2 (b)**, green bond studies on clean energy and gas markets mainly concentrate on the US and China, while less are based on the EU market.

**Table 2.2.** Key literature on the connectedness between green bonds and different assets.

**Panel (b).** Key literature on the connectedness between green bonds and energy assets.

| Theme | Market | Article |
|---|---|---|
| carbon emission trade | US | Hammoudeh et al. (2020) |
| | EU | Rannou et al. (2021)<br>Ren et al. (2022) |
| | China | Dai et al. (2023) |
| | Global | Jin et al. (2020)<br>Leitao et al. (2021)<br>Ren et al. (2022)<br>Wang, Li, et al. (2022)<br>Wang et al. (2023)<br>Zhang et al. (2022) |
| oil | US; EU; China | Long et al. (2022) |
| | US; China | Guo and Zhou (2021)<br>Dai et al. (2023) |
| | China | Ren et al. (2024) |
| | Global | Saeed et al. (2021)<br>Pham and Do (2022)<br>Wang, Li, et al. (2022)<br>Wang et al. (2023)<br>Rehman et al. (2023)<br>Umar et al. (2023)<br>Wei et al. (2023) |
| energy | US; EU | Reboredo et al. (2020) |
| | Global | Reboredo (2018)<br>Saeed et al. (2021)<br>Elsayed et al. (2022)<br>Pham and Do (2022) |

| | | |
|---|---|---|
| clean energy | US | Hammoudeh et al. (2020) |
| | China | Ren et al. (2024) |
| | Global | Saeed et al. (2021)<br>Chai et al. (2022)<br>Wang, Li, et al. (2022)<br>Abakah, Tiwari, Ghosh, et al. (2023)<br>Arfaoui et al. (2023)<br>Lu et al. (2023) |
| gas | China | Ren et al. (2024) |
| | Global | Abakah, Tiwari, Adekoya, et al. (2023)<br>Wang et al. (2023) |

**Table 2.2 (c)** compares studies examining the connectedness between green bonds and alternative or emerging assets, including cryptocurrencies, AI-related indices, and other alternative markets. Evidence shows that green bonds exhibit heavy-tail dependence on both cryptocurrencies and artificial intelligence stocks (e.g., Huynh et al., 2020; Le et al., 2021; Khalfaoui et al., 2023). It has been found that green bonds are an effective hedging tool against shocks arising from climate uncertainty, Fintech, and Bitcoin markets (Le et al., 2021; Cepni et al., 2022). For commodity markets, Pham and Do (2022) show that green bonds act as a net receiver of the spillover effect, but this relationship is again state-dependent. Similarly, Naeem et al. (2022) reveal that risk spillovers between green bonds and agricultural indices are weak when volatility is very low. Finally, findings on the impacts of geopolitical risks on green bonds are complex. Sohag et al. (2022) illustrate that all measures of geopolitical risk (except geopolitical acts) transmit positive shocks to green investments (both stocks and bonds). Tang et al. (2023) further add that the return on green bonds is negatively affected by US economic policy uncertainties and geopolitical threats. Moreover, Zhang et al. (2022) find that geopolitical risks have a more prolonged impact on the volatility of green bonds than on their returns.

**Table 2.2.** Key literature on the connectedness between green bonds and different assets.

**Panel (c).** Key literature on the connectedness between green bonds and emerging indices.

| Theme | Market | Article |
|---|---|---|
| crypto-currency | Global; US; EU | Khalfaoui et al. (2023) |
| | Global | Huynh et al. (2020)<br>Le et al. (2021)<br>Rizvi et al. (2022)<br>Abakah, Tiwari, Ghosh, et al. (2023)<br>Arfaoui et al. (2023) |
| AI robotics | Global | Huynh et al. (2020)<br>Abakah, Tiwari, Ghosh, et al. (2023) |
| FinTech | Global | Le et al. (2021)<br>Abakah, Tiwari, Ghosh, et al. (2023)<br>Tiwari et al. (2023) |
| Forex | US; China | Guo and Zhou (2021) |
| commodity | Global | Pham and Do (2022)<br>Cepni et al. (2022)<br>Cepni et al. (2023) |
| climate risk | US | Bouri et al. (2023) |
| | EU | Ma et al. (2024) |
| | Global | Tang et al. (2023) |

| | | |
|---|---|---|
| political uncertainty | US | Li, Li, et al. (2023) |
| | China | Sohag et al. (2022) |
| | Global | Wang, Li, et al. (2022)<br>Wang et al. (2023)<br>Zhang et al. (2023)<br>Raza et al. (2024)<br>Adekoya et al. (2021) |
| investor sentiment | US | Piñeiro-Chousa et al. (2022) |

### *2.3.2. Cluster 2: Corporate Finance of Green Bonds*

Cluster 2 covers corporate finance topics such as issuance, yield, liquidity, and investor behaviour of green bonds. Studies in this cluster typically require a solid theoretical foundation to support the proposed relationship. At the same time, empirical identification lies at the centre of causal inference.

Existing studies show that green bond issuance is determined by both internal and external factors. **Table 2.3** summarises the main studies in this literature. Internal factors include not only bond attributes (e.g., coupon rate, credit rating, issuance size) but also issuer-specific factors such as ESG disclosure score, brand reputation, and board structure (e.g., Barua and Chiesa, 2019; Cheng et al., 2023; García et al., 2023). As for external factors, existing studies show that oil supply and demand shocks, financing conditions, and sovereign green bond issuance all have significant impacts on issuers' decisions to issue green bonds (e.g., Azhgaliyeva et al., 2022; Lin and Su, 2022).

**Table 2.3.** Key literature on corporate finance topics on green bonds.

| Theme | Market | Article |
|---|---|---|
| issuance | China | Lin and Su (2022);<br>Wang, Wu, et al. (2022);<br>García et al. (2023) |
| | Global | Barua and Chiesa (2019);<br>Azhgaliyeva et al. (2022);<br>Cheng et al. (2023)<br>Sangiorgi and Schopohl (2023) |
| yield | US | Baker et al. (2022) |
| | EU | Agliardi and Agliardi (2021);<br>Agliardi and Agliardi (2021)<br>Gigante and Manglaviti (2022) |
| | German | Pástor et al. (2022) |
| | Global | Zerbib (2019);<br>Kanamura (2020);<br>Larcker and Watts (2020);<br>Russo et al. (2020);<br>Tang and Zhang (2020);<br>Braga et al. (2021);<br>Fatica et al. (2021);<br>Flammer (2021); |
| liquidity | EU | Boutabba and Rannou (2022) |
| investor behaviour | US | Baker et al. (2022) |
| | Global | Larcker and Watts (2020);<br>Tang and Zhang (2020);<br>Flammer (2021);<br>Sangiorgi and Schopohl (2021) |

Specifically, about half of the key studies in **Table 2.3** focus on the determinants of bond yields because there has been a long debate on whether green bonds enjoy a lower required yield (the "greenium"). The existence of greenium aligns with the taste-based asset pricing framework (Fama and French, 2007), and is supported by empirical research (e.g., Zerbib, 2019; Baker et al., 2022; Lau et al., 2022). However, other studies find that green bonds do not significantly differ from conventional bonds in yields once all factors are controlled (e.g., Larcker and Watts, 2020; Flammer, 2021; Gigante and Manglaviti, 2022). For example, Tang and Zhang (2020) show that the significant greenium in their baseline model disappears when comparing yield spreads within the same issuing firm in the same year. Further studies reveal that the existence of greenium depends on issuer type (e.g., Russo et al., 2020; Braga et al., 2021; Fatica et al., 2021) and label type (e.g., Ghitti et al., 2023; Zhou, Jin, et al., 2025). In contrast with the large volume of return premium, fewer studies investigate the liquidity premium of green bonds. Boutabba and Rannou (2022) reveal that the magnitudes of short-term and long-term premia in the German government bond market are affected by economic factors and by spillover effects between them, which contribute to the U-shape liquidity premium.

In addition to benefits on return and liquidity, green bond issuance also attracts greater market attention, which can result in increased stock turnover, market attention, and ownership diversity (e.g., Larcker and Watts, 2020; Tang and Zhang, 2020; Flammer, 2021). Flammer (2021) finds that green bond issuance is attractive to long-term and green retail investors, but the effect on institutional investors is not statistically significant. In contrast, Tang and Zhang (2020) document a significant rise in institutional holdings, which are particularly driven by domestic institutions. Furthermore, survey-based evidence from Sangiorgi and Schopohl (2021) explains that institutional investors value strong environmental credentials and competitive pricing, while inadequate reporting on the use of proceeds can significantly deter investor participation. These findings consistently suggest that issuing green bonds enhances corporate visibility and attracts an investor base that values transparency, sustainability, and long-term orientation.

From a theoretical perspective, studies in Cluster 2 primarily draw on the signalling theory, stakeholder theory, and strategic corporate social responsibility (CSR) frameworks to explain the motivations of green bond issuance. According to the signalling theory, firms are believed to use green bonds as a credible signal of environmental commitment, which is particularly supported by governance structures such as sustainability committees or enhanced ESG disclosure (e.g., Flammer, 2021; García et al., 2023). On the demand side, investor behavior is often interpreted through the taste-based asset pricing framework (Fama and French, 2007), suggesting that non-pecuniary motives may drive the willingness to accept lower returns in exchange for environmental benefits (e.g., Zerbib, 2019; Baker et al., 2022). These theoretical perspectives underpin a wide range of empirical strategies aimed at identifying the causal effects of green bond issuance.

From a methodological perspective, difference-in-differences (DiD) models are widely employed, often in combination with propensity score matching (PSM), to compare firm behavior or market reactions before and after green bond issuance (e.g., Tang and Zhang, 2020; Wang, Wu, et al., 2022). Meanwhile, as a special case of DiD, event study is also a popular choice to capture short-term market responses to issuance announcements (Flammer, 2021), while regression discontinuity designs (RDD) are used to test whether ESG performance thresholds influence borrowing costs (Gigante and Manglaviti, 2022). Matching techniques and fixed-effects panel regressions are also frequently employed to isolate the "greenium" by comparing green and conventional bonds with similar characteristics (e.g., Zerbib, 2019; Larcker and Watts, 2020; Flammer, 2021). Together, these theoretical and empirical advances enhance the credibility of research findings in this thematic cluster.

### *2.3.3. Cluster 3: Environmental Effects of Green Bonds*

The third cluster focuses on studies examining the environmental effects of green bonds. **Table 2.4** summarises the key studies in this strand. It is widely accepted that green bonds contribute to issuers' environmental performance (e.g., Chang et al., 2022; Alharbi et al., 2023), particularly in terms of CO2 emission reduction (e.g., Andersen et al., 2020; Li et al., 2022; García et al., 2023). Although studies from Benlemlih et al. (2023) and Jia (2023) reveal no conclusive evidence at the firm level, both studies claim that this may be due to limited information and reports on decarbonization. Since green bond markets remain significantly smaller than the conventional corporate bond markets (e.g., Hilbrandt and Grubbauer, 2020; Lee et al., 2023), corporate-level data are still in the process of being accumulated. As in Cluster 2, a solid theoretical foundation and rigorous empirical identification are needed for building causal relationships (Christophers, 2018).

Theoretical foundations in this body of literature also draw on the signalling theory, particularly in studies examining green bond issuance as a credible indicator of environmental commitment (e.g., Fatica and Panzica, 2021; Bedendo et al., 2023). The strength of the signal often depends on the presence of external certification and post-issuance disclosure, which help mitigate concerns about greenwashing (Shi et al., 2023). In addition, resource-based theory underpins arguments that green bonds enhance firms' capabilities to pursue green innovation by easing financial constraints (Wang et al., 2023).

In terms of empirical identification strategies, fixed-effect regressions and first-difference models are commonly used to control for unobservable confounding effects across firms and over time (e.g., Li et al., 2022; García et al., 2023). Similar to Cluster 2, quasi-experimental approaches such as DiD, PSM, and coarsened exact matching are also widely employed by studies in Cluster 3 (e.g., Tolliver et al., 2020; Fatica and Panzica, 2021; Shi et al., 2023). Furthermore, some cross-country studies apply fully modified ordinary least squares (FMOLS) to examine long-run relationships between green finance and renewable energy adoption (Wang and Taghizadeh-Hesary, 2023), while others use panel data cointegration techniques or common correlated effects estimators to address cross-sectional dependence (Alharbi et al., 2023). Additionally, policy-based identification strategies using nationally determined contributions (NDCs) as quasi-treatment variables are used to capture institutional drivers of green bond allocation (Tolliver et al., 2020). Despite methodological advances, the literature in Cluster 3 still calls for improved environmental disclosure standards and more granular, project-level data to accurately trace the environmental outcomes of green bond financing (e.g., Christophers, 2018; Jia, 2023).

**Table 2.4.** Key literature on the environmental effects of green bonds.

| Theme | Market | Article |
|---|---|---|
| sustainability | US; Russian Federation; China | Jia (2023) |
| | OECD countries | Wang and Taghizadeh-Hesary (2023) |
| | G10 countries | Li et al. (2022) |
| | China | Li, Yu, et al. (2023)<br>Shi et al. (2023) |
| | Indonesia | Suroso et al. (2022) |
| | Malaysia | Liu and Lai (2021) |
| | Global | Fatica and Panzica (2021);<br>Flammer (2021);<br>Benlemlih et al. (2023);<br>Chang et al. (2022);<br>Alharbi et al. (2023);<br>Bedendo et al. (2023)<br>García et al. (2023) |
| policy | Mexico | Hilbrandt and Grubbauer (2020) |
| | Global | Tolliver et al. (2020) |
| | China | Lee et al. (2023) |

## 2.4. Discussion

Based on the three clusters of literature, I synthesize insights regarding the theoretical foundation and empirical identification approaches in existing research on green bonds (RQ2). I additionally examine how research attention has evolved over time, offering evidence-based perspectives on future research directions (RQ3).

### *2.4.1. Theoretical Foundations*

Researchers make decisions like other economic agents. The three thematic clusters of literature on green bonds answer different research questions (“objectives”) using different types of data (“constraints”). For cases where high-frequency data (usually daily) are available and appropriate for questions at hand (e.g., Cluster 1), less theoretical foundation is needed apart from a general assumption of the Efficient Market Hypothesis (EMH). In contrast, when only low-frequency data (e.g., yearly or quarterly) is available, a more theoretical foundation is needed to understand corporate behavior and identify causal relationships in green bond markets (e.g., clusters 2 and 3). I summarize the following three popular theoretical foundations adopted in the green bond literature.

Taste-based Theory. This theoretical framework has been widely used to describe investor behavior in green bond markets (e.g., Halim et al., 2019; Flammer, 2021; Bellucci et al., 2023). This theory suggests that investors are willing to accept a lower financial return, known as the "greenium", in exchange for environmental benefits associated with green investments (Tang and Zhang, 2020). However, empirical evidence suggests that while taste-based preferences can explain some aspects of greenium, additional factors such as second-party opinion and the type of green labels must be at play (e.g., Ghitti et al., 2023; Yu et al., 2024; Zhou, Jin, et al., 2025). Future research should investigate the mechanisms behind the heterogeneous greenium across bond types, markets, and time periods.

Signalling Theory. The signalling theory emphasizes the role of asymmetric information and posits that firms issue green bonds as a way to signal their commitment to environmental sustainability and responsible practices to the market (Flammer, 2021). Green bonds, especially those certified by third-party regulators, are generally regarded as strong signals about firms' ESG (Environmental, Social, and Governance) objectives. This can bring about reputational benefits and investor trust. Empirical studies have shown that signalling effects can increase short-term investor attention (e.g., Halim et al., 2019; Flammer, 2021; Bellucci et al., 2023). Nonetheless, more research is needed to explore how these signalling effects vary across regulatory environments and certification standards (e.g., Climate Bond Standard, EU Green Bond Standard, Green Bond Principles).

Liquidity Theory. Developing markets tend to suffer from lower liquidity in green finance. For example, Boutabba and Rannou (2022) highlight liquidity challenges in the EU green bond markets. They show that the liquidity premium follows a U-shaped pattern where both short and long maturities carry higher liquidity premiums due to spillover effects and clientele segmentation. A recent theoretical model by Bongaerts and Schoenmaker (2024) links fragmentation, clientele preferences, and liquidity premiums in green bond design. They highlight that liquidity-induced rationing can limit both economic and environmental welfare when project types are mismatched with investor preferences. In the context of the African market, Owusu-Manu et al. (2022) also emphasize the importance of green bond liquidity in market deepening and renewable energy financing, though liquidity constraints remain a key concern. These studies underscore that theoretical exploration of liquidity in green bond markets, especially in emerging economies, requires deeper empirical investigation.

These theories are useful for corporate-level research on green bonds, but they downplay the role of stakeholders other than issuers and investors of green bonds. Given that environmental problems have significant market externalities, other theories involving broader stakeholders can be used to explain activities involving green bonds. For instance, future research could employ the institutional theory (DiMaggio and Powell, 1983) to analyse how regulatory pressures and evolving market norms influence the behaviours of issuers and investors of green bonds. Similarly, stakeholder theory (Parmar et al., 2010) provides insights into how firms issue green bonds to meet the demands of various stakeholders beyond shareholders, such as regulators, environmental groups, and consumers. Agency theory (Baiman, 1990) may also be relevant, offering explanations for how green bonds align managerial actions with shareholder preferences for sustainability. Issuing green bonds may reduce agency costs by directing capital toward projects that serve both corporate and societal interests.

### *2.4.2. Empirical Identification*

Empirical studies in clusters 2 and 3 predominantly rely on regression-based methods. A central methodological challenge in these studies is establishing causal inference, particularly addressing endogeneity concerns. Following the framework proposed by Roberts and Whited (2013), this subsection examines the economic mechanisms generating endogeneity in green bond relationships and evaluates whether current identification strategies adequately address them.

The green bond literature faces two primary endogeneity challenges: reverse causality and omitted variable bias. **Table 2.5** summarizes how these issues manifest across different research questions. To understand whether the proposed identification strategies are sufficient, we first need to examine the economic forces creating these endogeneity problems in each relationship.

**Table 2.5.** Endogeneity concerns and identification strategies in existing studies.

| Dependent Variable | Independent Variable | Endogeneity Issue | Identification Strategy |
|---|---|---|---|
| green bonds issuance | brand effects | reverse causation | Probit regress lagged green bonds issuance through brand effects (Cheng et al., 2023);<br>Regress lagged green bonds issuance through ESG score (Cheng et al., 2023).<br>Lag brand effects by 1 year (Cheng et al., 2023). |
| daily yield | demands to ESG | reverse causation | Instrumenting for the same-quarter ESG flow through its previous quarter value in the 2SLS estimation (Pástor et al., 2022). |
| offering yield | finance by green bond | omitted variable | Matching green issuers to similar non-green issuers based on a set of criteria (Fatica et al., 2021). |
| environmental outcome;<br>ownership structure | green bonds issuance | omitted variable | Matching green issuers to similar non-green issuers based on a set of criteria and then regressing in difference-in-difference (DiD) (Flammer, 2021). |
| climate risk concerns | green bonds issuance | omitted variable | Propensity score matching and DiD test (Wang, Wu, et al., 2022). |
| stock liquidity | green bonds issuance | reverse causation | Matching green issuers to similar non-green issuers based on a set of criteria and then regressing in DiD (Tang and Zhang, 2020). |
| liquidity premium | credit risk | reverse causation | The concern can be ignored if credit-related variables have insignificant coefficients when estimating the liquidity premium (Boutabba and Rannou, 2022). |
| traditional cointegration models | green bonds policy;<br>green bonds performance | reverse causality;<br>omitted variable;<br>serial correlation and heteroskedasticity | Apply the quantile-based cointegration test (e.g., Sinha et al., 2021; Chang et al., 2022);<br>Using the regression discontinuity design model (Lee et al., 2023).<br>Apply the fully modified ordinary least squares model (Wang and Taghizadeh-Hesary, 2023). |

*Green bond issuance and brand effects.* The relationship between green bond issuance and brand reputation suffers from reverse causality because the causal arrow runs both directions. Firms with established environmental reputations find it easier to access green bond markets due to lower information asymmetry and higher investor trust. Simultaneously, issuing green bonds enhances brand value by signalling environmental commitment to stakeholders. Cheng et al. (2023) employ lagged brand effects to address this issue, yet this approach assumes reputation adjusts slowly. In practice, green bond announcements generate immediate media coverage and stakeholder reactions, making temporal separation insufficient for causal identification.

*Daily yield and ESG demand.* Pástor et al. (2022) examine how ESG demand flows affect green bond yields, but face reverse causality because lower yields attract more ESG-focused investors while higher demand simultaneously drives yields down. They instrument same-quarter ESG flows with previous quarter values, assuming past flows predict current flows but do not directly affect current yields. However, this exclusion restriction becomes questionable when investor sentiment exhibits persistence or when past flows signal future environmental performance that directly impacts current pricing.

*Offering yield and green finance.* The relationship between offering yields and green bond status faces omitted variable bias. Unobservable firm characteristics such as management quality, long-term strategic orientation, or unreported environmental initiatives simultaneously influence both the decision to issue green bonds and the pricing these bonds receive. Fatica et al. (2021) match green and conventional issuers on observable characteristics, but cannot account for these unobservable characteristics. The mixed findings on greenium across studies may reflect these unresolved selection issues rather than true economic heterogeneity.

*Environmental outcomes and green bond issuance.* When examining whether green bonds improve environmental performance, omitted variables create significant challenges. Firms pursuing comprehensive sustainability strategies may simultaneously issue green bonds and improve environmental metrics through other channels. Flammer (2021) uses matching combined with DiD, but cannot eliminate the possibility that matched firms differ in unobservable environmental commitment or capabilities. Moreover, firms may strategically select their best environmental projects for green bond financing, creating a selection bias that matching on firm-level observables cannot address.

*Stock liquidity and green bond issuance.* Tang and Zhang (2020) investigate how green bonds affect stock market liquidity, facing reverse causality because firms with more liquid stocks may find it easier to issue green bonds due to lower information asymmetry. Their DiD approach with matched firms assumes parallel trends, but liquidity trends may diverge based on unobservable factors such as investor recognition or market-making arrangements that evolve differently across firms.

*Climate risk concerns and green bond issuance.* Wang, Wu, et al. (2022) examine how green bonds affect climate risk perceptions, but the relationship suffers from omitted variable bias. Firms facing high climate risks may issue green bonds while simultaneously implementing operational changes, making it difficult to isolate the bond's effect. Their PSM-DiD approach cannot account for concurrent but unobserved risk management activities.

*Liquidity premium and credit risk.* Boutabba and Rannou (2022) study liquidity premia in green bonds, arguing that reverse causality concerns can be dismissed if credit-related variables show insignificant coefficients. However, this logic assumes credit risk and liquidity risk are independent, which may not hold during market stress when both risks become correlated. The absence of statistical significance does not establish the absence of economic relationships.

*Cross-country relationships.* Studies using traditional cointegration models to link green bonds with environmental outcomes face multiple endogeneity issues. Countries developing green bond markets often simultaneously pursue renewable energy policies, environmental regulations, and sustainability initiatives. These concurrent policy changes create reverse causality, omitted variables, serial correlation, and heteroskedasticity. While studies apply quantile-based cointegration tests (e.g., Sinha et al., 2021; Chang et al., 2022) or FMOLS (Wang and Taghizadeh-Hesary, 2023), these methods address statistical properties but cannot resolve the fundamental problem that policy decisions are jointly determined.

The green bond literature also faces unique challenges from the accounting and disclosure environment. ESG reporting remains largely voluntary and unaudited, allowing firms to time disclosures strategically. Firms can coordinate green bond issuances with favourable sustainability announcements, or manage reported environmental metrics to justify green bond proceeds allocation. This creates additional endogeneity layers beyond those in traditional corporate finance settings.

Furthermore, the absence of strong instrumental variables limits causal inference. Potential instruments, such as regional environmental preferences or regulatory shocks, likely affect firm outcomes through multiple channels. For instance, regional green preferences influence not only green bond issuance but also customer demand, employee recruitment, and regulatory enforcement, violating exclusion restrictions.

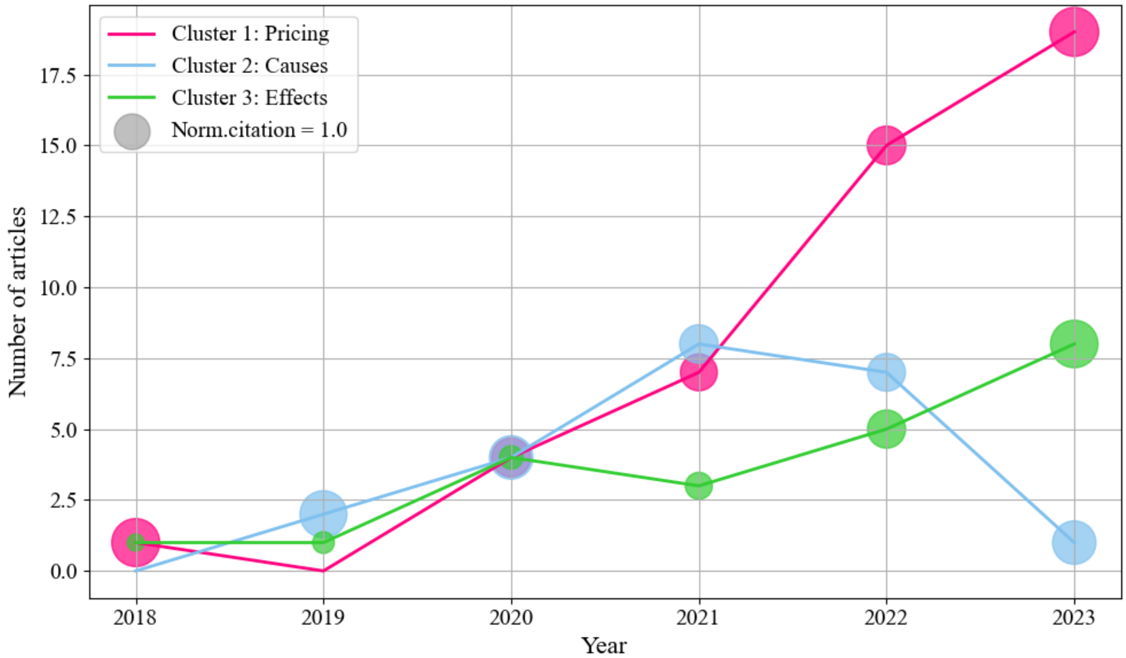
Future research should exploit institutional features generating plausibly exogenous variation. Regulatory discontinuities at specific thresholds, staggered implementation of green bond standards across jurisdictions, or mechanical index inclusion rules offer potential identification opportunities. Additionally, researchers should consider that in accounting settings, the joint determination of financial reporting, ESG disclosure, and financing decisions requires identification strategies that explicitly model these interdependencies.

### *2.4.3. Literature Evolution*

A comparison of **Figure 2.5** and **Figure 2.6** shows that the scales of all three clusters have grown in scale, but the distribution of research attention has shifted over time. Specifically, Cluster 2 has seen a relative decline in prominence (as reflected in the reduced number of larger nodes), while Clusters 1 and 3 have experienced a notable increase in academic interest. In general, research on green bonds pays more attention to the intrinsic value of green bonds (environmental effects).

To better visualize the evolution of literature, I use normalized citations as a proxy to plot changes in literature focus over time in **Figure 2.7**. The figure highlights a clear shift in research priorities: whereas early influential work was generally balanced, the period from 2021 to 2023 has seen a growing emphasis on the environmental and economic impacts of green bonds, reflected in Cluster 3's expansion.

**Figure 2.7**. Volumes and citations of published articles of the three clusters.




Note: The scatter size stands for the average normalized citations of each cluster in each year.

Shifting from the authors' perspective to the citers' perspective, the changes in circle size, representing normalized citations, demonstrate the growing prominence of Cluster 3 (green) through time. Following *VOSviewer*'s definition, a paper's normalized citations equal its raw citations divided by the average citations of all papers published in the same year that are included in the dataset. This adjustment compensates for the additional time older publications have had to accrue citations, enabling a fairer comparison across publication years.

This academic trend in green bond research aligns with the economic principle of rational decision-making, which seeks to maximize the "objective function" subject to "constraints". In the context, the "objective function" of scholars is research impact, which evolves with the historical conditions of markets. The revised ICMA[5] Green Bond Principles (June 2021) codified disclosure and external-review practices, while the EU proposed (2021) and finalized (2023) a voluntary European Green Bond Standard that reduces informational barriers for green bond issuers. As norms converged, take-up continued to rise, and global

[5] International Capital Market Association (ICMA) is a not-for-profit global trade association, for participants in the cross-border debt capital markets.

labelled green issuance reached 269.5 billion U.S. dollars in 2020[6]. Consequently, the academic return to research on antecedents (Cluster 2) fell, while research on consequences (Cluster 3) rose. Regulatory debates about "greenwash" and recent global crises require empirical answers.

Data availability imposes a fundamental constraint on research. When data are scarce, researchers must rely more heavily on theories; yet theory cannot falsify theory, only evidence can. Therefore, the high-frequency secondary-market data of green bond transactions gives asset pricing research (Cluster 1) a privilege and a head start. By contrast, assessing environmental impacts (Cluster 3) requires lengthy time series that have only become accessible as bonds issued in the mid-2010s mature, and their projects reach completion. The resulting ex-post information now permits researchers to track emissions, energy efficiency, and clean-investment metrics (e.g., Fatica and Panzica, 2021; Benlemlih et al., 2023; Wang and Taghizadeh-Hesary, 2023). In addition, exogenous shocks such as the COVID-19 market collapse in 2020 and the Russia-Ukraine war in 2022 generated sizable shifts in liquidity, risk premia, and energy prices. Daily indices, for example the S&P Green Bond Index, and newly released trade-and-quote datasets enable analysts to study the hedging properties and real-economy consequences of green bonds during these episodes, and empirical evidence already documents differential price behavior and resilience (e.g., Guo and Zhou, 2021; Batra et al., 2025; Zeng et al., 2025).

### *2.4.4. Research Agenda*

Based on the findings above, I propose several promising directions for future research. The growth of green bond studies has led to thematic saturation in pricing and issuance domains, while the environmental effects of green bonds remain relatively under-theorized and under-examined. Future research can enhance the field through the following directions:

First, although green bonds are defined by their use of proceeds, empirical studies rarely evaluate whether they deliver measurable environmental benefits. A major obstacle is the lack of project-level data that matches bond proceeds to environmental performance. Future research should leverage emerging environmental disclosure standards, satellite-based emissions tracking, and corporate sustainability reports to develop outcome-based measures. Methodologically, this calls for innovative matching strategies and the use of quasi-experimental designs anchored in impact measurement, not just market responses. In addition, future studies can also integrate climate policy modelling and organizational theories of legitimacy and sensemaking. This broader lens can help capture the long-run and

[6] Source from: The "Sustainable Debt Global State of the Market 2020" published by Climate Bonds Initiative (https://www.climatebonds.net/data-insights/publications/sustainable-debt-global-state-market-2020).

system-level effects of green bonds, including how they align (or misalign) with global climate goals and transition pathways.

Second, current studies have mainly drawn from countries with relatively mature financial and ESG infrastructure (e.g., the US, EU, and China). However, the mechanisms and motivations behind green bond issuance and investment may differ in emerging or low-trust environments. Future research can use comparative institutional approaches to explore how legal systems, policy coherence, and cultural expectations shape market functioning and the perception of green credibility. This calls for broader geographic coverage and inclusion of hidden dimensions of green finance under heterogeneous governance regimes.

Third, given that green bonds co-exist with many other sustainability-linked bonds, transition bonds, and social bonds, future research should explore whether these instruments compete for capital or create synergistic complementarity. For instance, do investors diversify across instruments to hedge regulatory or reputational risks? Do firms substitute one label for another to meet shifting disclosure requirements? Network-based methods and portfolio-level studies can offer fresh insights into cross-asset dynamics in sustainable finance.

Finally, one enduring limitation of the green bond market is the insufficient monitoring of issuers' post-issuance performance related to funded projects. Future research can explore how institutional designs (e.g., penalty clauses, bond covenants) might improve credibility and align long-term incentives for issuers. Contract theory (Hart and Moore, 1999) and public-private partnership frameworks (Martimort and Pouyet, 2008) may provide theoretical frameworks to assess how rules and incentives shape green outcomes over time.

### 2.5. Conclusion

Drawing on 206 high-quality articles on green bonds research, this systematic literature review employs bibliometric and content analyses to identify thematic clusters, theoretical framings, and empirical strategies. I categorize the literature into three primary thematic clusters: asset pricing, issuance determinants, and environmental effects. Trend analysis reveals a noticeable shift in research attention from financial attributes toward sustainability-related outcomes.

From a theoretical perspective, I show that the three clusters of research rely on different theoretical foundations depending on their data structure and research foci. Cluster 1, which investigates pricing and connectedness, generally draws on minimal theoretical underpinnings, as there are rich high-frequency datasets on secondary-market transactions. In contrast, studies in Clusters 2 and 3, which analyse firm-level decisions and environmental outcomes, rely more heavily on robust theoretical frameworks such as signalling theory, stakeholder theory, and the resource-based view to offset their limited empirical data. Moreover, studies in Clusters 2 and 3 need to handle more empirical challenges regarding endogeneity. One key contribution of this review is its comprehensive summary of empirical identification strategies, particularly in addressing endogeneity.

A central theoretical contribution lies in synthesizing fragmented perspectives into a coherent framework that distinguishes between instrumental and intrinsic approaches to green bond valuation. The instrumental perspective treats green bonds primarily as financial tools serving market functions like signalling and diversification, while the intrinsic perspective emphasizes genuine environmental substance and measurable outcomes. My analysis demonstrates these approaches are complementary rather than competing, with a comprehensive understanding requiring consideration of both financial mechanisms and environmental effectiveness simultaneously.

The temporal evolution reveals a clear shift from exploratory research documenting basic market phenomena toward rigorous evaluation of environmental effectiveness and policy impact. This trajectory reflects market maturation, growing greenwashing concerns, improved data availability, and intensified policy focus on climate finance. However, this progression should not diminish attention to financial market mechanisms, as green bonds' success as environmental policy tools ultimately depends on their effective functioning within market systems.

In addition to synthesizing the current state of green bond research, this review outlines evidence-based directions for advancing the field. By moving from measuring short-term financial responses to evaluating long-term environmental effectiveness, green bond research can play a more meaningful role in supporting the global transition toward sustainability. However, the literature shows signs of thematic concentration and methodological repetition, especially within pricing studies. To advance the field, future research should adopt a more integrative agenda that connects financial market outcomes with real-world environmental impact, embraces greater institutional and investor diversity, and achieves stronger alignment between theoretical frameworks and empirical methods. Furthermore, practical implications for policy design, issuer accountability, and investor decision-making should be more explicitly investigated, ensuring that academic insights translate into effective climate finance strategies.

# Chapter 3. Choices and Effects of Green Labels in the EU Bond Market

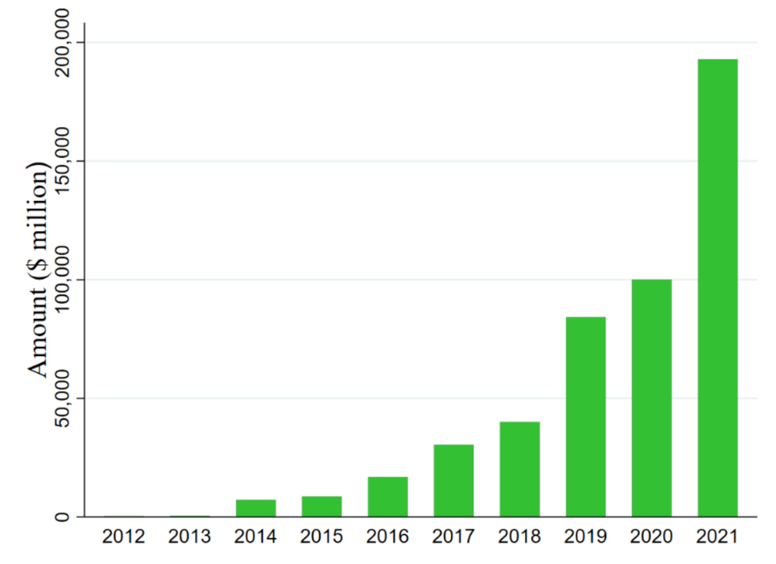
**Abstract:** This paper demonstrates that green-labelling forms an integral part of financial investment vehicles. We use data from the EU green bond market to show that green labels reduce the required yields on bonds (the "greenium") in the long run, with the effect being more pronounced when labels are externally certified. We also find that green bonds can increase investors' short-term attention when they are externally labelled. Further evidence suggests that the greenium of self-labelled green bonds is mainly attributed to a weak signaling effect, whereas that of externally-labelled bonds results from a combination of signalling effect and pro-environmental preferences. Our findings indicate that investors value the reassurance that third-party certifications provide about the ethical use of bond proceeds. This highlights the potential benefits of introducing stricter oversight of green bond proceeds in the bond market.

**Keywords:** Green Bond Label; Signalling Effect; Pro-environmental Taste

## 3.1. Introduction

Green bonds have become a popular financial instrument for investors to diversify their portfolios (e.g., Reboredo, 2018; Guo and Zhou, 2021) and for issuers to raise funds for their environmentally-friendly projects (e.g., Zerbib, 2019; Tang and Zhang, 2020; Díaz and Escribano, 2021). The EU green bond market has experienced substantial growth over the past decade, with a total issuance surpassing $350 billion of rated bonds (see **Figure 3.1**). This surge in demand for green bonds has also increased scholarly attention (Jankovic et al., 2022). However, a consensus remains elusive in the empirical studies as to whether green bond labelling affects investors' required returns. For instance, Zerbib (2019) and Lau et al. (2022) find a small green premium, or 'greenium', but Larcker and Watts (2020), Fatica et al. (2021), and Flammer (2021) show that the greenium is insignificant. Even studies that report a significant greenium offer disparate interpretations, with some attributing it to investors' pro-environmental taste (Zerbib, 2019) while others to issuers' signalling effect (Flammer, 2021). Hereafter, I refer to this ongoing debate as the "greenium puzzle".

**Figure 3.1.** Annual amounts of green bonds issued in the EU market.




Notes: This figure depicts the annual total dollar amount of proceeds funded through issuing green bonds in the EU market. The sample period is from 2012 to 2021.

Prior studies mainly used matching techniques to estimate greenium. For instance, Zerbib (2019) uses a two-step approach that emphasizes the importance of liquidity and maturity in matching green bonds with equivalent synthetic conventional bonds. Flammer (2021) applies the multivariate nearest neighbour matching method to pair a green bond with its conventional counterpart. Nevertheless, existing evidence is mixed and sensitive to the matching technique used (see **Table 3.1**). In an attempt to resolve the greenium puzzle, I go one step further by carefully examining the differences in the labels used by various green bond issuers. I believe that tapping into the "green box" will enhance the understanding of how green bonds are labelled and the relationship between greenness labels and greenium.

**Table 3.1.** Key empirical findings on green bonds' greenium.

| Prior empirical studies | Matching Criteria | Greenium |
|---|---|---|
| Zerbib (2019) | issuer, maturity, currency, rating, seniority, collateral, coupon, issue date, size, liquidity | 2 bps |
| Tang and Zhang (2020) | issuer, market to book value, liquidity, size, issue date | 6.94 bps |
| Larcker and Watts (2020) | issuer, rating, callable, call date, coupon, maturity | not significant |
| Flammer (2021) | rating, issuance amount, maturity, coupon, issue date | not significant |
| Lau et al. (2022) | issuer, currency, rating, issue date, maturity | 1 bp |

This table lists the key findings in prior empirical studies pertaining to the estimation of green bonds' greenium. This table also summarizes the matching criteria each paper employed in their model specification.

In this paper, I use the term 'greenness' to describe the credibility of green labels. Arguably, the greenness of the label is closely correlated with the authenticity of green bonds. Specifically, the greenness signals carried by externally-labelled bonds are likely to be more credible ('darker greenness') thanks to stricter compliance rules, so these green bonds are likely to have higher authenticity. In contrast, self-labelled bonds are more likely to be subject to greenwashing and may, therefore, be considered to be 'lighter greenness'. As a result, green bonds with external labels should generate different greeniums vis-à-vis their self-labelled counterparts. Between 2012 and 2021, the two most popular green labels in the EU are certified by the International Capital Market Association[7] (ICMA) and Climate Bonds Initiative[8] (CBI). Compared with self-labelled green bonds, issuing green bonds in line with ICMA or/and CBI's requirements stands for higher assurance of authenticity of green projects. However, marketing green bonds with external certification may mitigate, but not necessarily eliminate, investors' concerns about greenwashing (Gounopoulos et al., 2023). Besides, external certifications can involve substantial compliance costs and administrative burdens for issuers, which might offset some of the perceived benefits to investors (Montiel et al., 2016). Therefore, this chapter aims to provide a more comprehensive analysis of the choices and effects of various green labels. To achieve this, I have developed two key hypotheses.

First, I hypothesize that investors require lower yields on externally-labelled green bonds compared to self-labelled green bonds. The signalling theory (Riley, 1979) underscores the idea that reputable standards and certifications can serve as credible signals, reducing information asymmetry between investors and managers (e.g., Halim et al., 2019; Flammer, 2021; Bellucci et al., 2023). Bedendo et al. (2023) show that institutional investors issue green bonds to "signal their commitment to finance the green transition". In this vein, I argue

[7] For more information about ICMA, please see https://www.icmagroup.org.
[8] For more information about CBI, please see https://www.climatebonds.net.

that external labels can serve as a stronger signal of assurance to stakeholders that the proceeds will be appropriately used. The taste-based framework (Fama and French, 2007) also predicts that investors are willing to accept lower payoffs from assets that align with their preferences or tastes (Du et al., 2017). As corporate environmental responsibility and climate concerns gain increasing prominence (e.g., El Ghoul et al., 2011; Ferriani, 2023), green investors are increasingly willing to accept lower returns in exchange for higher assurance of green projects (El Ghoul et al., 2018).

Second, I conjecture that, by having a third-party endorsement on the pro-environmental mission of the bond proceeds, issuing green bonds with external labels attracts more investor attention. As a trending topic, green bond issuance receives wider media coverage and public attention than conventional bonds (e.g., Krüger, 2015; Tang and Zhang, 2020; Flammer, 2021). Although investor attention is often short-lived (Ben-Rephael et al., 2017), external labels can significantly enhance issuers' information transparency, especially when the market is acutely concerned about how the proceeds will be utilized.

To test these hypotheses, I manually collected the label information for all green bonds issued in EU markets and employed the endogenous treatment effect model for the baseline tests. I first show that issuers have distinct motives for issuing green bonds. Specifically, issuers prefer financing through externally-labelled green bonds when they are from countries with lower sustainable development scores or after the EU signed the Paris Agreement on climate change. I then confirm the hypothesis that externally-labelled green bonds have a lower required yield than self-labelled and conventional bonds. These findings are robust to alternative empirical measures and modelling techniques. Furthermore, I employ the Propensity Score Matching jointly with the Difference-in-Differences (PSM-DID) approach to confirm the hypothesis that green bonds with external labels attract greater investors' attention. I also conduct heterogeneity tests to quantify the taste-based and the signalling channels. Further analysis suggests that the effect of external labels on bond yields is attributed to both channels, while that of self-labelling can only be partly explained by the signalling effect.

This study makes three contributions to the literature. First, most empirical studies on greenium implicitly assume that green labelling is a random event rather than an endogenous corporate decision. Only a few studies consider the motivations for labelling bonds (e.g., Daubanes et al., 2021; Dutordoir et al., 2023). For example, Daubanes et al. (2021) investigate the impacts of managerial incentives and carbon pricing on firms' decisions to issue green bonds. In contrast, this chapter emphasizes the choice between different green labels (no label, self-label, and external label) and addresses the potential selection bias when investigating the impact of these labels on bond yield and investor attention.

Second, I contribute to the business ethics literature by extending the research from the extensive margin ('to be green or not to be green') to the intensive margin ('to be light green or to be dark green'). I show that a higher level of greenness not only attracts pro-environmental investors, but also enables issuers to send a more credible signal about their commitment to environmental responsibility. By complying with externally assured standards, issuers can differentiate themselves in a competitive market, enhancing their reputation, and benefiting from a higher greenium, as investors view these bonds as more credible and impactful in driving environmental progress.

Third, this chapter makes a step towards resolving the greenium puzzle in the green finance literature. For example, Flammer (2021) and Larcker and Watts (2020) do not find evidence for the greenium, while Zerbib (2019) and Lau et al. (2022) show that the greenium is positive and significant. In contrast, I find that self-labelled green bonds do not attract significant investors' attention, carry weak signals, or receive insignificant greeniums, whereas externally-labelled green bonds attract higher investor attention, send stronger signals, and generate significant greeniums. Thus, the discrepancies in the literature can be reconciled by the nuanced relationship between greenness and greenium.

The remainder of this chapter proceeds as follows. Section 3.2 describes the institutional background of the EU bond market and develops the hypotheses. Section 3.3 presents the data and outlines the empirical methods. Section 3.4 discusses the empirical findings, and Section 3.5 concludes.

## 3.2. Institutional Background and Hypothesis Development

### *3.2.1. Institutional Background*

The EU market represents a mature financial environment, with well-established regulations, legislation, and institutions. These characteristics have nurtured a stronger green taste among market participants. Green bond issuers in the EU markets choose one of the following three labels: self-, ICMA-, or CBI-label. The self-labelled bond issuers assert that bond proceeds will be used for green projects, but without committing themselves to third-party principles. In contrast, issuers of green bonds with external certification obtain third-party recognition and declare their adherence to standards set by ICMA or CBI.

I conduct a formal content comparison of ICMA and CBI standards and organize the main certification requirements of these bodies in Appendix **Table A 3.4**. The analysis suggests that ICMA and CBI have similar requirements for pre- and post-issuance stages of green bonds[9].

[9] Employing the machine learning textual analysis methods of Ali and Qaiser (2018), I also compare the TF-DFI scores of keywords between ICMA and CBI's documentations. The similarity metric of the two standards is 85.3%, confirming the qualitative content analysis in Appendix **Table A 3.4**. Results are available on request.

They not only provide additional assurance to the bond proceeds, but also ask for additional disclosures of impacts from the project. Since obtaining external certification involves additional compliance costs as well as more assurance of the project's environmental effects, I argue that externally-labelled green bonds should generate different greeniums from their self-labelled counterparts. Given these labelling discrepancies among EU green bonds, analysing issuers' selection of green bond labels can potentially resolve the conflicting findings on greeniums associated with green bond issuance (e.g., Zerbib, 2019; Tang and Zhang, 2020; Díaz and Escribano, 2021).

### *3.2.2. Research Hypothesis*

My work relates to the numerous empirical studies that have investigated the process of ESG label selection. However, most of the existing work focuses primarily on how these labels affect mutual funds, highlighting the ethical concerns that relate to the motives behind ESG label selections. For instance, Raghunandan and Rajgopal (2022) underscore the ethical risks associated with self-labelled ESG funds, revealing that mutual funds may not adhere to their ethical claims and may invest in companies with poor compliance records. This suggests that the motivation to select an ESG label might sometimes be driven more by marketing considerations than by a genuine commitment to ethical standards, potentially leading to greenwashing. Similarly, Kim and Yoonb (2023) reveal that even funds affiliated with well-known ESG initiatives, such as the United Nations Principles for Responsible Investment (UN PRI), may fail to deliver on their ethical promises, as their ESG performance does not always improve post-affiliation. Gounopoulos et al. (2023) further emphasize that while investors are drawn to ESG-labelled funds, this attraction often leads to an overemphasis on the label itself rather than the underlying ethical or sustainability practices. This behavior highlights the ethical implications of labelling, as the decision to adopt an external label can drive investment flows and shape perceptions, regardless of the fund's underlying ethical practices.

To investigate green label selection for green bonds, I draw upon the following theoretical perspectives. First, the signalling hypothesis, as outlined by Riley (1979), suggests that since investors often lack sufficient information to evaluate the company's commitment to the environment (e.g., Lyon and Maxwell, 2011; Lyon and Montgomery, 2015), adherence to reputable standards/certifications can be viewed as a credible signal[10] that mitigates information asymmetry and provides additional assurance to the project (e.g., Halim et al., 2019; Flammer, 2021; Bellucci et al., 2023). Existing literature emphasizes the role of certification in enhancing the firm's reputation and reducing investor scepticism. For

[10] During the whole financing period of a project, both ICMA and CBI require issuers to disclose third-party verified documents, such as Green Bond Framework, Allocation Report, and Impact Report, which allow investors to be better informed about the uses of bond proceeds as well as the monitoring processes and safeguards applied.

instance, Paeleman et al. (2024) document that the adverse effects of higher leverage are weaker for Certified B Corporations than for common commercial firms. Chen et al. (2023) discuss how industry reputation crises can lead firms to seek certification as a strategy to differentiate themselves and restore trust among consumers and investors. These findings support the idea that widely accepted standards can increase market confidence, which further reinforces the value of external certifications (Montiel et al., 2016).

Furthermore, the taste-based theory predicts that investors are willing to accept lower payoffs from assets that satisfy their preferences or tastes (e.g., Du et al., 2017; Fatica et al., 2021). In this sense, with increasing attention to corporate environmental responsibility, investors who prioritize climate concerns will accept lower returns on green projects (e.g., El Ghoul et al., 2011; El Ghoul et al., 2018; Ferriani, 2023). Thus, based on the signalling and taste-based frameworks, I hypothesize that green bonds with external labels have a lower required yield (or a higher greenium) than their self-labelled (and conventional) counterparts:

*(H1a) Investors require lower yields on green bonds than conventional bonds.*

*(H1b) Externally-labelled green bonds have lower yields than their self-labelled counterparts.*

The second hypothesis relates to the spillover effect of green bond issuance on investor attention to the issuing firms. Investors' attention to corporate news is scarce and limited. As a trending topic, green bond issuance receives wider media coverage than its conventional counterpart (e.g., Krüger, 2015; Flammer, 2021). Tang and Zhang (2020) find that green bond issuance can raise investors' attention to the issuers' stock and benefit the shareholders. In turn, investor attention can also influence green bond returns and volatility, with the effect being stronger in the short run (Pham and Huynh, 2020). These findings highlight the importance of investor attention in directing financial flows toward green bonds. Furthermore, existing literature also underscores that external certification can attract investor attention by providing credibility and visibility. For example, Miles and Munilla (2004) find certifications can enhance a firm's market positioning and attract new investor segments by providing additional transparency and trust in the firm's environmental commitments. Accordingly, I posit that since external certification is more effective in mitigating information asymmetry than self-labelling, green bonds with external labels can attract more attention from green investors. This leads me to hypothesize that:

*(H2) Issuing externally-labelled green bonds can attract more investor attention than issuing self-labelled green bonds.*

## 3.3. Data and Methods

### *3.3.1. Data Collection and Preliminary Findings*

My sample contains all green and conventional bonds issued in the EU market from 2012 to 2021. Since the number of conventional bonds is far greater than that of green bonds, I employ the propensity score matching (PSM) method to pair the green and conventional bonds in terms of price at issuance, amount, years to maturity, issuance time, and issuer's sector. I find significant structural differences between the conventional bonds and green bonds before matching, but there are no significant differences in the issuers and bond characteristics between the two types of bonds after PSM[11]. Next, I manually collected each bond's detailed labelling information from the issuers' Green Bond Framework and other related documents, including the official websites and the annual financial reports. Data on bond characteristics, such as years to maturity, bond size, issuer size at issuance, and ISIN number, are obtained from the Refinitiv database. Bond market activity data, such as daily yield, bid-ask spread, and issuers' default probability, are collected from Bloomberg. Finally, I web crawl the Google search volume of each issuer 12 months before and after the issuance of green bonds. **Table A 3.5** in the Appendix provides a detailed description of the data sources and variable definitions.

**Table 3.2** reports descriptive statistics of the key variables. Green bonds and paired convention bonds tend to have low coupon rates (with a mean of 3.848% and a standard deviation of 3.852) and longer maturities (with a mean of 9.355 years and a standard deviation of 6.649). Meanwhile, the differences between the maximum and mean values for both coupon rates and maturity suggest that a small proportion of green bonds are exposed to high levels of interest rate risk. The mean value of the dummy variable *FirstGreen* (first-time green bond issuer) is 0.211, indicating that the majority of green bonds are brought to market by experienced issuers. Green bonds are especially popular among infrastructure-related projects, such as clean transportation, with such projects accounting for slightly over a third of green bond proceeds[12] (34.88%).

[11] The t-test results of covariates between the conventional and green bonds before and after PSM are available on request.
[12] More detailed summary of green bonds' use of proceeds can be found in Appendix **Table A 3.6**.

**Table 3.2.** Descriptive statistics of key variables.

| Variable | Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| YieldIssue | 2,003 | 4.060 | 4.527 | 0.000 | 32.167 |
| Amount ($million) | 2,003 | 624.115 | 753.441 | 1.000 | 15817.033 |
| Coupon | 2,003 | **3.848** | **3.852** | 0.050 | 13.260 |
| Yrs2Maturity | 2,003 | **9.355** | **6.649** | 3.003 | 30.019 |
| RatingScale | 2,003 | 11.990 | 7.193 | 1 | 20 |
| FirstGreen | 2,003 | **0.211** | 0.408 | 0 | 1 |
| GreenBond | 2,003 | 0.540 | 0.499 | 0 | 1 |
| Self-label | 2,003 | 0.040 | 0.197 | 0 | 1 |
| External-label | 2,003 | 0.499 | 0.500 | 0 | 1 |
| ICMA | 2,003 | 0.477 | 0.500 | 0 | 1 |
| CBI | 2,003 | 0.065 | 0.247 | 0 | 1 |
| Financials | 2,003 | 0.442 | 0.497 | 0 | 1 |
| Listed | 2,003 | 0.240 | 0.427 | 0 | 1 |
| Callable | 2,003 | 0.407 | 0.491 | 0 | 1 |
| CleanTransport | 2,003 | 0.189 | 0.391 | 0 | 1 |
| SDG | 2,003 | 77.694 | 5.323 | 7.580 | 86.420 |
| ParisAgreement | 2,003 | 0.948 | 0.223 | 0 | 1 |
| MarketSentiment | 2,003 | 1.907 | 0.805 | 1 | 3 |
| ECB_PolicyRate | 2003 | 3.714 | 3.490 | 1 | 10 |
| Inflation | 2,003 | 7.886 | 3.167 | 1 | 10 |
| GoogleTrends | 73,712 | 36.967 | 26.679 | 0.000 | 100.000 |
| NewsHeat | 18,256 | 0.040 | 0.175 | 0 | 1 |

This table shows the summary statistics for paired bonds' cross-sessional data and investors' monthly attention data. *Yrs2Maturity* is the number of years from the issuance date to the maturity date. *GreenBond* equals 1 when the bond has a green label. *FirstGreen* equals 1 when it is the issuer's first time issuing green bonds and 0 otherwise. *Self-label* equals 1 when the green bond does not follow external green bond standards. *External-label* equals 1 when a green bond is labelled by third parties. Dummy variables *ICMA* and *CBI* are used to identify which external green bond principle is followed by the issuer. *Financials* and *Listed* identify whether the issuer belongs to the financial sector and is listed, respectively. *Callable* is a dummy variable used to identify whether the bond has a call option, respectively. *CleanTransport* equals 1 when green bonds are financed for clean transport projects and 0 otherwise. *SDG* stands for the issuer-located country's overall sustainable score in the year before the bond issuance. *ParisAgreement* equals 1 when the green bond is issued after April/2016. *MarketSentiment* is the categorized value of the Sentix Economic Indices Euro Aggregate Overall Index. *ECB_PolicyRate* stands for the categorized value of the European Central Bank's interest rate on the main refinancing operations. *Inflation* is the categorized value of the EU inflation rate. *GoogleTrends* refers to the issuers' monthly Google Search Volume, a proxy for individual investor attention. *NewsHeat* is the institutional investor attention from Bloomberg News Heat. More variable definitions and sources are provided in Appendix **Table A 3.5**.

**Table 3.3** presents the Pearson correlation coefficients between the main variables. It shows that green labelling is significantly associated with certain bond characteristics. For example, *GreenBond* is negatively correlated with $YieldIssue$ (-0.151***), indicating that green bonds are more likely to have a lower yield than paired conventional bonds. *SDG* is positively correlated with the propensity of choosing external labels (0.132***), but not related to the self-labelling decision. This suggests that issuers from countries with high sustainable development scores prefer to issue externally-labelled green bonds. Finally, the self- and externally-labelled green bonds are correlated differently with the *YieldIssue*, with correlations being 0.0227 and -0.160***, respectively. The varying significance and magnitude of the greenness-greenium relationship provide a potential explanation for the controversial findings in prior literature on greenium (e.g., Zerbib, 2019; Larcker and Watts, 2020; Flammer, 2021).

**Table 3.3.** Correlation coefficient matrix of main variables.

| | YieldIssue | lnAmount | Coupon | Years to Maturity | Rating Scale | Green Bond | Self-label | External-label | Financials | Listed | Callable | Clean Transport | SDG | Paris Agreement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YieldIssue | 1 | | | | | | | | | | | | | |
| lnAmount | 0.0477* | 1 | | | | | | | | | | | | |
| Coupon | 0.965*** | 0.0535* | 1 | | | | | | | | | | | |
| Yrs2Maturity | -0.0508* | 0.0157 | -0.0296 | 1 | | | | | | | | | | |
| RatingScale | 0.274*** | -0.205*** | 0.274*** | -0.164*** | 1 | | | | | | | | | |
| GreenBond | **-0.151***** | -0.302*** | -0.170*** | -0.0946*** | 0.0468* | 1 | | | | | | | | |
| Self-label | **0.0227** | -0.0464* | 0.0280 | -0.0273 | 0.0352 | 0.190*** | 1 | | | | | | | |
| External-label | **-0.160***** | -0.283*** | -0.181*** | -0.0835*** | 0.0328 | 0.922*** | -0.205*** | 1 | | | | | | |
| Financials | -0.191*** | -0.116*** | -0.195*** | -0.0812*** | -0.206*** | 0.152*** | 0.0572* | 0.129*** | 1 | | | | | |
| Listed | -0.00785 | 0.0799*** | 0.00993 | 0.0123 | -0.0205 | -0.0928*** | -0.0383 | -0.0775*** | -0.0154 | 1 | | | | |
| Callable | 0.162*** | 0.260*** | 0.182*** | 0.162*** | 0.0777*** | -0.153*** | -0.0978*** | -0.114*** | -0.291*** | 0.196*** | 1 | | | |
| CleanTransport | -0.168*** | -0.0774*** | -0.180*** | -0.0597** | 0.0122 | 0.443*** | 0.0435 | 0.424*** | 0.108*** | -0.0292 | -0.0800*** | 1 | | |
| SDG | -0.351*** | -0.144*** | -0.373*** | 0.00214 | -0.00274 | 0.119*** | **-0.0320** | **0.132***** | -0.00510 | -0.0655** | -0.0322 | 0.113*** | 1 | |
| ParisAgreement | -0.00846 | -0.0426 | -0.0106 | -0.112*** | -0.00998 | 0.0884*** | -0.168*** | 0.154*** | -0.00274 | -0.00412 | 0.122*** | 0.0963*** | 0.0501* | 1 |

This table reports the Pearson correlation between the test variables' cross-sessional data. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

I then use univariate analyses to examine the potential structural differences between groups of bonds with different green labels. **Table 3.4** reports the by-group mean of the bond characteristics and the t-test results. Panel A compares the green and conventional bonds, whereas Panel B reports the differences between the self- and externally-labelled green bonds. Panel A shows that the green and conventional bonds differ significantly in their characteristics, such as the coupon rate, maturity, and issuer types. Similar results are reported in Panel B, which indicates that the characteristics of the self-labelled bonds are significantly different from those of externally-labelled counterparts. These discrepancies among different groups of green bonds, together with the potential self-selection issue call for the heterogeneous treatment of green bonds with different labels.

**Table 3.4.** Univariate tests on differences in bond characteristics.

| **Panel A:** Conventional bonds vs. green bonds | | | | | | |
|---|---|---|---|---|---|---|
| | Conventional | Green | diff. | St. Err. | T-value | P-value |
| | (N=1,038,540) | (N=1,073,811) | | | | |
| Yield | 3.832 | 3.397 | 0.434 | 0.005 | 101.450 | 0.000 |
| Amount($million) | 874.104 | 479.293 | 394.810 | 1.032 | 382.800 | 0.000 |
| Coupon | 4.618 | 3.337 | 1.281 | 0.005 | 242.150 | 0.000 |
| Yrs2Maturity | 10.524 | 8.988 | 1.536 | 0.009 | 170.800 | 0.000 |
| Puttable | 0.007 | 0.002 | 0.005 | 0.000 | 53.150 | 0.000 |
| Callable | 0.441 | 0.308 | 0.132 | 0.001 | 200.500 | 0.000 |
| Financials | 0.348 | 0.521 | -0.175 | 0.001 | -259.550 | 0.000 |
| Listed | 0.284 | 0.204 | 0.080 | 0.001 | 136.150 | 0.000 |
| CleanTransport | 0.001 | 0.322 | -0.322 | 0.001 | -699.900 | 0.000 |
| **Panel B:** Green bonds self-labelled vs. externally-labelled | | | | | | |
| | Self-label | External-label | diff. | St. Err. | T-value | P-value |
| | (N=118,835) | (N=954,976) | | | | |
| Yield | 3.388 | 3.466 | -0.077 | 0.009 | -8.000 | 0.000 |
| Amount($million) | 479.811 | 475.137 | 4.675 | 1.871 | 2.500 | 0.013 |
| Coupon | 3.257 | 3.980 | -0.723 | 0.011 | -65.750 | 0.000 |
| Yrs2Maturity | 8.971 | 9.121 | -0.150 | 0.019 | -7.800 | 0.000 |
| Callable | 0.333 | 0.110 | 0.224 | 0.002 | 159.000 | 0.000 |
| Financials | 0.510 | 0.618 | -0.108 | 0.002 | -70.450 | 0.000 |
| Listed | 0.208 | 0.164 | 0.045 | 0.001 | 36.150 | 0.000 |
| CleanTransport | 0.336 | 0.207 | 0.130 | 0.002 | 90.650 | 0.000 |

This table reports the bond characteristics with different labels. I report t-values and p-values of the between-group t-tests on bond characteristics. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

### *3.3.2. Estimation Approach*

Before presenting the formal econometric specification, it is useful to briefly explain the intuition behind the empirical strategy. The key challenge in analysing green bond labels is that the decision to obtain external certification is not random. Issuers strategically choose whether to adopt external labels based on characteristics that may also affect bond yields and investor attention. Ignoring this self-selection may therefore lead to biased estimates. To address this issue, I employ a two-step endogenous treatment effect model (e.g., Cumming et al., 2019; Akins et al., 2020), which jointly models the labelling decision and the outcome equations. The first step of the model estimates the selection equation for green bond labels:

$$Pr(D=1) = \Phi(\boldsymbol{\alpha}_z' \boldsymbol{z} + \boldsymbol{\alpha}_x' \boldsymbol{x}), \tag{3.1}$$

Where $D$ is one of the dependent (dummy) variables: *GreenBond*, *Self-label*, *External-label*; $\mathbf{z}$ is a vector of endogenous variables (*SDG* and *ParisAgreement*), where $SDG$ is the issuer-located country's sustainable score in the year before the bond issuance, and *ParisAgreement* is a dummy to identify whether the bond is issued after the EU signed the Paris Agreement[13]; $\mathbf{x}$ is a vector of other explanatory variables including $DefaultProbability$, $Bid - Ask\ Spread$, $Listed$, $Financials$, $Listed$, *CleanTransport*, and $Callable$. I compute the inverse Mills' ratio ($IMR$) based on equation (3.1) and include it in the second step, i.e., outcome equation (3.2), to correct for the self-selection bias:

$$Yield = \delta D + \gamma IMR + \boldsymbol{\beta}'\mathbf{x} + \epsilon, \tag{3.2}$$

The endogenous treatment effect model is similar to, but not to be confused with, the Heckman selection model, which deals with sample selection rather than self-selection bias. In the Heckman selection model, the dependent variable is not observable when untreated ($D = 0$). The endogenous treatment effect model is superior to the nearest neighbour matching and the propensity score matching, as the matching process does not control for the non-randomness in the green labels. The "matched" counterparts in the treated and control groups are still systematically different due to the self-selection bias. In contrast, the endogenous treatment model explicitly integrates the selection equation (3.1) into the estimation of the Heckman outcome model, equation (3.2).

The estimation results of equations (3.1) and (3.2) can shed light on (H1), while (H2) is tested by using a PSM-DID method. This method can test the spillover effect of green bond issuance by treating the green labels as shocks to stock market investors. The treatment effect on investor attention can be estimated based on equation (3.3):

[13] The Paris Agreement on climate change was signed by EU on 22/Apr/2016. More information can be found from: https://www.consilium.europa.eu/en/press/press-releases/2016/04/22/paris-agreement-global-climate-action/

$$InvestorAttention = \sum_{\tau=-2}^{2} d_\tau D_{t+\tau} + \boldsymbol{b}'\tilde{\boldsymbol{x}} + \xi. \tag{3.3}$$

The lag and lead periods ($\tau$ = -2, -1, 0, 1, and 2 months) relative to the bond issuance day ($D$) are included to gauge the persistence of the impact on investors' attention. The vector of control variables $\tilde{\mathbf{x}}$ includes*Callable*, *FirstGreen*, *Listed*, *Financials*, *CleanTransport*, *SDG*, and *ParisAgreement*. Following the framework of Fatica et al. (2021), I also control for the fixed effects of issuers and time, bond size, maturity, rating, and market conditions in all regressions.

## 3.4. Empirical Results

### *3.4.1. Green Label and Bond Yield*

I use the endogenous treatment effect to deal with endogeneity concerns relating to the structural differences among green bonds with different labels. **Table 3.5** presents the estimation results of the issuers' label selection process. Columns (1) to (3) outline the issuers' choice between green and conventional bonds, while column (4) distinguishes the choice between self-labelling and external certification.

**Table 3.5.** The estimation results of the selection equation.

| | (1)<br>Green vs.<br>conventional bonds | (2)<br>Self-labelled green<br>vs. conventional bonds | (3)<br>Externally-labelled<br>vs. conventional bonds | (4)<br>Externally-labelled<br>vs. self-labelled |
|---|---|---|---|---|
| **SDG** | **0.014***** | 0.035*** | 0.012*** | **-0.005***** |
| | (69.900) | (62.190) | (56.590) | (-11.730) |
| **ParisAgreement** | **0.142***** | -0.937*** | 0.449*** | **1.489***** |
| | (40.520) | (-168.850) | (107.480) | (223.558) |
| Callable | -0.172*** | -0.648*** | -0.114*** | 0.522*** |
| | (-62.762) | (-107.044) | (-40.364) | (86.361) |
| DefaultProbability | 2.465*** | 4.080*** | 1.892*** | -4.442*** |
| | (80.971) | (67.626) | (60.027) | (-72.465) |
| BA_Spread | 0.159*** | -0.005 | 0.191*** | 0.109*** |
| | (52.405) | (-0.914) | (60.802) | (19.389) |
| Listed | 0.115*** | 0.107*** | 0.095*** | -0.053*** |
| | (13.841) | (4.498) | (11.692) | (-3.594) |
| Financials | 0.420*** | 0.404*** | 0.394*** | -0.181*** |
| | (161.572) | (81.926) | (147.444) | (-37.543) |
| CleanTransport | 3.484*** | 8.906*** | 3.475*** | 0.052*** |
| | (193.670) | (487.178) | (198.350) | (11.904) |
| Constant | -1.056*** | -3.320*** | -1.165*** | 0.275*** |
| | (-52.207) | (-75.168) | (-57.288) | (8.505) |
| Controls | Yes | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes | Yes |
| Pseudo $R^2$ | 0.310 | 0.385 | 0.320 | 0.242 |
| Observations | 1,915,743 | 764,073 | 1,799,413 | 879,650 |

Results from the 1st stage estimation of the treatment effect model. Dependent variables in columns (1) and (2) are *GreenBond* and *Self-label,* respectively. The dependent variable of both columns (3) and (4) is *External-label*. Control variables include bond size, maturity, rating, and market conditions (ECB policy rate). Two-way fixed effects (issuer, time) are included. Robust *t*-statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

The significantly positive coefficients on endogenous variables, *SDG* and *ParisAgreement* (0.014*** and 0.142***), in column (1) of **Table 3.5** present issuers' concern regarding environmental awareness, indicating that issuers from countries with high SDG scores or after the EU signed the Paris Agreement are more inclined to issue green bonds than conventional bonds. Meanwhile, the significantly positive coefficient on default probability in column (1) is consistent with the view that riskier issuers tend to send stronger signals to reassure investors. Similar results are reported in columns (2) and (3). Furthermore, I estimate the label selection within green bonds. The significantly negative coefficient on *SDG* (-0.005***) in Column (4) of **Table 3.5** implies that issuers from countries with low SDG scores exert greater efforts to signal their commitment to the environment. The coefficient on *ParisAgreement* (1.489***) suggests that green bond issuers are more likely to obtain external certification after the EU signed the Paris Agreement. The above findings show that issuers' selections of green bonds and green labels involve the consideration of their green image to investors, suggesting the existence of selection bias[14]. **Table 3.6** reports the regression results of the outcome equation, which provides a further distinction between the effects of self- and external-labels on bond yield. I visualize this label-greenium relationship in **Figure 3.2**. These results illustrate that the significant greenium within green bonds is mainly the outcome of external labelling. In addition, the statistically significant *IMR*s observed in column (1) of **Table 3.6** indicate the existence of selection bias when directly comparing green bonds with their conventional counterparts, providing a further potential explanation for the controversial findings in prior literature (e.g., Zerbib, 2019; Larcker and Watts, 2020; Flammer, 2021). Combined with **Table 3.5**, results from the treatment effect model substantiate the existence of the signal and/or green taste channel in decreasing bond yield, and, thereby, support both (H1a) and (H1b).

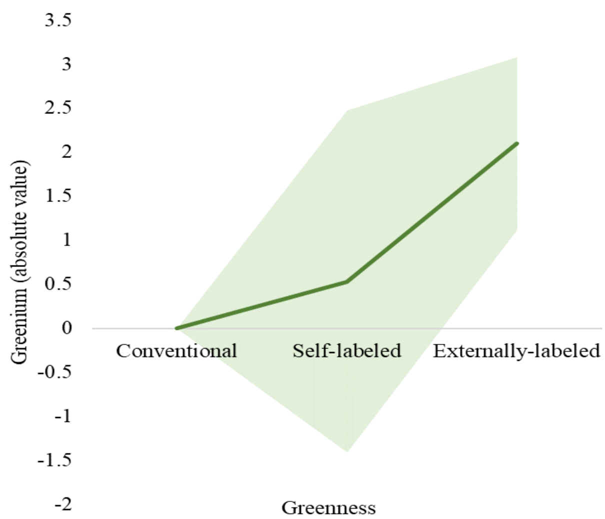
[14] My results remain robust when replacing the European Central Bank (ECB) policy rate by inflation rate to control market conditions (as results shown in **Appendix Table A 3.8** and **Table A 3.9**).

**Table 3.6.** The estimation results of the outcome equation.

| Yield | (1)<br>Green<br>vs. conventional | (2)<br>Self-labelled<br>vs. conventional | (3)<br>Externally-labelled<br>vs. conventional | (4)<br>Externally-labelled<br>vs. self-labelled |
|---|---|---|---|---|
| *D* = GreenLabel | **-1.971**$^{***}$ | | | |
| | (-3.960) | | | |
| *D* = Self-label | | **-0.533** | | |
| | | (-0.537) | | |
| *D* = External-label | | | **-2.099***** | **-1.829**** |
| | | | (-4.202) | (-2.077) |
| IMR | **1.073***** | 0.298 | 1.139*** | 0.785* |
| | (3.865) | (0.563) | (4.062) | (1.719) |
| Callable | 0.651*** | 0.596*** | 0.724*** | 0.836*** |
| | (4.478) | (2.899) | (5.049) | (3.061) |
| DefaultProbability | 21.191*** | 25.255*** | 19.811*** | 17.873*** |
| | (8.372) | (6.653) | (7.711) | (5.136) |
| BA_Spread | 2.441*** | 2.025*** | 2.441*** | 3.024*** |
| | (10.249) | (5.753) | (9.632) | (9.832) |
| Listed | -0.657*** | -0.925*** | -0.667*** | -0.591* |
| | (-3.405) | (-3.393) | (-3.405) | (-1.818) |
| Financials | 0.514*** | 0.372* | 0.515*** | 0.096 |
| | (3.190) | (1.872) | (3.331) | (0.433) |
| CleanTransport | 0.654** | 0.089 | 0.763** | -0.078 |
| | (2.077) | (0.114) | (2.367) | (-0.468) |
| Constant | 5.726*** | 0.705 | 6.295*** | 3.782*** |
| | (8.057) | (0.910) | (9.128) | (3.428) |
| Controls | Yes | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes | Yes |
| Adjusted $R^2$ | 0.557 | 0.522 | 0.557 | 0.559 |
| Observations | 1,915,743 | 764,073 | 1,799,413 | 879,650 |

Estimation results from the 2nd stage of the endogenous treatment effect model. The dependent variable of all columns is *Yield*. *IMR*s are generated through the corresponding estimations in **Table 3.5**. Control variables include bond size, maturity, rating, and market conditions (ECB policy rate). Two-way fixed effects (issuer, time) are included. Robust *t*-statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Figure 3.2.** The greenness-greenium relationship.




Notes: This figure depicts the yield greenium induced by the label greenness. The shaded area is the 95% confidence interval.

In the robustness tests, I verify the sensitivity of the label-greenium relationship observed in the baseline analysis. Instead of the binary endogenous treatment effect model, I use the ordered-Heckman model, following the framework of Chiburis and Lokshin (2007) to deal with the self-selection bias. More specifically, I include an ordinal variable as an additional independent variable in the ordered-Heckman model and use the following specification to estimate a consistent $IMR*$ (Chiburis and Lokshin, 2007):

$$IMR_{\mathrm{i}}^{*} = \frac{\phi(\hat{\mu}_j - \hat{s}_i^*) - \phi(\hat{\mu}_{j+1} - \hat{s}_i^*)}{\Phi(\hat{\mu}_{j+1} - \hat{s}_i^*) - \Phi(\hat{\mu}_j - \hat{s}_i^*)}, \text{ for issuer } i \text{ with label greenness } j \in [0, 1, 2]. \quad (3.4)$$

The cutting value $\hat{\mu}_j$ and predicted score $\hat{s}_i^*$ are based on an ordered probit regression of the 3-scale “label (assurance to) greenness”, which replaces the probit regression of the baseline endogenous treatment effect model.

Panel A of **Table 3.7** presents the regression results of alternative Heckman outcome model specifications. I present the issuers’ label selection process in column (1) and further report each factor’s marginal effects in Appendix **Table A 3.7**. The overall results show that issuers primarily focus on the selection between conventional bonds and externally-labelled green bonds, with the main determinants being the use of proceeds and the need for signalling lower risks. Following these factors, the climate concerns raised by the Paris Agreement exert relatively greater marginal effects compared to other factors in the issuers’ label selection process.

Besides, the coefficients on *LabelGreenness* and $IMR$ in **Table 3.7** are both significant, highlighting the importance of considering the self-selection bias. Compared with the OLS estimation results reported in Panel B, both results from **Table 3.6** and Panel A of **Table 3.7** indicate the presence of selection bias behind green bonds’ labelling, biasing the OLS estimates of the yield on green bonds. Furthermore, given the ordered-Heckman model is more restrictive in the model specification, it does not appropriately capture the selection process between self- and externally-labelled green bonds in column (4) of **Table 3.5**. This result not only reconfirms the necessity of making comparisons within different groups of green bonds, but also highlights the difference between green and conventional bonds. Therefore, I draw conclusions based on the treatment effect model and use the ordered-Heckman model solely for robustness purposes.

**Table 3.7.** Results of the ordered-Heckman and OLS analysis.

| | **Panel A:** Ordered Heckman | | **Panel B:** OLS | | |
|---|---|---|---|---|---|
| | (1) Stage 1 Label selection | (2) Stage 2 Outcomes | (3) Green vs. conventional | (4) Self-labelled vs. conventional | (5) Externally-labelled vs. conventional |
| | LabelGreenness | Yield | Yield | Yield | Yield |
| LabelGreenness | | **-0.150**** | | | |
| | | (-2.012) | | | |
| IMR | | **3.392***** | | | |
| | | (4.982) | | | |
| *D* = GreenLabel | | | -0.323** | | |
| | | | (-1.969) | | |
| *D* = Self-label | | | | -0.048 | |
| | | | | (-0.146) | |
| *D* = Externally-label | | | | | -0.354** |
| | | | | | (-2.134) |
| SDG | 0.013*** | | | | |
| | (63.997) | | | | |
| ParisAgreement | 0.319*** | | | | |
| | (98.693) | | | | |
| Controls | Yes | Yes | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes | Yes | Yes |
| Pseudo R-squared | 0.211 | | | | |
| Adjusted R-squared | | 0.566 | 0.539 | 0.508 | 0.538 |
| Observations | 1,915,743 | 1,915,743 | 1,915,743 | 764,073 | 1,799,413 |

Panel A presents results from the ordered-Heckman model, in which column (1) shows results from the ordered probit model in which the dependent variable *LabelGreenness* refers to different levels of label greenness (conventional bond=0, self-label=1, external-label=2). Colum (2) records the 2nd stage results of ordered-Heckman estimation. Panel B reports results from the OLS regression. The dependent variable of columns (2) to (5) is bond yield. Control variables include *Callable*, *Financials*, *Listed*, *CleanTransport*, bond size, maturity, rating, and market conditions (ECB policy rate and investor sentiment). Two-way fixed effects (issuer, time) are included. Robust *t*-statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

### *3.4.2. Green Label and Investor Attention*

After showing that investors have a special taste for green bonds (see **Table 3.7**), I test the extent to which different green labels attract wider investor attention (H2). I treat the month of the bond issuance as an exogenous event to the market and apply the PSM-DID method to compare the effect of green bond issuance on investor attention.

Following the literature summarized in **Table 3.1**, I apply the PSM approach to match green and conventional bond issuers using a comprehensive set of factors, including issuer size, bond size, years to maturity, issuance year and month, rating, call option, sector, and issuer location. I web crawl the monthly Google search volume of issuers to measure the individual investor attention and I use the Bloomberg news heat[15] data to construct a proxy for institutional investor attention. I then employ DID estimation to investigate the impact of green bond issuance on individual and institutional investor attention, respectively. **Table 3.8** reports the DID estimation results.

Panel A of **Table 3.8** reports regression results for individual investor attention. I show that the contemporaneous month dummies ($D_t$) are the only significant coefficients in regressions, consistent with (H2). I also find that only green bonds with external certification are more effective than conventional bonds in raising issuers' investor attention in the short term. This finding is consistent with evidence from Tang and Zhang (2020) and Flammer (2021) that the shocks in stock returns resulting from the green bond issuance are short-lived.

**Table 3.8.** The impact of bond issuance on investor attention.

| **Panel A:** Impact on issuers' Google Trends | | | |
|---|---|---|---|
| GoogleTrends | (1) Green vs. conventional | (2) Self-labelled vs. conventional | (3) Externally-labelled vs. conventional |
| Month(-1): $D_{t-1}$ | 4.178 | 6.201 | 0.690 |
| | (1.46) | (1.05) | (0.22) |
| Month(0): $D_t$ | 8.008** | **7.201** | **6.609**** |
| | (2.30) | (1.51) | (2.01) |
| Month(+1): $D_{t+1}$ | 2.298 | 6.001 | 6.073 |
| | (0.94) | (0.98) | (1.36) |
| Adjusted $R^2$ | 0.083 | 0.090 | 0.082 |
| Observations | 53,332 | 48,776 | 51,992 |
| **Panel B:** Impact on issuers' Bloomberg news heat | | | |
| NewsHeat | (1) Green vs. conventional | (2) Self-labelled vs. conventional | (3) Externally-labelled vs. conventional |
| Month(-1): $D_{t-1}$ | 0.0205 | 0.103 | 0.0007 |
| | (0.81) | (1.47) | (0.16) |
| Month(0): $D_t$ | -0.0009 | **0.155** | **0.0296**** |
| | (-0.29) | (1.07) | (2.09) |
| Month(+1): $D_{t+1}$ | -0.0205 | -0.0516 | 0.0003 |
| | (-1.00) | (-0.77) | (0.07) |
| Adjusted $R^2$ | 0.511 | 0.351 | 0.377 |
| Observations | 14,438 | 13,674 | 14,547 |
| Controls($\tilde{\mathbf{x}}$) | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes |

Result from the PSM-DID estimation. The dependent variables in Panels A and B are the issuers' monthly Google Trends and Bloomberg news heat, respectively. Control variables $\tilde{\mathbf{x}}$ includes *SDG*, *ParisAgree*, *Callable*, *Financials*, *Listed*, *CleanTransport*, bond size, maturity, rating, and market conditions. Two-way fixed effects (issuer, time) are included. Robust *t*-statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

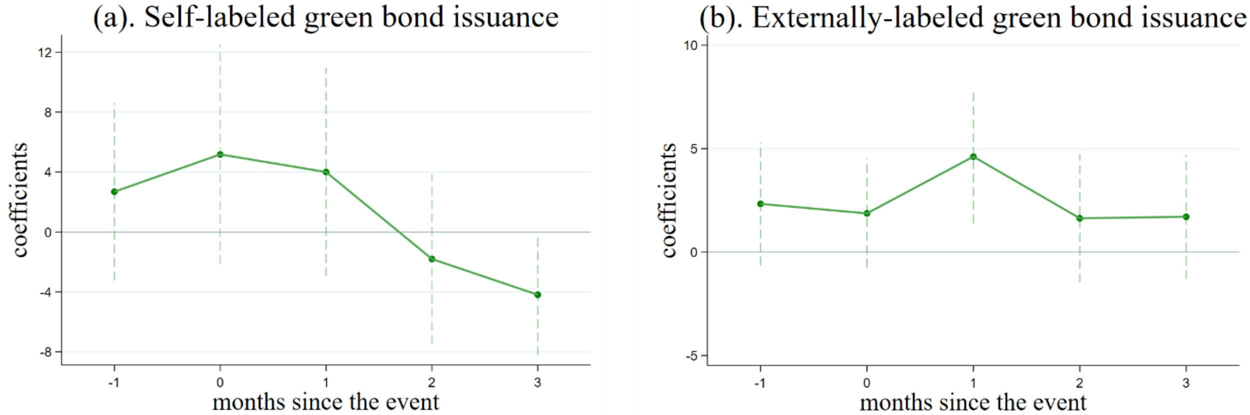
[15] As the subscribers of Bloomberg Terminals are mainly institutional investors, the search and reading activities ("news heat") on the stock-specific news on Bloomberg Terminals track the attention a specific stock is receiving from institutional investors.

Since the proportion of listed issuers is less than one-fourth (as the figure shown in **Table 3.2**), using Google Trends as the proxy allows me to retain as many issuers as possible. However, the Google Trends measure captures mainly retail investors' attention while institutional investors are nowadays dominant in financial markets, especially green bond markets. To gauge institutional investors' attention, I follow Ben-Rephael et al. (2017) and download the Bloomberg news heat data. The original daily Bloomberg news heat is assigned with a score of 1, 2, 3, or 4. Higher scores represent higher numbers of reading and searching activities of the firm-specific news. Following Huang et al. (2022), I first generate a dummy variable (*AIA*) for daily abnormal institutional attention that equals 1 if Bloomberg's daily maximum is 3 or 4, and 0 otherwise. I then calculate the monthly average of the daily *AIA* as the proxy for monthly institutional investor attention (*NewsHeat*). I run a regression of equation (3.3) using *NewsHeat* as the dependent variable. Panel B of **Table 3.8** shows that externally-labelled green bonds can increase the attention for institutional investors.

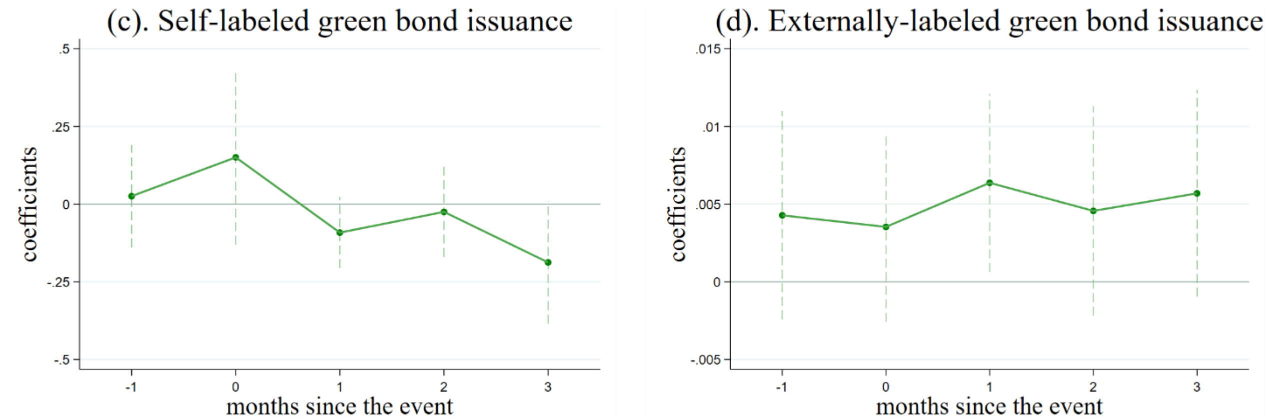
Furthermore, I address the overestimation bias in the PSM-DID and verify the robustness of (H2) using the stacked DID framework from Cengiz et al. (2019). The traditional DID method has been heavily criticized for its biased estimates of the average treatment effect, especially in the absence of strong restrictions on treatment-effect homogeneity. Instead, the stacked DID allows me to address the under-identification problems of the conventional DID method in the staggered treatment setting. To further verify the validity of the results relating to the investor attention hypothesis, I repeat the analysis using the propensity score matching jointly with the stacked DID method. **Figure 3.3** presents the coefficient estimates of each month relative to the issuance of bonds with green labels and their 90% confidence intervals.

**Figure 3.3.** Robustness tests of investor attention around the issuance of green bonds.

**Panel A:** Impact on issuers' Google Trends



**Panel B:** Impact on issuer-related news readership heat




Notes: This figure shows the dynamics of investor attention, as measured by Google Trends (in Panel A) and Bloomberg news heat (in Panel B), in the month around the issuance of green bonds following the stacked DID approach from Cengiz et al. (2019). The panels show the pre-trend and the treatment effects of self- and externally-labelled green bond issuance, respectively. The vertical bars are 95% confidence intervals.

**Figure 3.3** confirms the results in **Table 3.8**. Specifically, green bonds with self-labels do not attract investor attention, suggesting the market essentially treats such bonds as being equivalent to their conventional counterparts. In Panel B, the coefficients on *Month* $t = 1$ are positive and significant, while none of the coefficients on the post-event months are significant. This implies that the issuance of externally-labelled green bonds increases investor attention in the contemporaneous month, but such an effect is short-lived. This evidence is again consistent with the regression results in columns (2) and (3) of both Panels in **Table 3.8**. Overall, the use of a more rigorous DID model specification also supports the investor attention hypothesis.

*3.4.3. Signalling Effect and Pro-environmental Taste*

The signalling effect and pro-environmental taste can exert similar influences on the greenness-greenium relationship. This is because, in addition to greenness assurance, the external certification embedded in green labels can carry other signals. For example, external certification might imply that the issuing firm is more transparent or more committed to being eco-friendly, which, in turn, attracts green investors. To distinguish the pro-environmental taste channel from the credit-related signalling effect channel, I conduct heterogeneity tests and report the results in **Table 3.9**.

I begin by categorizing the sample into four groups of bonds based on issuers' default probability and bond label type. I posit that if green labels carry signals of the firms' financial health, the credit-related signalling effect from the label would be influenced by issuers' default probabilities. As results shown in Panel A of **Table 3.9**, the coefficients on both externally- and self-labelled bonds in columns (2) and (4) are significantly negative, with the credit signal from the former being stronger. In addition, the coefficients on both labels in the high default probability group are insignificant, suggesting that the signalling effect is weaker for bonds with higher default risks. Hence, the results confirm that all green bond labels have a signalling effect on the yield, with the effect being stronger for externally-labelled ones. Meanwhile, this effect is the icing on the cake for issuers, which offers limited assistance to issuers with higher default rates.

**Table 3.9.** Heterogeneity tests for the signalling effect and the green taste effect.

| **Panel A:** Heterogeneity test for the signalling effect | | | | |
|---|---|---|---|---|
| Yield | (1)<br>Subsample: Higher DefaultProbability | (2)<br>Subsample: Lower DefaultProbability | (3)<br>Subsample: Higher DefaultProbability | (4)<br>Subsample: Lower DefaultProbability |
| D = Self-label | **0.421** | **-0.468*** | | |
| | (0.66) | (-1.82) | | |
| D = External-label | | | **-0.255** | **-0.297**** |
| | | | (-0.89) | (-2.33) |
| Constant | 1.562*** | 1.776*** | 1.397*** | 1.577*** |
| | (3.53) | (8.16) | (4.15) | (8.82) |
| Controls(**x**) | Yes | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes | Yes |
| Chow test F-value | 7,883.200*** | | 576.380*** | |
| Adjusted $R^2$ | 0.581 | 0.522 | 0.609 | 0.530 |
| Observations | 356,925 | 695,727 | 619,758 | 1,237,338 |
| **Panel B:** Heterogeneity test for the green taste | | | | |
| Yield | (1)<br>Subsample: BrownIssuer | (2)<br>Subsample: Non-BrownIssuer | (3)<br>Subsample: BrownIssuer | (4)<br>Subsample: Non-BrownIssuer |
| D = Self-label | 0.879 | 0.0248 | | |
| | (1.40) | (0.07) | | |
| D = External-label | | | **-0.383** | **-0.375**** |
| | | | (-0.86) | (-2.14) |
| Constant | 3.070*** | 1.491*** | 2.757*** | 1.475*** |
| | (4.60) | (7.40) | (5.13) | (8.98) |
| Controls(**x**) | Yes | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes | Yes |
| Chow test F-value | 390.090*** | | 296.790*** | |
| Adjusted $R^2$ | 0.657 | 0.566 | 0.619 | 0.581 |
| Observations | 92,126 | 960,334 | 205,411 | 1,651,493 |

This table presents the results of subsample regressions to examine the signalling effect and green taste hypothesis. The dependent variable in each regression is bond yield. Control variables **x** include *SDG*, *ParisAgree*, *Callable*, *DefaultProbability*, *BA_Spread*, *Listed, Financials*, *CleanTransport*, bond size, maturity, rating, and market conditions. Two-way fixed effects (issuer, time) are included. Robust *t*-statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

In a similar vein, if the impact of green labels on yield is supported by the green taste channel, the greenness-greenium relationship would be different for issuers from ‘brown’ (high emission) industries. Panel B of **Table 3.9** confirms that the effect of external labels is weaker for issuers in the brown industries, implying the existence of a pro-environment taste. In contrast, the coefficients on *Self-label* in columns (1) and (2) are not significantly different, indicating that the effect of self-labelled green bonds is unlikely due to investors’ taste for green assets.

## 3.5. Conclusion

This chapter investigates the choice and effects of green bond labelling and the mechanisms through which green labels affect bond yield and investor attention. Based on the certification requirements for the EU green bond issuers, I classify green bonds into groups based on their labelling approach. I find that green bond issuers with greater information asymmetry prefer to use external certification for signalling purposes (e.g., when the issuer-located country's image is relatively less eco-friendly). Furthermore, I confirm the hypothesis that externally-labelled bonds have a lower required yield than self-labelled and conventional bonds. The findings are robust to alternative empirical measures and modelling techniques. Furthermore, I employ the Propensity Score Matching jointly with the Difference-in-Differences (PSM-DID) approach to confirm the hypothesis that green bonds with external labels attract greater investors' attention. I also conduct heterogeneity tests to quantify the taste-based and the signalling channels. Further analysis suggests that the effect of external labels on bond yields is attributed to both channels, while that of self-labelling can only be partly explained by the signalling effect.

One key contribution of this study stems from the endeavour to resolve the greenium puzzle by providing novel insights into the role of labelling in green bonds. My approach enables me to reconcile some of the conflicting findings in the literature. On the one hand, consistent with Flammer (2021) and Larcker and Watts (2020), I find that self-labelling hardly attracts investor attention, sends signals, or generates greenium. On the other hand, and in line with Zerbib (2019) and Lau et al. (2022), I show that external labelling reduces bond yield in the long term and heightens investor attention in the short term. Further analysis indicates that the lower green bond yield associated with self-labelling is mainly driven by the (weak) signalling effect, while that of their externally-labelled counterparts aligns with both the signalling effect and taste-based framework.

My study provides several practical implications for issuers, investors, and policymakers in the green bond markets. First, it highlights the necessity of paying careful attention to different green bond labels rather than using a single umbrella label to encompass all green bonds. Issuers should carefully choose labels that accurately reflect the environmental impact of their projects, as this can influence investor perception and, consequently, the cost of capital. A one-size-fits-all label might undermine the distinct advantages that certain green projects offer, potentially leading to higher borrowing costs or reduced market attention. Second, investors need to assess the specific criteria and standards behind each label to make informed decisions. Recognizing the heterogeneity in green labelling allows investors to better align their portfolios with their ESG goals and avoid greenwashing risks. Investors should also advocate for regular and detailed disclosures from issuers, ensuring that the proceeds are used as intended and deliver the promised environmental benefits. Third, the global nature of environmental problems and financial markets calls for policymakers to join their effort towards standardizing green labels and regulatory frameworks that ensure transparency and comparability across countries, in order to mitigate market confusion and improve the reliability of green investments. Specifically, in countries with weak third-party institutions (e.g., developing countries), it may be necessary for governments to step in. The establishment of credible third parties and green certifications has positive externalities, which justify an appropriate level of government intervention (e.g., subsidy, endorsement) as seen in other environment-related problems and solutions.

Like most other academic studies, this chapter is not free from limitations that could be addressed by future research. This study acknowledges several important limitations that suggest caution in generalizing findings beyond their specific context. The analysis concentrates on the EU market, characterized by a uniquely supportive institutional environment, sophisticated investor base, and progressive regulatory framework. Results may not fully generalize to markets with different governance structures or investor attitudes toward environmental issues. Additionally, while I analyse market-based proxies for environmental credibility through yields and investor attention, I do not directly measure ultimate environmental outcomes of funded projects, reflecting broader challenges in sustainable finance research where time lags and measurement difficulties constrain definitive environmental impact assessment.

Future research could extend this work in several promising directions. First, direct links between bond labels and granular project-level environmental performance data would help close the loop between financial market mechanisms and real-world environmental impact. Second, comparative cross-market studies could illuminate how labelling credibility value varies across different regulatory regimes and institutional contexts. Third, as regulations like the EU Green Bond Standard take full effect, research will be needed to track how evolving frameworks influence issuer behavior and market dynamics. Finally, examining emerging innovations such as sustainability-linked bonds and transition bonds could provide insights into how different sustainable finance instruments interact and compete for investor attention and capital.

# Chapter 4. Sustainable Assets as Oil Shock Hedges: Evidence from the EU Market

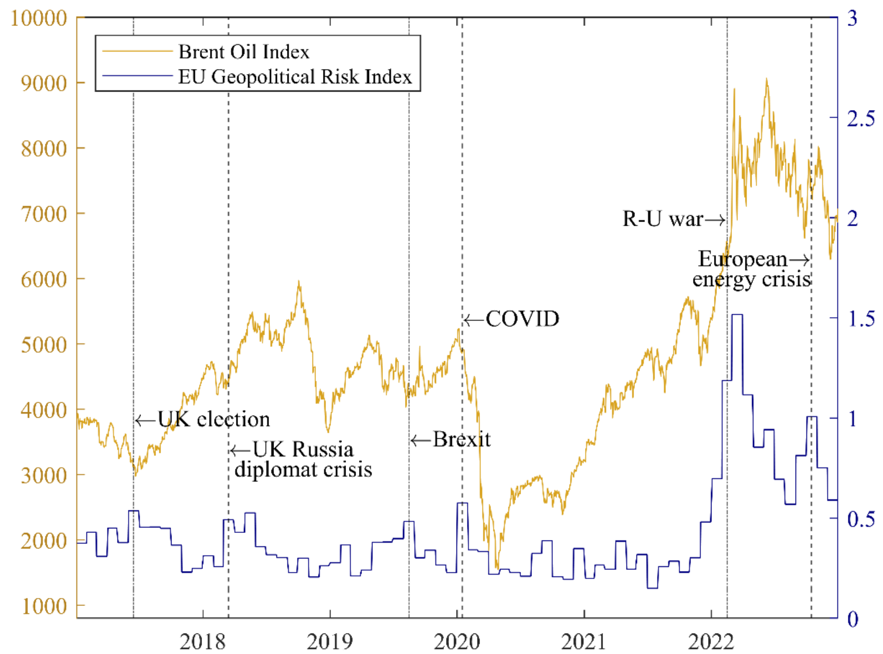
**Abstract:** This study investigates the role of sustainability in hedging oil shocks. Using structural vector autoregression (SVAR), connectedness, copula, and wavelet analyses, we evaluate the hedging performance of assets across four sustainability tiers: brown, neutral, self-labeled green, and externally certified green bonds. The results reveal that externally certified green bonds provide the most effective hedge against oil shocks. Moreover, green bonds exhibit the potential to surpass gold as a safe-haven asset for Brent crude oil investors. By identifying the mechanisms underpinning green bonds' hedging advantages, this study contributes to the literature on sustainability finance and energy risk management. Our findings offer practical implications for oil investors seeking resilient, sustainability-aligned portfolio strategies, as well as for policymakers aiming to enhance financial stability through the promotion of green finance.

**Keywords:** Green Bond; Asset sustainability; Oil Shock; Tail risk; Hedging; Geopolitical risk

### 4.1. Introduction

Despite global efforts toward a more environmentally friendly economy (Xi et al., 2022), oil still plays a crucial role, with fossil fuels still accounting for more than 80% of global energy demand[16]. As a fundamental commodity, oil is subject to various economic and political shocks, which create substantial financial risks for investors, particularly during periods of macroeconomic instability and geopolitical uncertainty. As shown in **Figure 4.1**, spikes in the geopolitical risk index (GPR) are typically followed by upward trends in the oil price. However, during the early stage of the COVID pandemic, a sharp rise in GPR was accompanied by a dramatic collapse in oil prices. This anomaly underscores the complex nature of GPR-related oil shocks, highlighting the importance of effective hedging strategies to protect against extreme oil price shocks (i.e., the "tail risks").

**Figure 4.1.** Changes in the Brent oil index and the EU geopolitical risk




Note: The daily price of the Brent crude oil benchmark index and the monthly geopolitical risk in the EU area. The data is collected from Caldara and Iacoviello (2022) and the Refinitiv database.

While prior research suggests that green bonds may provide some protection against oil price shocks (e.g., Mokni et al., 2022; Su et al., 2023), the underlying mechanisms behind their hedging effectiveness remain insufficiently understood. Studies, such as Guo and Zhou (2021) and Sohag et al. (2023), have also highlighted the role of green bonds as hedging instruments during extreme market conditions. However, little attention has been given to heterogeneity in hedging performance across green bonds with different levels of

[16] For full information about the World Energy Outlook 2024, please see: https://www.iea.org/reports/world-energy-outlook-2024

sustainability. This study addresses that gap by investigating whether the level of an asset's sustainability influences its effectiveness in hedging oil shocks, particularly under tail-risk scenarios. To this end, I classify bonds in four categories: brown, neutral, self-labelled green, and externally-labelled green. Specifically, I use the S&P Europe energy industry group index and ICE BofA Euro corporate index to represent brown and neutral assets, respectively, and adopt the framework of Zhou, Jin, et al. (2025) to distinguish between self- and externally-labelled green bonds.

I maintain that the hedging advantage of sustainability-focused assets during the two seemingly unrelated events, the COVID pandemic and the Russia-Ukraine war, follows a common logic of fighting global crises, namely the necessity of international cooperation during systemic threats and the formation of partnerships, as highlighted in Sustainable Development Goal 17 of the United Nations. During the pandemic, the urgent need for international cooperation amplified the value of firms with strong sustainability frameworks. These firms, as shown by Ferriani (2023), were not only shielded by investor preferences for assets aligned with Environment, Social, and Governance (ESG) goals but also benefited operationally from supply chains and governance practices designed for resilience in a hyper-connected world. Their reliance on multilateral norms and ethical networks mirrored the cooperative systems critical to pandemic recovery, effectively buffering them against shocks exacerbated by isolated national responses. Similarly, the Russia-Ukraine (R-U) war disrupted traditional mechanisms of international cooperation, fuelling energy nationalism and strategic decoupling. Yet, sustainability assets, such as green bonds, retained their hedging power because their underlying value, rooted in addressing climate change, a challenge that transcends geopolitical rivalries, remained insulated from short-term political ruptures. For instance, green bonds continued to finance renewable infrastructure, which serves universal climate goals rather than competing national interests (Fatica and Panzica, 2024). Thus, whether global governance is unified or divided, sustainable assets derive resilience because they are anchored in two ways: they thrive with cooperation by advancing shared objectives, and they remain relevant without it by tackling global challenges that no single country or actor can manage alone.

Based on these premises, I hypothesize that assets with higher levels of sustainability offer stronger hedging effectiveness against extreme oil shocks during the COVID pandemic and the R-U war. To test this hypothesis, I begin by decomposing oil fluctuations into supply-, demand-, and risk-driven shocks. Using connectedness analysis and copula methods, the baseline results indicate that assets with higher sustainability are more effective in hedging against various oil shocks, with externally-labelled green bonds providing the strongest protection against tail risks. To ensure robustness, I also employ wavelet analysis to examine the relationship between asset sustainability and hedging effectiveness across both time and frequency domains. This approach allows me to refine the comparison by capturing the temporal variation in the time domain and spectral variation in the frequency domain. The findings remain consistent across a wide range of investment trading strategies.

Furthermore, I extend the analysis by comparing the hedging effectiveness of green bonds, both self-labelled and externally labelled, with that of traditional safe-haven assets such as gold, its digital counterpart, Bitcoin. While bonds with stronger sustainability profiles exhibit greater resilience against oil shocks, the findings reveal green bonds still offer weaker hedging benefits than gold. This raises a practical question: why use green bonds, rather than gold, as hedging tools? To address this question, I demonstrate that the hedging effectiveness of green bonds has steadily improved, particularly during periods of heightened uncertainty like the COVID pandemic and the R-U war. This upward trend suggests that green bonds are not merely alternatives to gold, but emerging tools tailored to address systemic risks in an era where sustainability and geopolitics increasingly intersect.

This study contributes to the literature in three ways. First, it evaluates the evaluation of hedging effectiveness by introducing a more nuanced classification of asset sustainability. I demonstrate that green bonds with different levels of sustainability provide incremental hedging benefits to oil investors. While previous research has explored the de-risking aspects of green bonds (e.g., Braga et al., 2021; Zhang et al., 2022; Sohag et al., 2023), their role as hedging instruments for oil shocks, particularly the mechanisms behind it, remains underexplored. By distinguishing between self- and externally-labelled green bonds, I provide evidence that externally-certified green bonds are the most effective at mitigating tail risks in the Brent oil market, thereby refining the understanding of the sustainability-hedging relationship. Second, the findings contribute to the literature on hedging strategies from extreme oil shocks triggered by geopolitical events. Although prior research has widely documented the substantial impact of GPR on asset returns, including energy commodities, stock markets, and exchange rates (e.g., Xu et al., 2019; Sharif et al., 2020; Costola and Lorusso, 2022), effective strategies for mitigating GPR-related oil shocks remain limited. The findings suggest that, in an era of growing global interdependence, assets with higher levels of sustainability offer valuable hedging benefits. Recognizing this potential can help investors and policymakers develop resilient strategies to manage oil price risks driven by geopolitical- and pandemic-related uncertainties.

Third, I contribute to the broader understanding of the evolving role of green bonds in financial markets by assessing their potential as emerging safe-haven assets. While gold has traditionally served as the default safe-haven, the findings indicate that externally labelled green bonds are increasingly demonstrating this capability, particularly during times of heightened uncertainty. This rising hedging effectiveness stems not only from investor preferences for ESG-aligned assets but also from these bonds' structural ties to multilateral sustainability frameworks. During global crises, such as the COVID pandemic and the R-U war, the demand for international cooperation strengthens the appeal of sustainability-focused assets. By highlighting this trend, this study provides valuable insights for investors seeking to incorporate resilient, sustainability-driven assets into their portfolio strategies.

The remainder of the chapter is organized as follows. Section 4.2 reviews the literature underlying the hypotheses. Section 4.3 discusses the methods for evaluating the hedging effectiveness. Section 4.4 reports baseline results and compares the effectiveness of different assets in hedging extreme oil shocks. Section 4.5 further evaluates the hedge performance of green bonds relative to gold and Bitcoin. Section 4.6 concludes the study.

### 4.2. Hypothesis Development

Green bonds have been increasingly recognized as a potential hedging tool against oil price fluctuations (e.g., Mokni et al., 2022; Su et al., 2023), but the underlying mechanisms through which green bonds function as a risk management tool for oil investors, particularly in the presence of tail risks, remain insufficiently explored. Given that stock market volatility indices are highly correlated with oil price volatilities (Antonakakis et al., 2020), and sustainable assets offer diversification benefits against oil shocks across various market conditions and timescales (Elsayed et al., 2024), I argue that an asset's level of sustainability plays a critical role in its effectiveness as a hedge for oil investors. Furthermore, sustainability has become a central component of international economic policies, particularly in the context of increasing global financial cooperation[17]. Since both the COVID and the R-U war triggered extreme oil shocks and highlighted the critical importance of international collaboration in sustainable finance, these events provide critical contexts for examining the hedging benefit of sustainable assets under extreme market conditions.

Firstly, prior studies have examined how environmental, social, and governance (ESG) preferences influence institutional trading behaviours and stock return patterns. Cao et al. (2022) find that socially responsible institutions prioritize ESG performance over traditional value signals, leading to distinct return patterns in stocks favoured by these investors. This shift in investor preference toward sustainable assets has broader implications during periods of systemic stress. For instance, during the early stages of the pandemic, financial markets experienced unprecedented volatility, exposing the limitations of traditional forecasting models in accounting for systemic risks, and leading to a growing emphasis on sustainable

17 For full information about United Nation and WordBondk's insights about sustainable financial system, please see: https://www.imf.org/en/Blogs/Articles/2019/10/10/Blog-connecting-the-dots-between-sustainable-finance-and-financial-stability; and https://www.worldbank.org/en/news/statement/2023/09/07/enhancing-imf-world-bank-collaboration

investments[18]. Meanwhile, global institutions, including the G20 and IMF, responded by implementing sustainability-focused recovery strategies[19], integrating green finance into economic stabilization policies. Additionally, empirical studies reveal that firms with strong ESG ratings enjoyed lower capital costs during the COVID period, driven both by investor preferences for sustainable assets and by risk factors unrelated to firms' creditworthiness (Ferriani, 2023). Meanwhile, sustainable investments demonstrated superior returns, lower volatility, and stronger operating profit margins, while oil prices experienced a sharp decline (e.g., Albuquerque et al., 2020; Jin et al., 2023). These findings indicate that, supported by global cooperation in sustainable finance, assets with higher sustainability, such as externally-labelled green bonds, serve as an effective hedge against oil price shocks during the COVID pandemic:

> *(H1) Assets with higher levels of sustainability exhibit greater hedging effectiveness against extreme oil shocks during the COVID period.*

Secondly, climate change remains a pressing concern for all of humanity, necessitating international cooperation (Caldara and Iacoviello, 2022). While the geopolitical risks arising from the R-U war have disrupted global collaboration on climate policies, international institutions continue to uphold sustainable finance initiatives. For example, the European Union launched the "REPowerEU plan" to accelerate green energy investments, and the Global Sustainable Investment Alliance (GSIA) has reinforced commitments to climate finance despite geopolitical uncertainty[20]. Similarly, investment firms, such as BlackRock[21], highlight green spending as a crucial driver of long-term structural growth, emphasizing its role in mitigating geopolitical risk. Recent research further suggests that green bonds may serve as effective hedging instruments during periods of geopolitical uncertainty (e.g., Liu et al., 2024; Mertzanis and Tebourbi, 2024). Moreover, consistent with the intertemporal hedging theory, Huynh and Xia (2020) document that the hedging demand for sustainable assets intensifies during periods of heightened climate-related risks, leading to stronger negative pricing effects. Suggesting that when systemic risks, such as geopolitical tensions or climate concerns, rise, investors increasingly favour assets with strong environmental profiles for risk mitigation purposes. These findings together indicate that sustainable assets,

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[18] For full information about J.P.Morgan's insights about COVID and ESG investing, please see: https://www.jpmorgan.com/insights/research/covid-19-esg-investing

[19] For full information about G20 and IMF's insights about environmentally sustainable investment, please see: https://www.elibrary.imf.org/view/journals/007/2021/025/007.2021.issue-025-en.xml

[20] For full information about the EU's REPowerEU plan and GSIA's report, please see: https://www.businesswire.com/news/home/20241114446926/en/GSIA-releases-report-and-recommendations-for-investors-and-policymakers-in-attendance-at-COP29; and https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

[21] For full information about BlackRock's insights about the long-term lens, please see: https://www.blackrock.com/uk/solutions/investment-trusts/our-range/blackrock-greater-europe-investment-trust/trust-information/insights/unlocking-structural-growth-opportunities-in-europe

supported by persistent international financial cooperation, may provide a superior hedging strategy against extreme oil price shocks during the R-U war period. Therefore, I also propose that:

> *(H2) Assets with higher levels of sustainability exhibit greater hedging effectiveness against extreme oil shocks during the R-U war.*

### 4.3. Data and Methods

#### *4.3.1. Data and Measures*

I explore whether assets with varying sustainability levels can protect investors against Brent oil shocks in the EU market. For the oil price, I use the daily return of the Brent crude oil benchmark index as a proxy for the performance of the Brent oil market. Based on the GPR data from Caldara and Iacoviello (2022), I also use each EU country's GDP from the previous year as a proxy to generate the weighted average GPR of the overall EU area. To capture the differences in sustainability, I construct four indices, namely the brown, neutral, self-labelled green, and externally-labelled green indices.

I use the S&P Europe Energy Industry Group Index to measure the dynamics of the "brown assets" (with a negative level of sustainability), as this index comprises companies primarily engaged in traditional energy sectors, such as oil, gas, and coal, which are typically associated with high carbon emissions and low environmental sustainability. For the neutral assets, I employ the ICE BofA Euro Corporate Index because it reflects the overall market composition without any specific sustainability focus, thereby encompassing both brown and green assets in proportion to their market presence. While the neutral index may include some brown and/or green assets, it is not dominated by them. It also includes companies from sectors with lower environmental impact, ensuring the neutral index reflects a balanced market perspective rather than a sustainability-focused portfolio.

Additionally, Recent evidence suggests that not all sustainable claims translate into tangible environmental outcomes (Duchin et al., 2024), highlighting the necessity to distinguish among different levels of asset sustainability. Thus, I distinguish two positive levels of sustainability by whether these green bonds are self- or externally-labelled. According to Zhou, Jin, et al. (2025), green bond labels in the EU market provide varying levels of assurance regarding the sustainability of the project by these bonds. Compared to self-labelled issuers, who merely declare that all bond proceeds will be allocated to green projects without external validation, externally labelled green bond issuers adhere to more rigorous standards. Specifically, they comply with the Green Bond Principles (GBPs) issued by the International Capital Market Association (ICMA) and/or the Climate Bond Standard (CBS) established by the Climate Bonds Initiative (CBI). These external standards enhance the credibility of both the intended use of bond proceeds and the environmental impact of the funded projects.

To ensure accountability, both ICMA and CBI require issuers to establish a Green Bond Framework in the pre-issuance stage. This framework contains four core components: the use of proceeds, the process for project evaluation and selection, management of proceeds, and reporting. Meanwhile, in the post-issuance stage, both standards require the disclosure of allocation reports and impact reports. In addition, the CBI requires issuers to provide an eligibility report in which issuers are required to document that nominated projects and assets can satisfy the CBI's Sector Eligibility Criteria. Since external green labels impose similar requirements on issuers, I do not differentiate further among externally labelled green bonds.

To compare the hedging effectiveness of self- and externally-labelled green bonds, I construct the following indices[22]:

$$Green = \sum(\mathrm{MidPrice}_{i,t} \times \mathrm{Proxy}_{i,t}), \text{ where } \mathrm{Proxy}_{i,t} = \frac{\mathrm{AmountIssue}_{i,t}}{\sum \mathrm{AmountIssue}_{i,t}} \tag{4.1}$$

Where *Green* stands for the daily price of a green bond index. In this analysis, I use two indices: one representing self-labelled green bonds (*Self-labelled*) and the other representing externally-labelled green bonds (*Externally labelled*). $MidPrice_{i,t}$ refers to the mid-price of green bond $i$ at time $t$. Since the green bonds' performance depends on the project characteristics (Russo et al., 2020), I use the proxy ($Proxy_{i,t}$) of bond $i$ at time $t$, defined as the ratio of the focal bond's proceeds to the total proceeds of all bonds at issuance, as a measure for the scale of the green project.

Furthermore, to evaluate the incremental hedging benefits of asset sustainability to oil investors, I incorporate the S&P GSCI gold index and S&P Bitcoin index to represent returns of two competing hedging assets: gold and Bitcoin. Although fluctuations in cryptocurrency prices may not be directly correlated with those of conventional commodities like gold and oil, Bitcoin's perceived store-of-value characteristics position it as a potential digital alternative to gold (Bouazizi et al., 2023).

My data period spans from January 3, 2017, to December 30, 2022. A more detailed description of the data sources and variable definitions is reported in **Table 4.1**.

[22] The results remain robust when replacing these green bond indexes through Bloomberg Global Green Bond Index (GBGLTREH).

**Table 4.1.** Variable information and sources.

| Variable | Description | Source (Ticker) |
|---|---|---|
| GPR | The weighted average GPR in the EU area, which generated by summarizing each EU country's monthly GPR with its GDP in the previous year as a weight. | GPR: Caldara and Iacoviello (2018)<br>GDP: World Bank |
| Brent | The daily return of the Brent crude oil benchmark index. | Refinitiv (SGICBRB) |
| OilFirm | The daily return of the EURO STOXX Oil & Gas price index. | Refinitiv (SXEE) |
| EuroVIX | The daily return of the EURO STOXX 50 volatility index. | Refinitiv (V2TX) |
| Brown | The daily return of the S&P Europe Large-MidCap energy (industry group) capped index. | Bloomberg (SPEXEDET) |
| Neutral | The daily return of the ICE BofA Euro corporate index. | Refinitiv (MERER00) |
| Self-labelled<br>Externally labelled | Two green bond indexes are based on the return of green bonds issued in the Eurobond market and the labelling approach. | Bond data at issuance: Refinitiv<br>Daily price: Bloomberg |
| Gold | The daily return of the S&P GSCI gold index spot. | Bloomberg (SPGSGC) |
| Bitcoin | The daily return of the S&P Bitcoin index. | Bloomberg (SPBTC) |

**Table 4.2** presents the descriptive statistics and correlation matrix of the various assets included in the analysis. The average daily return on the Brent oil index and other selected hedge assets are all close to zero. However, the returns on the green bond indices display lower standard deviations than other assets, implying green bonds are relatively more stable and entail lower risks. Conversely, Brent oil and Bitcoin returns exhibit much higher standard deviations (0.025 and 0.047, respectively), indicating elevated volatility in these markets. These results underscore the importance of robust risk management strategies for investors in oil and Bitcoin, raising concerns about Bitcoin's reliability as a digital substitute for gold in serving as a safe-haven asset for oil investors.

**Table 4.2.** Summary statistics.

| Row | Brent | Brown | Neutral | Self-labelled | Externally labelled | Gold | Bitcoin |
|---|---|---|---|---|---|---|---|
| Obs. | 1488 | 1488 | 1488 | 1488 | 1488 | 1488 | 1488 |
| Max | 0.210 | 0.164 | 0.030 | 0.010 | 0.010 | 0.058 | 0.235 |
| Min | -0.239 | -0.183 | -0.029 | -0.050 | -0.028 | -0.049 | -0.231 |
| Mean | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 |
| Std. | 0.025 | 0.018 | 0.005 | 0.002 | 0.002 | 0.009 | 0.047 |
| Skew. | -0.601 | -0.407 | -0.197 | -7.457 | -1.727 | -0.116 | 0.152 |
| Kurt. | 18.516 | 20.367 | 6.113 | 164.699 | 20.677 | 7.845 | 6.377 |
| ADF test p-value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| JB test p-value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| **Corr.** | **Brent** | **Brown** | **Neutral** | **Self-labelled** | **Externally labelled** | **Gold** | **Bitcoin** |
| Brent | 1 | | | | | | |
| Brown | 0.567 | 1.000 | | | | | |
| Neutral | 0.025 | 0.032 | 1.000 | | | | |
| Self-labelled | -0.047 | -0.081 | 0.339 | 1.000 | | | |
| Externally labelled | -0.018 | -0.063 | 0.396 | 0.899 | 1.000 | | |
| Gold | 0.136 | 0.051 | 0.390 | 0.224 | 0.264 | 1.000 | |
| Bitcoin | 0.116 | 0.158 | 0.114 | 0.047 | 0.039 | 0.100 | 1 |

Note: Descriptive statistics and the correlation matrix of main variables. The null hypothesis of the Augmented Dickey-Fuller (ADF) test is that vector x has a unit root. The null hypothesis of the Jarque-Bera (JB) test is the vector x comes from a normal distribution.

The results of the Augmented Dickey-Fuller tests and Jarque-Bera tests suggest that the return distributions of all sampled assets are characterized by stationary means and thick tails. In addition, with the increase in asset sustainability (from brown to green), the correlation with Brent oil shifts from positive to negative, suggesting that sustainability plays an important role in enhancing an asset's effectiveness as a hedge against oil price fluctuations.

### *4.3.2. Empirical Methods*

#### *4.3.2.1. Structural Vector Autoregression*

Before presenting the formal econometric specification, it is useful to briefly outline the intuition behind the structural vector autoregression (SVAR) framework. This approach allows different types of oil shocks (e.g. supply, demand, and risk shocks) to be identified based on their underlying economic interpretations. By decomposing oil price movements into these structural components, the model enables us to analyse how different shocks transmit to financial assets and affect the hedging performance of different asset classes.

To evaluate each asset's hedging effectiveness against different types of oil shocks, I adopt the structural decomposition framework proposed by Kilian (2009) and Ready (2018). Specifically, the following SVAR model is used to disentangle the observed GPR-related Brent oil shocks into three distinct structural components:

$$\begin{bmatrix} Supply \\ Demand \\ Risk \end{bmatrix} = \begin{bmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{32} & \alpha_{32} & \alpha_{33} \end{bmatrix}^{-1} \begin{bmatrix} OilPrice \\ Producer \\ Volatility \end{bmatrix} \tag{4.2}$$

Where *Supply*, *Demand*, and *Risk* represent the supply shock, the demand shock, and the risk shock, as in Ready (2018), respectively. *OilPrice* stands for the return of the Brent oil index, *Producer* represents the return on the index of EU oil & gas producers, and *Volatility* is the change in the EU market volatility index.

#### *4.3.2.2. Connectedness*

Intuitively, the connectedness framework from Diebold and Yilmaz (2009; 2012) measures how volatility shocks are transmitted across markets. It allows us to identify which assets mainly transmit shocks to others and which assets primarily absorb shocks, providing useful insights into the hedging role of different assets in response to oil market disturbances.

Formally, the spillover analysis proposed by Diebold and Yilmaz (2009) is based on forecast error variance decomposition (FEVD), which measures the contribution of variable j to the forecast error variance of variable $i$ :

$$FEVD_j^i(h)=E(y_{i,t+h}-y_{i,t}(h))^2 \tag{4.3}$$

where $y_t$ is a reduced-form N-variable VAR model, and in the generalized VAR approach, the FEVD is computed at horizon $h = H$ as follows:

$$d_{ij}^H=\frac{\sum_{h=0}^{H-1}(e_i^{'}\Phi_h\Sigma_u e_j)^2}{\sum_{h=0}^{H-1}(e_i^{'}\Phi_h\Sigma_u e_j)} \tag{4.4}$$

where $e_i$ is column $i$th of the $I_N$ matrix. Since results from generalized FEVD do not guarantee the sum of row (the spillover from the asset itself and spillovers from other assets) is always equal to 1, Diebold and Yilmaz (2012) further consider the following normalization equation to allow $\sum_{j=1}^N \widetilde{d_{ij}^H}=1$ and $\sum_{i,j=1}^N \widetilde{d_{ij}^H}=K$:

$$\widetilde{d_{ij}^H}=\frac{d_{ij}^H}{\sum_{j=1}^N d_{ij}^H} \tag{4.5}$$

*4.3.2.3. Copula Models*

Since the connectedness approach cannot fully capture hedging performance during market stress, copula models are used to analyse nonlinear dependence between asset returns. Unlike traditional correlation measures, copula methods allow the dependence structure in the tails of the distribution to be examined, which is particularly important for understanding hedging effectiveness during market crises. Formally, I allow oil asset (o) and each selected hedge asset (*i*) to have a time-varied (*t*) mean ($\mu_{\blacksquare,t}$) and return ($r_{\blacksquare,t}$):

$$r_{o,t}=\mu_{o,t}+\xi_{o,t}, \text{ where } \xi_{o,t}=\delta_{o,t}\epsilon_{o,t} \tag{4.6}$$

$$r_{i,t}=\mu_{i,t}+\xi_{i,t}, \text{ where } \xi_{i,t}=\delta_{i,t}\epsilon_{i,t} \tag{4.7}$$

For each asset, the mean ($\mu_{\blacksquare,t}$ ($\blacksquare=o, i$)) is estimated using an autoregressive moving average ARMA(p, q) process, while its volatility ($\delta_{\blacksquare,t}$) is modelled using the threshold generalized autoregressive conditional heteroskedasticity (TGARCH or GJR-GARCH) model. Subsequently, I estimate marginal cumulative distribution functions (CDFs) for all random variables ($\epsilon_{\blacksquare,t}$), and calculate the join CDF ($F(\epsilon_{o,t},\epsilon_{i\,t})$) between $F_o(\epsilon_{o,t})$ and each $F_i(\epsilon_{i,t})$ using the copula function $C(\blacksquare, \blacksquare)$:

$$F(\epsilon_{o,t}, \epsilon_{i,t}) = C(F_o(\epsilon_{o,t}), F_i(\epsilon_{i,t})) \tag{4.8}$$

Where the probabilities that assets *o* and *i* are in their lower or upper joint tails are noted as:

$$\tau_U = \lim_{x \to 1} (Pro(F_o(\epsilon_{o,t}) \geqslant x | F_i(\epsilon_{i,t}) \geqslant x) = \lim_{x \to 1} \frac{1\text{-}2x\text{+}C(x, x)}{1\text{-}x} \tag{4.9}$$

$$\tau_L = \lim_{x \to 0} Pro(F_o(\epsilon_{o,t}) \leqslant x | F_i(\epsilon_{i,t}) \leqslant x) = \lim_{x \to 0} \frac{C(x, x)}{x} \tag{4.10}$$

To better visualize the upper and lower tail dependence between $r_{o,t}$ and $r_{i,t}$, I apply a range of copula models during the estimation process and select the optimal model based on the Akaike information criterion (AIC). **Table 4.3** presents the five classic copula models applied in the estimation process, along with their key characteristics.

**Table 4.3.** Characteristics of copula models.

| Model | Tail Distributions | Tail Dependence |
|---|---|---|
| Clayton copula | Asymmetry | Variables only have gradual tail dependence at the lower tail. |
| Clayton rotate copula | | Variables only have gradual tail dependence at the upper tail. |
| SJC copula | | Variables have gradual tail dependences at upper and lower tails, but upper and lower tail distributions are asymmetry. |
| Normal copula | Symmetry | Variables have gradual tail independence at both upper and lower tails. |
| Student's t copula | | Variables have gradual tail dependence at both upper and lower tails. |

Note: A summary of popular copula models' main features.

#### *4.3.2.4. Wavelet Coherency*

Wavelet coherence analysis enables the examination of relationships between financial assets across both time and frequency domains. In other words, it allows us to observe how the strength of the relationship between oil shocks and financial assets evolves across different investment horizons. To further test the robustness of the findings, I apply the cross-wavelet transform to analyse the coherence between Brent oil returns and those of other assets across different time-frequency domains (Daubechies, 1990).

Based on the cross-wavelet transform, the connection between two financial time series $W_x$ and $W_y$ under different time-frequency domains is:

$$W_{xy}(u, s) = W_x(u, s) W_y(u, s) \tag{4.11}$$

Where $u$ and $s$ represent the position and scale, respectively. Both $W_x$ and $W_y$ are constructed using the Morlet wavelet, which provides a good balance between time and frequency localization (Grinsted et al., 2004). Then, the wavelet coherence between those two time series in different time-frequency domains is estimated as:

$$R^2(u, s) = \frac{|(S^{-1} W_{xy}(u, s))|^2}{(S^{-1}|W_x(u, s)|^2)(S^{-1}|W_y(u, s)|^2)}, \tag{4.12}$$

where $R^2(u, s)$ measures the weak-strong cross-correlation by ranging between 0-1, while $S$ is used to smooth the time and scale. The statistical inference is suggested to be done through the Monte Carlo simulation approach (Torrence and Compo, 1998). Furthermore, the phase difference $\Phi_{xy}(u,s)$ between $W_x$ and $W_y$ is defined as (Torrence and Webster, 1999):

$$\Phi_{xy}(u, s) = \tan^{-1}\left(\frac{I_M\{S(S^{-1} W_{xy}(u, s))\}}{R_E\{S(S^{-1} W_{xy}(u, s))\}}\right), \tag{4.13}$$

where $I_M$ and $R_E$ are the imaginary and real parts of the wavelet coefficient, respectively. As the wavelet model follows "squared terms", phase differential arrows use right (left) directions to measure the positive (negative) correlation between $W_x$ and $W_y$. Meanwhile, arrows pointing to right-up or left-down (right-down or left-up) indicate that $W_x$ leads (lags) $W_y$.

*4.3.2.5. Hedging Effectiveness*

Finally, I examine whether assets with higher sustainability, particularly externally-labelled green bonds, have the potential to serve as a new safe-haven for oil investors. I adopt the methods proposed by (Ku et al., 2007) and (Jin et al., 2020) to quantify the hedging effectiveness of green bonds for investors seeking to minimize portfolio volatility. Specifically, the effectiveness ($HE_{\blacksquare}$) of an asset ($\blacksquare$ = *Green, Gold, Bitcoin*) in hedging the Brent oil index can be measured as:

$$HE_{\blacksquare} = \frac{V(r_{oil,t}) - V(r_{p,t})}{V(r_{p,t})} \tag{4.14}$$

where $r_{oil,t}$ and $r_{p,t}$ are the returns on the Brent oil index and portfolios formed by holding the oil index with each hedging asset, respectively. Meanwhile, the optimal weight ($HW_{\blacksquare,t}$) of that hedging asset needs to minimize the variance of portfolio return ($V(r_{p,t})$):

$$\frac{\partial V(r_{p,t})}{\partial HW_{\blacksquare,t}} = 0 \rightarrow HW_{\blacksquare,t} = \frac{V(r_{oil,t}) - Cov(r_{oil,t}, r_{\blacksquare,t})}{V(r_{oil,t}) + V(r_{\blacksquare,t}) - 2Cov(r_{oil,t}, r_{\blacksquare,t})} \tag{4.15}$$

## 4.4. Empirical results

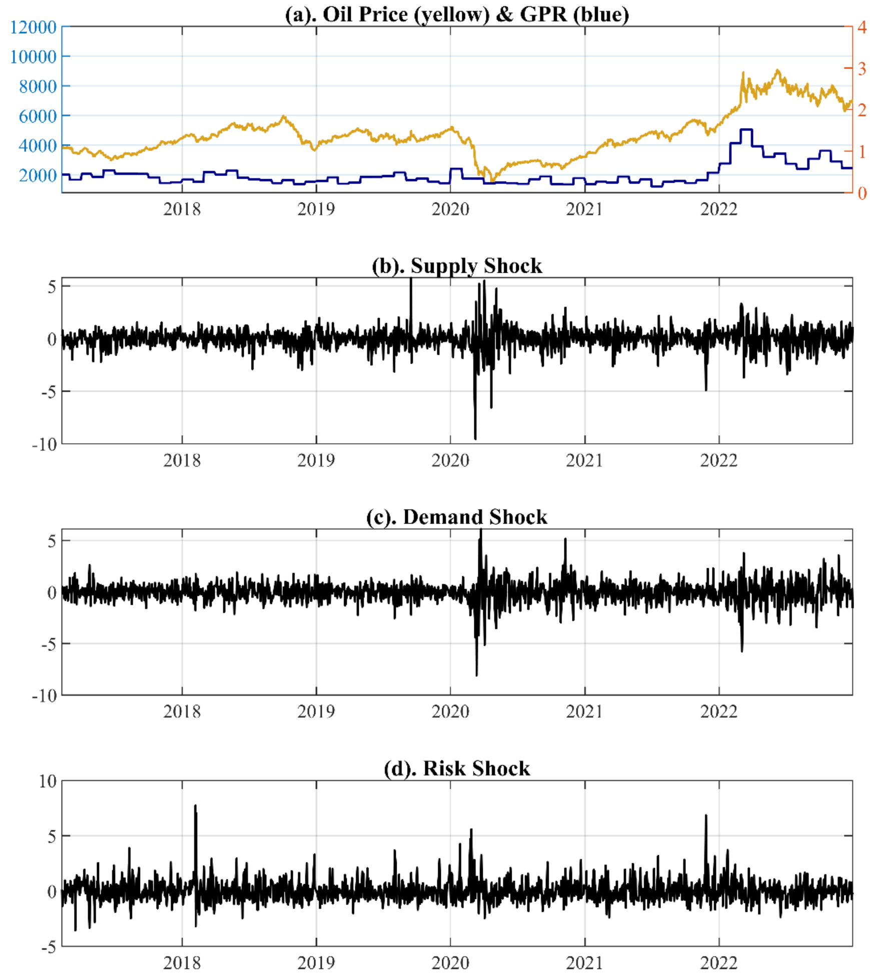
This section begins by identifying the structural shocks driving oil price fluctuations and then evaluates the hedging performance of various assets during the COVID pandemic and the R-U war. My analysis integrates SVAR, connectedness analysis, copula models, and wavelet coherence to provide a comprehensive understanding of the relationship between asset sustainability and hedging effectiveness.

### *4.4.1. Baseline Results*

I use Equation (2) to decompose oil price fluctuations into three structural shocks.

shows the history of the three identified shocks. Panels (a) and (d) suggest that rises in GPR are typically followed by fluctuations in risk shocks, though the oil price changes linked to GPR fluctuations in 2018 are less severe than those in 2020 and 2022. This finding supports Ready's (2018) claim that oil demand and supply shocks account for the majority of extreme oil price movements. Furthermore, panels (b) and (c) in **Figure 4.2** demonstrate that extreme oil price changes during the COVID pandemic and the R-U war are driven by different structural shocks. Specifically, the oil price during the COVID pandemic is mainly driven by supply shocks, while the extreme oil price changes around the R-U war are caused by demand shocks. Thus, to better understand the time-varying hedging effectiveness of different assets, I divide the data into three subsample periods: pre-COVID (Jan/2017-Dec/2019), COVID (Jan/2020-Jan/2022), and R-U war (Feb/2022-Dec/2022).

**Figure 4.2.** Oil shock identification.




Note: Oil structural shock identification by the methods from Kilian (2009) and Ready (2018).

**Table 4.4** presents the directional connectedness between oil shocks and various hedging assets during the COVID and the R-U war, based on the Diebold and Yilmaz (2009; 2012) spillover framework. In this framework, the “TO” column measures the volatility transmitted from a given market to others, while the “FROM” column captures the volatility received from other markets. The difference between these two measures represents the net spillover (NET) of each market. Since both self- and externally-labelled green bond indexes are constructed based on EU green bonds, I separate them into Panel A and Panel B to prevent their strong correlation from distorting the estimation of connectedness with other markets. Panel A shows that the overall spillover results align with the patterns in **Figure 4.2**, indicating that supply shocks (56.862) and demand shocks (36.693) contribute to market volatility far more than risk shocks (2.205). From a portfolio perspective, assets that receive fewer spillovers from oil markets tend to provide stronger diversification and hedging benefits. The last row in Panel A further reveals that the Brent crude oil market transmits more shocks to assets with higher sustainability. Panel B presents similar results.

Collectively, these findings suggest that the sustainability level of an asset plays a crucial role in determining its effectiveness as a hedging or diversification instrument for oil investors.

**Table 4.4.** Diebold and Yilmaz's connectedness analysis of oil shock spillovers.

***Panel A:*** *Connectedness analysis with self-labelled green bonds and other assets*

| | Supply Shock | Demand Shock | Risk Shock | Brent | Brown | Neutral | Self-labelled | FROM OTHERS |
|---|---|---|---|---|---|---|---|---|
| Supply Shock | 43.760 | 0.079 | 0.093 | 40.694 | 14.771 | 0.258 | 0.345 | 56.240 |
| Demand Shock | 0.135 | 60.713 | 0.390 | 0.120 | 30.272 | 7.770 | 0.600 | 39.287 |
| Risk Shock | 0.068 | 0.809 | 97.369 | 0.096 | 0.352 | 0.768 | 0.539 | 2.631 |
| Brent | 39.977 | 0.380 | 0.364 | 42.934 | 15.905 | 0.220 | 0.221 | 57.066 |
| Brown | 15.281 | 22.141 | 0.271 | 16.646 | 44.844 | 0.393 | 0.423 | 55.156 |
| Neutral | 0.791 | 11.693 | 0.536 | 0.909 | 4.138 | 68.618 | 13.315 | 31.382 |
| Self-labelled | 0.610 | 1.591 | 0.552 | 0.550 | 1.016 | 15.265 | 80.416 | 19.584 |
| TO OTHERS | **56.862** | **36.693** | **2.205** | 59.015 | 66.453 | 24.673 | 15.444 | 37.335 |
| NET | 0.622 | -2.595 | -0.425 | 1.949 | **11.298** | **-6.709** | **-4.140** | |

***Panel B:*** *Connectedness analysis with externally labelled green bonds and other assets*

| | Supply Shock | Demand Shock | Risk Shock | Brent | Brown | Neutral | Externally labelled | FROM OTHERS |
|---|---|---|---|---|---|---|---|---|
| Supply Shock | 43.817 | 0.081 | 0.094 | 40.732 | 14.809 | 0.276 | 0.191 | 56.183 |
| Demand Shock | 0.149 | 60.751 | 0.367 | 0.121 | 30.278 | 7.562 | 0.771 | 39.249 |
| Risk Shock | 0.093 | 0.778 | 97.361 | 0.115 | 0.311 | 0.788 | 0.554 | 2.639 |
| Brent | 39.989 | 0.380 | 0.360 | 42.961 | 15.904 | 0.252 | 0.154 | 57.039 |
| Brown | 15.244 | 22.094 | 0.255 | 16.579 | 44.745 | 0.406 | 0.677 | 55.255 |
| Neutral | 0.755 | 10.908 | 0.519 | 0.846 | 3.943 | 64.690 | 18.339 | 35.310 |
| Externally labelled | 0.755 | 3.821 | 0.204 | 0.666 | 2.588 | 20.592 | 71.374 | 28.626 |
| TO OTHERS | **56.987** | **38.063** | **1.799** | 59.059 | 67.832 | 29.876 | 20.685 | 39.186 |
| NET | 0.804 | -1.186 | -0.840 | 2.021 | **12.577** | **-5.434** | **-7.941** | |

Note: The volatility spillover table from Diebold and Yilmaz (2009, 2012), in which the $ij$th entry reports the estimated contribution to the forecast error variance of factor $i$ coming from innovations to factor $j$ (generalized *FEVD*). The row TO OTHERS represents the total spillover transmitted from a variable to others, calculated as the sum of generalized *FEVD* in each column excluding the diagonal, while FROM OTHERS represents the total spillover received by a variable from all other variables, calculated as the sum of generalized *FEVD* in each row excluding the diagonal. Data period: 01/Jan/2020-31/Dec/2022.

Since connectedness analysis primarily examines risk transitions at the mean level, I use copula models to further investigate the sustainability-hedging relationship during extreme market conditions, focusing on tail dependencies. First, I assess the suitability of various copula models for capturing the joint distribution between the Brent oil returns and the return of each hedging asset. The ARMA (p, q) process (where p, q $\in$ [0,1,2,3,4,5]) and GJR-GARCH model (with GARCH(m) and ARCH(n), where m, n $\in$ [1,2]) are employed to estimate the long-term marginal distributions of each asset's return mean and variance. The optimal lag selections (p, q, m, n) are determined using the AIC and Bayesian information criterion (BIC). I rely on AIC values to compare the goodness-of-fit of copula models in capturing the joint return distributions between Brent oil and hedging assets. **Table 4.5** shows that the Student's t copula provides the best fit among the models evaluated. Accordingly, I use the Student's t copula to visualize these distributions in **Figure 4.3**.

**Table 4.5.** Copula model selection via Akaike Information Criterion.

| | Brown | Neutral | Self-labelled | Externally labelled |
|---|---|---|---|---|
| Clayton | -467.941 | -6.695 | 2.009 | 2.014 |
| Clayton r | -546.422 | -4.922 | 1.974 | 1.791 |
| SJC | -524.409 | -0.469 | -12.924 | -9.626 |
| Normal | -599.765 | -5.867 | 10.485 | 10.612 |
| Student's t | **-634.113** | **-38.179** | **-60.393** | **-26.049** |

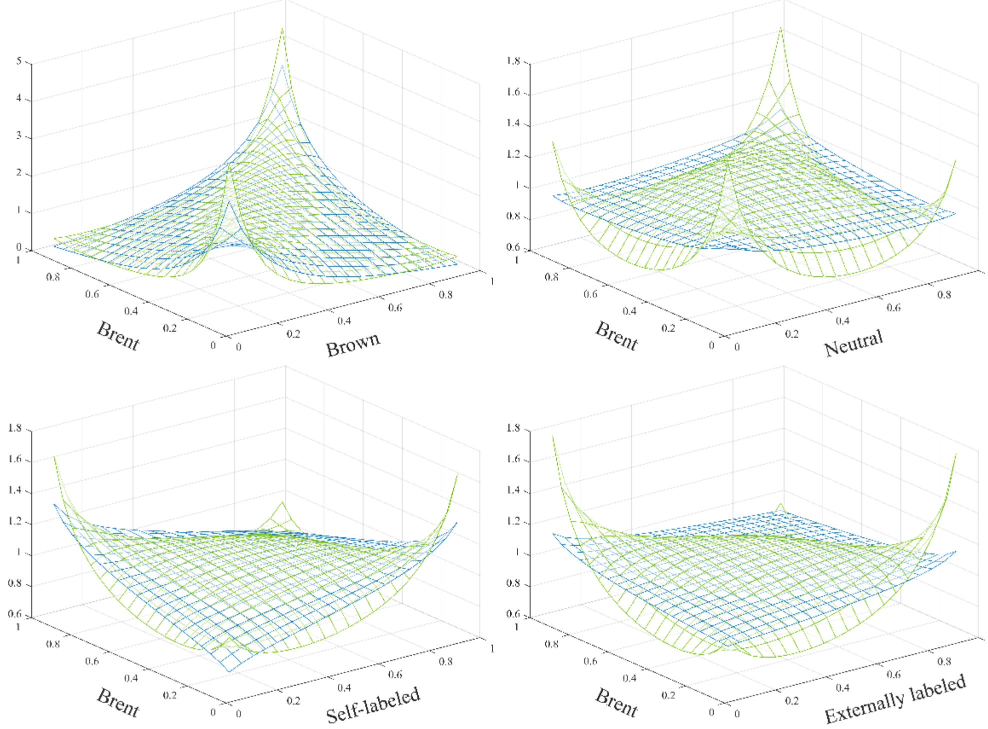
Note: AIC values for comparing the appropriateness of using different static Copula models to describe joint marginal distributions of the Brent oil index returns with different hedge asset returns.

**Figure 4.3** maps the marginal return distribution of each asset to a standardized scale between 0 and 1, with 0 and 1 representing the lower and upper tails, respectively. Panel A illustrates that when dealing with supply-shock-driven tail risks during the COVID period, the blue and green webs show that the joint return distributions between Brent oil and hedge assets (the brown, neutral, and green bond indexes) exhibit increased accumulation in positions (0, 1, z) and (1, 0, z). This suggests that all of the selected hedge assets have some potential to hedge against extreme price shocks in the Brent oil market. However, comparing positions (0, 1, z) and (1, 0, z) with (0, 0, z) and (1, 1, z) reveals that the brown index experiences simultaneous extreme losses and gains with Brent oil. Similarly, while the neutral index can hedge tail risks, it also comoves with Brent oil, highlighting the time-varying connection between the corporate bond market and the Brent crude oil market. In contrast, the joint return distributions between Brent oil and the green indexes differ markedly from those with the brown index, implying that green bonds offer more consistent hedging capabilities against extreme oil shocks. Meanwhile, compared with self-labelled green bonds, externally-labelled green bonds and oil returns have relatively higher accumulations in positions (0, 1, z) and (1, 0, z) (1.6 vs. 1.75). These findings suggest that as asset sustainability increases, the relationship with Brent oil transitions from comovement to hedging, highlighting the enhanced hedging benefits associated with higher sustainability.

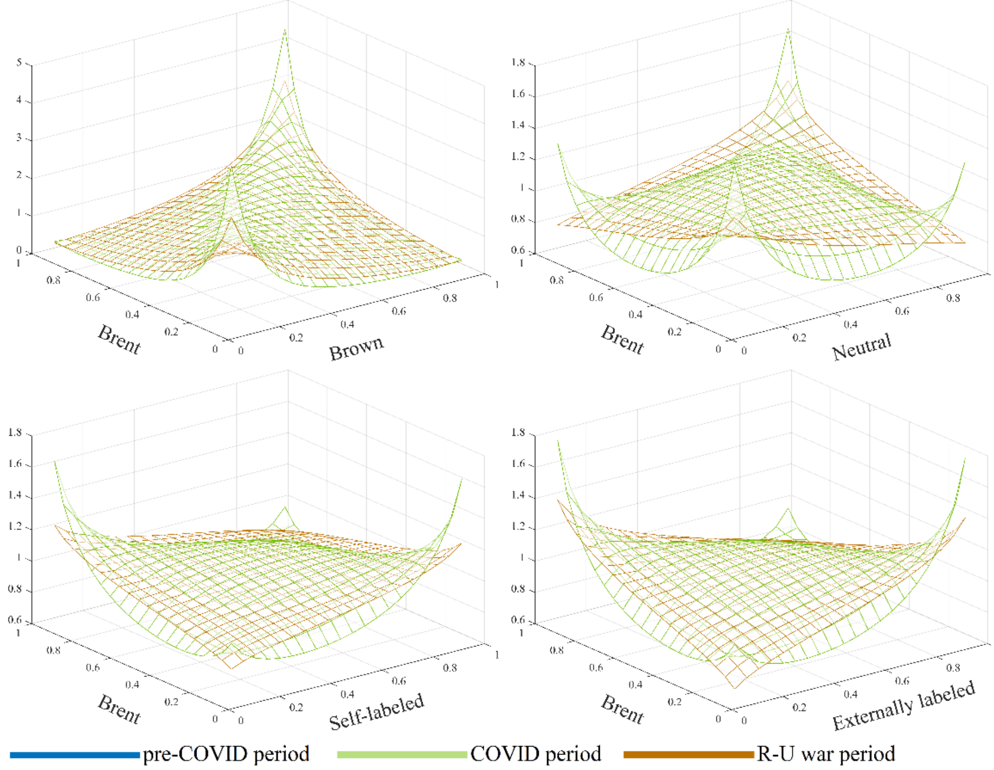
Panel B reports the demand-oriented shocks after the R-U war. It shows that the joint return distribution between Brent oil and hedge assets at positions (0,1,z) and (1,0,z) declines considerably. Nevertheless, externally-labelled green bonds continue to demonstrate superior hedging effectiveness compared to hedge assets, further indicating that the level of sustainability is a critical factor in an asset's ability to hedge against tail risks in the oil market.

**Figure 4.3.** Copula distributions of different hedge assets in different periods.

***Panel A:*** *Copula distributions of different hedge assets before and during the COVID*




***Panel B:*** *Copula distributions of different hedge assets before and during the R-U war*




Note: Copula figures of joint distributions formed by returns from Brent oil and different hedge assets. The pre-COVID period spans from 2017/Jan/04 to 2020/Jan/01, the COVID period covers data from 2020/Jan/01 to 2022/Feb/24, and the R-U period in panel (b) is from 2022/Feb/24 to 2022/Dec/30.

In conclusion, the baseline results suggest that asset significantly influences their relationship with the Brent oil index. Specifically, the green bond index outperforms both the brown and neutral indexes in hedging extreme oil shocks during the COVID and R-U war periods. These findings underscore the importance of sustainability in managing oil market risks and strongly support the two hypotheses.

*4.4.2. Robustness Tests*

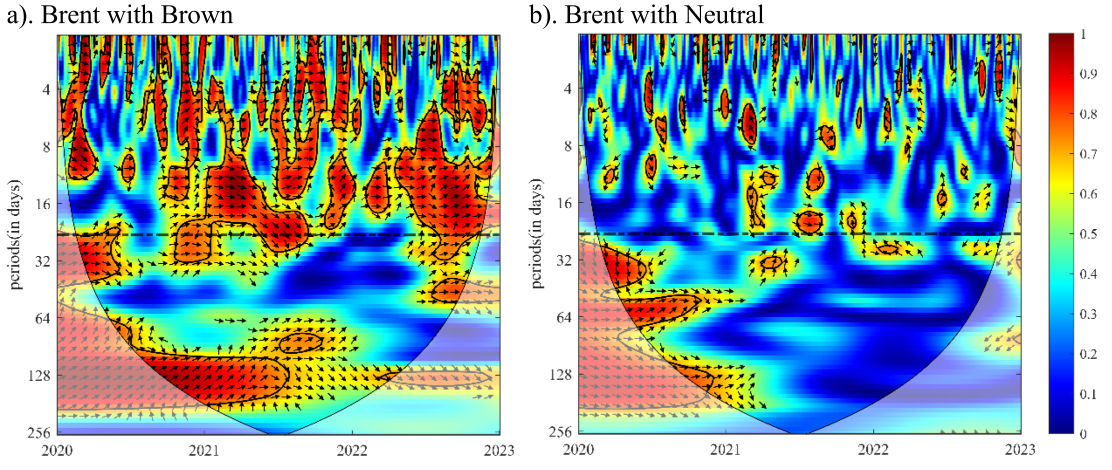
To examine the robustness of the above findings, I conduct a battery of robustness tests. First, I apply wavelet analysis to further investigate the hedging benefits of brown, neutral, and green indexes over time and at different frequency domains. **Figure 4.4** presents the cross-wavelet coherence between the returns of the Brent oil and those of the hedging assets. Red areas with rightward-pointing arrows appear in the lower sections of all panels during 2020, indicating strong positive correlations in high-frequency domains. This result may reflect the impact of the systematic downside risk caused by COVID across all markets, rather than the hedging ineffectiveness of these assets. Notably, as index sustainability increases, the extent of the red areas in 2020 declines, and the arrow directions shift from right-up to right-down. This suggests that the leading effect of Brent oil returns on other asset returns weakens as asset sustainability rises.

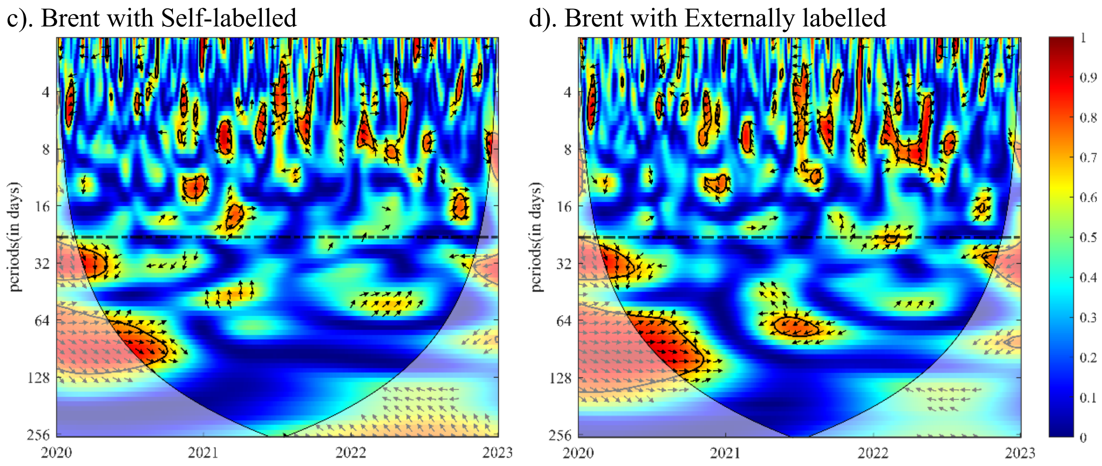
The bottom parts of the four panels in **Figure 4.4** further reveal that as asset sustainability increases, the long-term correlation with the Brent oil transitions from positive to insignificant and, in some cases, even negative. This reinforces the long-term hedge benefits of green assets for Brent oil investors. Meanwhile, more red areas with leftward arrows emerge in the upper part of each subfigure, reinforcing the hedging benefits of green assets in low-frequency domains. Overall, the results from wavelet analysis reconfirm that asset sustainability matters for hedging Brent oil shocks, consistent with the baseline findings.

**Figure 4.4.** Brent oil returns' cross-wavelet coherence with other assets.

a). Brent with Brown

b). Brent with Neutral



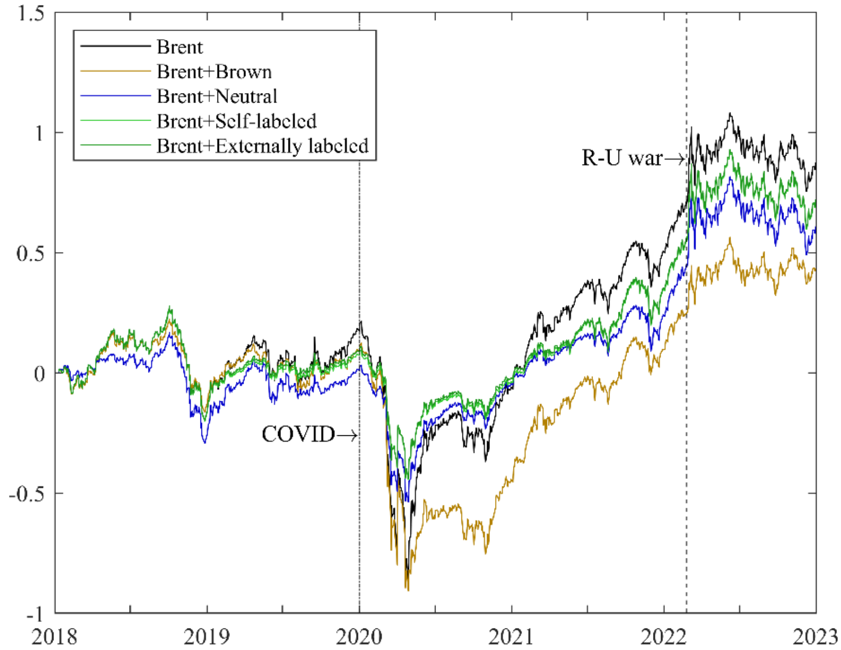



Note: Cross-wavelet coherence between Brent oil and each asset. The right bar in each panel is the statistical significance level represented by colours. The significance is estimated through Monte Carlo methods.

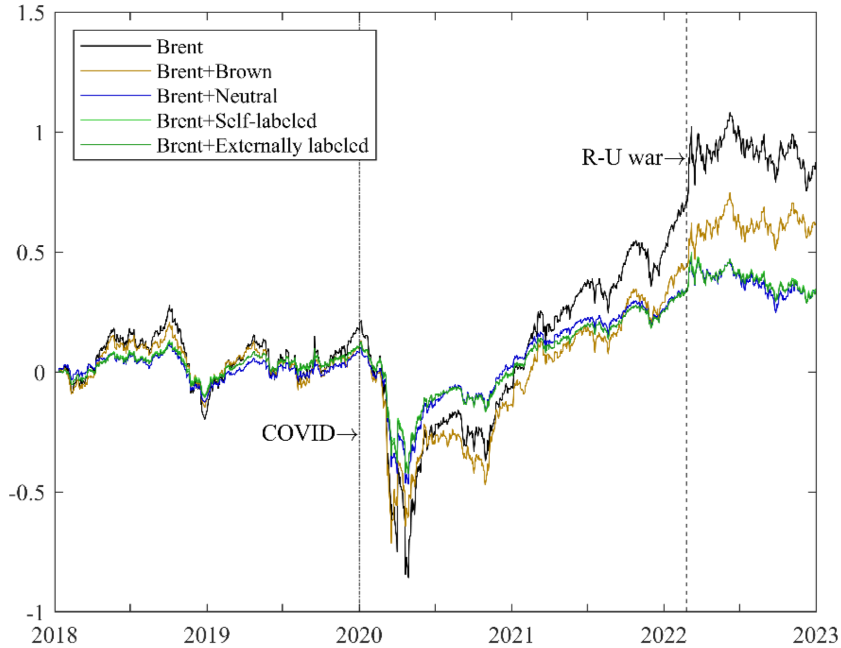
Second, I construct separate portfolios for each asset type to individually hedge against oil price fluctuations. I assume that an oil investor is permitted to short-sell a hedge asset, with a minimum of 50% maintained in Brent oil. **Figure 4.5** displays the cumulative returns of these portfolios, based on a one-year in-sample period and seasonally adjusted portfolio weights. The results in **Figure 4.5** and **Table 4.6** show that as the sustainability of the hedging assets increases, portfolios targeting a maximum Sharpe ratio show progressively higher cumulative returns and improved Sharpe ratios. Additionally, when portfolios are constructed for minimum volatility, increases in the sustainability of the hedge assets lead to lower overall volatility. These results are consistent with the earlier evidence, demonstrating that asset sustainability is a critical element for the hedging effectiveness of oil shocks. Accordingly, results from the robustness analysis confirm that the sustainability of the hedging instrument is vital for oil investors, regardless of whether their portfolio strategies prioritize a higher Sharpe ratio or lower volatility.

**Figure 4.5.** Oil portfolios formed by assets with varied greenness.

***Panel A:*** *Portfolios with the aim of maximum Sharpe ratio*




***Panel B:*** *Portfolios with the aim of minimum volatility*




Note: Cumulated returns of portfolios formed by Brent crude oil and assets with different greenness. The in-sample period is 1 year (252 trading days), and the portfolio weight is seasonally updated (63 trading days). I assume an oil investor accepts short-selling green bonds and requires the weight of Brent oil to be no lower than 25%.

**Table 4.6.** Oil portfolios formed by assets with varied greenness.

| ***Panel A:*** *Portfolios with the Aim of Maximum Sharpe Ratio* | | | | | |
|---|---|---|---|---|---|
| | Brent Only | Brent+ Brown | Brent+ Neutral | Brent+ Self-labelled | Brent+ Externally labelled |
| Min | -0.857 | -0.907 | -0.538 | -0.470 | -0.444 |
| Max | 1.081 | 0.564 | 0.816 | 0.867 | 0.923 |
| Std | 0.027 | 0.023 | 0.019 | 0.019 | 0.019 |
| Sharpe Ratio | 0.318 | **0.303** | **0.483** | **0.516** | **0.542** |
| Cumulated Return | 0.741 | 0.744 | 0.834 | 0.852 | 0.855 |
| ***Panel B:*** *Portfolios with the Aim of Minimum Volatility* | | | | | |
| | Brent Only | Brent+ Brown | Brent+ Neutral | Brent+ Self-labelled | Brent+ Externally labelled |
| Min | -0.857 | -0.713 | -0.467 | -0.396 | -0.418 |
| Max | 1.081 | 0.747 | 0.480 | 0.529 | 0.500 |
| Std | 0.027 | **0.020** | **0.014** | **0.013** | **0.013** |
| Sharpe Ratio | 0.318 | 0.457 | 0.445 | 0.455 | 0.432 |
| Cumulated Return | 0.741 | 0.697 | 0.703 | 0.726 | 0.728 |

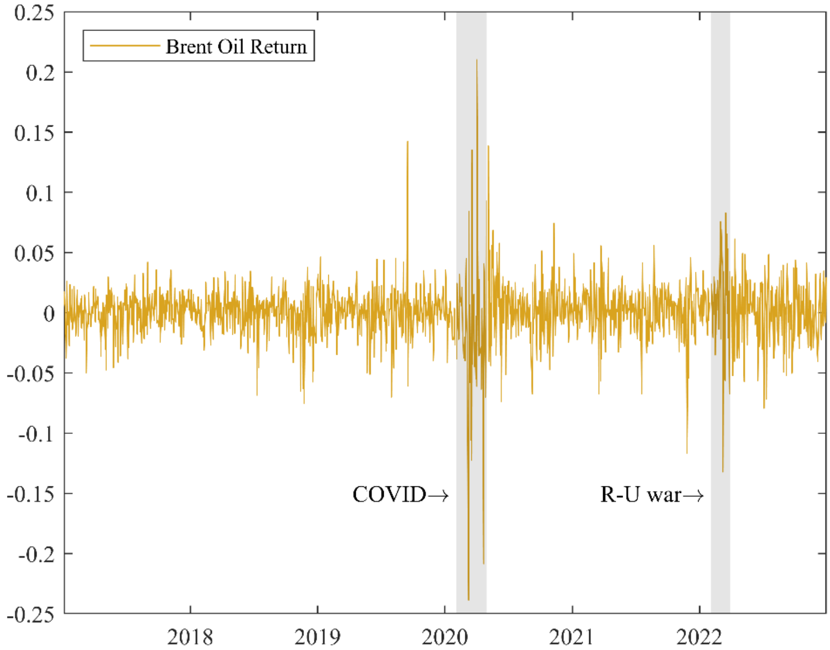
Note: This table records the overall performance of portfolios formed by Brent crude oil and assets with different greenness in **Figure 4.5**.

## 4.5. Hedging Effectiveness: Green bonds vs Bitcoin and gold

This section further explores whether green bonds can be appropriately classified as safe-haven assets for Brent crude oil investors. Specifically, I compare the hedging effectiveness of green bonds with two forms of "gold", conventional gold and the "digital gold" (Bitcoin), which, due to its store-of-value properties, has increasingly been recognized as a potential alternative to gold (Bouazizi et al., 2023).

Following others (e.g., Ku et al., 2007; Jin et al., 2020), I use a dynamic copula model to quantify the hedging effectiveness of each asset against extreme short-term oil losses during the shaded periods in **Figure 4.6**. As results reported in **Table 4.7**, the hedging effectiveness of a green bond index increases with its sustainability. This also confirms that the hedging benefits of green bonds to Brent oil investors are derived from the actual environmental sustainability of the projects they finance, rather than merely their "green" label. Additionally, gold exhibits the highest hedging effectiveness (0.2755 and 0.3094) in both panels of **Table 4.7**, while the hedging effectiveness of Bitcoin is negative, implying the latter cannot serve as a reliable hedging tool for oil investors.

**Figure 4.6.** Daily return of Brent oil index.




Note: The daily return of the Brent crude oil benchmark index from 2017/Jan/03 to 2022/Dec/30. The data source is Refinitiv.

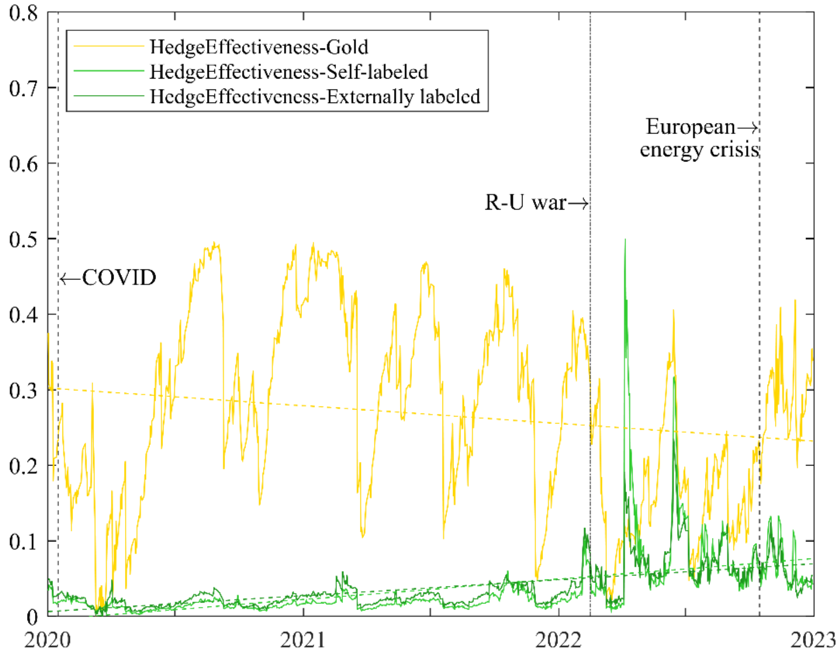
**Table 4.7.** Hedging effectiveness in minimum volatility.

| | | | | |
|---|---|---|---|---|
| ***Panel A:*** *Hedging effectiveness during extreme shocks in COVID* | | | | |
| | Self-labelled | Externally labelled | Gold | Bitcoin |
| hedge weight | 0.0235 | 0.0302 | 0.1606 | 0.8595 |
| hedging effectiveness | **0.0469** | **0.0601** | **0.2755** | **-3.9974** |
| ***Panel B:*** *Hedging effectiveness during extreme shocks in the R-U War* | | | | |
| | Self-labelled | External labelled | Gold | Bitcoin |
| hedge weight | 0.0279 | 0.033 | 0.1828 | 0.8424 |
| hedging effectiveness | **0.0557** | **0.0672** | **0.3094** | **-2.4278** |

Note: This table reports different assets' hedging effectiveness and optimal hedge weight in handling extreme oil shocks shadowed in **Figure 4.6.**

Finally, **Figure 4.7** plots the daily hedging effectiveness of green bonds and gold. It shows that the hedging effectiveness of gold is consistently higher than green bonds over the entire data period, though with a downward trend. In contrast, the hedging effectiveness of both types of green bonds not only shows an upward trend but also reaches a level comparable to gold during the R-U war period. This evidence highlights that, in the context of increasing global cooperation and pursuing financial stabilization through green investments, assets with a higher degree of sustainability, such as green bonds, have the potential to emerge as a new safe-haven asset for Brent oil investors.

**Figure 4.7.** Hedging effectiveness and long-term trend.




Note: This figure shows the daily hedging effectiveness and the trend of that effectiveness when using gold and green bonds against oil shocks.

Overall, the results show that asset sustainability matters for hedging Brent oil shocks. Although gold, a historically well-established safe-haven asset, currently provides more hedging benefits than green bonds during both the COVID and R-U war periods, the relatively short history of the green bond market, compared to the gold market, suggests its strong potential to develop into a new safe-haven asset for Brent oil investors.

### 4.6. Conclusion

This chapter evaluates whether assets with higher sustainability can effectively hedge oil price shocks, particularly during both the COVID pandemic and the R-U war periods. It reveals that externally-labelled green bonds outperform other assets with less or no sustainability in hedging extreme oil shocks during these periods, consistent with my argument that the level of asset sustainability matters for managing oil shocks.

Additionally, I explore the safe-haven potential of green bonds by comparing their hedging effectiveness with gold and Bitcoin. The results reveal that green bonds, while currently offering lower hedge benefits than gold, show a consistent upward trend in their hedging effectiveness. This upward hedge benefit stems not only from investor preferences for ESG-aligned assets but also from global cooperation in shaping the resilience of a sustainable finance system. This evidence implies that externally-labelled green bonds may evolve into a viable safe-haven asset for Brent crude oil investors, particularly after green finance markets and regulatory standards become more mature and rigorous.

The theoretical foundation underlying my findings rests on the premise that assets aligned with multilateral cooperation frameworks and long-term global stability objectives demonstrate enhanced resilience during systemic crises. This framework provides a novel lens for understanding why sustainable assets perform differently across various types of market stress. During the COVID pandemic, when supply chain disruptions and international coordination needs dominated market dynamics, sustainability-focused assets benefited from their structural embedding in collaborative networks designed for resilience. Similarly, during the Russia-Ukraine war, despite different underlying shock mechanisms, these assets retained their protective properties because their fundamental value proposition, addressing universal challenges like climate change, transcends short-term geopolitical rivalries.

A particularly significant finding emerges from the dynamic analysis showing that externally-labelled green bonds exhibit steadily improving hedging effectiveness over time. This trend suggests these instruments are not merely benefiting from temporary investor sentiment shifts but are developing fundamental characteristics that enhance their crisis-period performance. The evidence indicates that as global cooperation frameworks become increasingly critical for managing complex, interconnected systemic risks, assets structurally aligned with these frameworks gain competitive advantages in providing portfolio protection. This evolution has important implications for understanding the future landscape of safe-haven assets in an era of mounting environmental and geopolitical challenges.

My findings carry significant implications for multiple dimensions of investment practice and policy design. For institutional investors managing large portfolios with oil market exposure, incorporating externally-labelled green bonds can enhance portfolio resilience while simultaneously supporting environmental objectives, creating valuable synergies between risk management and sustainability goals. For asset managers developing systematic risk management strategies, the evidence that sustainable assets' hedging benefits manifest most strongly in low-frequency domains suggests they are particularly valuable for long-term strategic allocation rather than short-term tactical hedging.

For policymakers, the results underscore the systemic stability benefits of promoting credible green finance markets through standardized certification frameworks and transparent impact reporting requirements. The evidence that sustainable assets derive hedging benefits from their alignment with international cooperation frameworks has important implications for understanding financial stability in an increasingly interconnected world facing mounting environmental and geopolitical challenges. This suggests that policies supporting sustainable finance may contribute to broader financial system resilience in ways that traditional regulatory approaches might not capture.

Despite the various insightful findings, this study comes with several caveats. First, this analysis is limited to the EU market, where sustainability policies and investor preferences may differ from other global regions. Future research could examine whether similar patterns hold in markets with different green finance structures, such as the US or Asia. Second, while the results highlight the increasing hedging effectiveness of sustainable assets, the long-term evolution of this trend remains uncertain, particularly as financial markets adapt to climate policies and sustainability reporting frameworks. Third, this analysis focuses on oil market risks, and the hedging properties I identify may not generalize to other types of systematic risks such as interest rate shocks, currency crises, or broader equity market downturns.

# Chapter 5. General Conclusion

## 5.1. Summary of the Findings

This thesis examines the heterogeneity within the European Union's green bond market. The central argument advanced through three interconnected studies is that green bonds do not constitute a homogeneous asset class, despite their common treatment as such in both academic literature and market practice. Instead, their financial characteristics, investor reception, and behavior under stress are significantly shaped by the credibility of their environmental claims, as conveyed through the strategic choice of labelling approaches. By systematically deconstructing the green bond category and examining the mechanisms that differentiate various types of green financial instruments, this research provides a more nuanced understanding of the forces that govern this vital segment of sustainable finance.

The thesis begins with a comprehensive systematic review of 206 peer-reviewed articles, which maps the intellectual terrain of green bond research and establishes the theoretical and empirical foundations for the subsequent empirical analyses. This review identifies three principal thematic clusters: asset pricing, issuance determinants, and sustainability outcomes. It also traces a clear evolution in the literature's focus, shifting from early studies that emphasised instrumental financial attributes such as yield and liquidity to more recent research concerned with intrinsic values like credibility and real-world environmental impact.

The second study directly tackles the economic incentives and consequences of labelling, analysing the strategic choice between self-labelling and obtaining external verification from reputable organizations such as the International Capital Market Association or the Climate Bonds Initiative. Employing an endogenous treatment effect model on a unique hand-collected dataset of EU green bonds issued from 2012 to 2021, this analysis finds that externally labelled green bonds command a statistically significant yield discount (or "greenium") of approximately 210 basis points and attract substantially greater short-term investor attention compared to their self-labelled counterparts.

The third study extends this inquiry into the realm of risk management, assessing the hedging performance of different bond types during the severe oil price shocks triggered by the COVID-19 pandemic and the Russia-Ukraine war. By constructing four distinct asset classes ranging from brown (traditional energy) to externally labelled green bonds, the analysis employs multiple complementary methodologies, including structural vector autoregression, connectedness analysis, copula modelling, and wavelet coherence to provide a comprehensive assessment across time and frequency domains. The results demonstrate that only externally certified green bonds consistently provide effective hedging benefits under tail-risk scenarios, offering substantial downside protection when oil markets experience severe stress.

## 5.2. Research Contributions

Taken together, these findings make several significant contributions to the sustainable-finance literature. Most importantly, they reconcile the inconsistent evidence that has characterised previous research on the greenium and other market effects associated with sustainable-finance instruments. By demonstrating that financial outcomes are conditional on the specific type and credibility of environmental labelling, this thesis shows that earlier conflicting results are likely a product of treating green bonds as a monolithic category rather than recognising their inherent heterogeneity.

The research also refines theoretical understanding of market mechanisms in sustainable finance, providing empirical support for the complementary roles of signalling theory and taste-based investor preferences. The evidence demonstrates that an external label acts as a powerful and credible signal that reduces information asymmetry and mitigates greenwashing concerns, while simultaneously enabling investors with pro-environmental preferences to invest with confidence in genuinely sustainable projects.

Methodologically, the thesis highlights the necessity of addressing the endogeneity of labelling choices, showing how models that properly account for self-selection bias can yield more reliable and interpretable insights. The endogenous-treatment approach in the second study and the multi-faceted empirical framework of the third provide methodological templates for future sustainable-finance research.

## 5.3. Implications

From a practical and policy standpoint, the findings carry several critical implications that extend across multiple stakeholder groups. For investors, this research underscores the imperative to look beyond superficial “green” labels and conduct thorough due diligence on the credibility of environmental verification processes. The evidence that only externally certified green bonds provide meaningful pricing advantages and risk management benefits suggests that investors seeking to align their portfolios with sustainability objectives while maintaining competitive financial performance must carefully differentiate among available green finance options. Recognizing this heterogeneity is essential not only for achieving genuine sustainability goals but also for avoiding greenwashing risks and understanding that only certain high-credibility green assets may offer portfolio diversification benefits during periods of market stress.

For issuers, the results illuminate a clear strategic trade-off that requires careful consideration of costs and benefits associated with different labelling approaches. While pursuing external certification involves substantial compliance costs, administrative burdens, and ongoing monitoring requirements, these investments may be more than offset by the tangible benefits of lower borrowing costs and enhanced market visibility. The evidence suggests that this cost-benefit calculation is evolving as markets become more sophisticated and as regulatory frameworks develop, implying that issuers must continuously reassess their green finance strategies in response to changing market conditions and investor expectations.

For regulators and policymakers, this thesis provides strong empirical justification for the development and enforcement of transparent, standardized, and credible labelling frameworks, such as the EU Green Bond Standard, which was finalized during the period covered by this research. The evidence that market outcomes depend critically on the credibility of environmental claims supports policy approaches that emphasize mandatory third-party verification, standardized impact reporting requirements, and robust post-issuance monitoring mechanisms. Such standards are vital not only for protecting investors and ensuring market integrity but also for maximizing the effective channelling of capital toward projects that deliver verifiable environmental benefits rather than merely satisfying superficial disclosure requirements.

## 5.4. Limitations and Challenges

This thesis acknowledges several important limitations that, in turn, open promising avenues for future inquiry and suggest caution in generalizing the findings beyond their specific context. The analysis concentrates on the EU market, a region with a uniquely supportive institutional and regulatory environment for sustainable finance, characterized by progressive policy frameworks, sophisticated investor bases, and relatively strong governance structures. The findings may not be fully generalizable to markets with different governance structures, regulatory approaches, or investor attitudes toward environmental issues. Emerging markets, in particular, may exhibit different relationships between environmental credibility and market outcomes due to varying levels of institutional development, different risk profiles, and distinct investor preferences.

Furthermore, while the studies analyse financial proxies for greenness and credibility through market-based indicators such as yields, investor attention, and risk characteristics, they do not directly measure the ultimate long-term environmental outcomes of the funded projects. This limitation reflects broader challenges in sustainable finance research, where the time lag between financial investment and measurable environmental impact, combined with the difficulty of establishing causal relationships between specific financial instruments and environmental outcomes, constrains the ability to provide definitive assessments of environmental effectiveness. These limitations mirror the broader challenges of sustainable-finance research, where data availability, institutional differences, and evolving regulation make comparative and longitudinal analyses essential.

Future research could address this limitation by linking financial market data with project-level environmental outcomes. Emerging datasets, such as satellite-based emissions monitoring, firm-level carbon disclosures, and project-level impact reporting, may allow researchers to directly examine whether green bond financing leads to measurable environmental improvements. Integrating financial and environmental data would provide a more complete assessment of the effectiveness of sustainable finance instruments.

### 5.5. Directions for Future Research

Future research could extend this work in several promising directions that would address these limitations while building on the methodological and theoretical contributions of this thesis. First, there is a significant opportunity to link green bond financing with granular project-level environmental outcomes, such as emissions reduction, renewable energy generation, or energy efficiency improvements. Combining financial market data with environmental performance data would help close the loop between financial market mechanisms and real-world environmental impact. Emerging technologies such as satellite emissions tracking, blockchain-based impact monitoring, and artificial intelligence-powered environmental outcome assessment may provide promising tools for such analysis.

Second, comparative cross-market studies are needed to understand how the value of label credibility varies across different regulatory regimes, institutional contexts, and stages of market development. Such research would help identify the conditions under which credible green finance markets can develop and thrive, providing valuable insights for policymakers in markets that are still developing their sustainable finance frameworks. Third, as new regulations like the EU Green Bond Standard take full effect and as other jurisdictions develop their own standards, research will be needed to track how these evolving regulatory frameworks influence issuer behavior, investor responses, and market dynamics more broadly.

Fourth, the rapid evolution of sustainable finance markets calls for research that examines emerging innovations such as sustainability-linked bonds, transition bonds, blue bonds, and other specialized instruments that address different aspects of environmental and social challenges. These instruments present new theoretical and empirical challenges that may require extensions of existing frameworks or development of entirely new analytical approaches. Finally, there is a significant opportunity for research that examines the interaction between green finance and other policy instruments, such as carbon pricing, environmental regulations, and fiscal incentives, to understand how these various approaches can work together most effectively to address environmental challenges.

### 5.6. Closing Remarks

Overall, this thesis demonstrates that green bonds cannot be treated as a homogeneous asset class; their financial and risk-management properties depend critically on the credibility of environmental labelling. Labelling is far more than a simple disclosure choice or marketing strategy; it is an integral and powerful component of a green bond's financial and risk profile that fundamentally shapes market outcomes. The credibility of the "green" promise emerges as a primary determinant of a bond's value, its reception by the market, and its resilience in the face of uncertainty. By documenting the profound role of credibility in shaping these market outcomes, this research offers critical insights for academics seeking to understand the mechanisms of sustainable finance, investors aiming to construct effective and genuine sustainable portfolios, issuers developing optimal green finance strategies, and regulators working to design policy frameworks that channel capital effectively toward environmental solutions.

The findings ultimately contribute to the collective effort to build a more effective, transparent, and impactful system of sustainable finance that can play a meaningful role in addressing the urgent environmental challenges facing the global economy. As climate change intensifies and as the need for massive capital mobilization toward environmental solutions becomes increasingly urgent, the stakes for getting green finance right continue to rise. This thesis provides both theoretical insights and practical guidance that can help ensure that the promise of green finance translates into genuine environmental progress, rather than merely satisfying the appearance of environmental responsibility while leaving underlying challenges unaddressed.

## References


Abakah, E.J.A., Tiwari, A.K., Adekoya, O.B., Oteng-Abayie, E.F. 2023. An analysis of the time-varying causality and dynamic correlation between green bonds and US gas prices. Technol. Forecast. Soc. 186, 122134. https://doi.org/10.1016/j.techfore.2022.122134

Abakah, E.J.A., Tiwari, A.K., Ghosh, S., Doğan, B. 2023. Dynamic effect of Bitcoin, fintech and artificial intelligence stocks on eco-friendly assets, Islamic stocks and conventional financial markets: Another look using quantile-based approaches. Technol. Forecast. Soc. 192. https://doi.org/10.1016/j.techfore.2023.122566

Adekoya, O.B., Oliyide, J.A., Asl, M.G., Jalalifar, S. 2021. Financing the green projects: Market efficiency and volatility persistence of green versus conventional bonds, and the comparative effects of health and financial crises. Int. Rev. Financ. Anal. 78, 101954. https://doi.org/10.1016/j.irfa.2021.101954

Agliardi, E., Agliardi, R. 2021. Corporate green bonds: Understanding the greenium in a two-factor structural model. Environ. Resour. Econ. 80 (2), 257–278. https://doi.org/10.1007/s10640-021-00585-7

Agliardi, E., Agliardi, R. 2021. Pricing climate-related risks in the bond market. J. Financ. Stabil. 54, 100868. https://doi.org/10.1016/j.jfs.2021.100868

Akins, B., De Angelis, D., Gaulin, M. 2020. Debt contracting on management. J. Financ. 75 (4), 2095–2137. https://doi.org/10.1111/jofi.12893

Albuquerque, R., Koskinen, Y., Yang, S., Zhang, C. 2020. Resiliency of environmental and Social stocks: An analysis of the exogenous COVID-19 market crash. Rev. Corp. Financ. Stud. 9 (3), 593–621. https://doi.org/10.1093/rcfs/cfaa011

Alharbi, S.S., Al Mamun, M., Boubaker, S., Rizvi, S.K.A. 2023. Green finance and renewable energy: A worldwide evidence. Energ. Econ. 118, 106499. https://doi.org/10.1016/j.eneco.2022.106499

Andersen, T.M., Bhattacharya, J., Liu, P. 2020. Resolving intergenerational conflict over the environment under the Pareto criterion. J. Environ. Econ. Manag. 100, 102290. https://doi.org/10.1016/j.jeem.2019.102290

Antonakakis, N., Cunado, J., Filis, G., Gabauer, D., de Gracia, F.P. 2020. Oil and asset classes implied volatilities: Investment strategies and hedging effectiveness. Energ. Econ. 91. https://doi.org/10.1016/j.eneco.2020.104762

Arfaoui, N., Naeem, M.A., Boubaker, S., Mirza, N., Karim, S. 2023. Interdependence of clean energy and green markets with cryptocurrencies. Energ. Econ. 120, 106584. https://doi.org/10.1016/j.eneco.2023.106584

Azhgaliyeva, D., Kapsalyamova, Z., Mishra, R. 2022. Oil price shocks and green bonds: An empirical evidence. Energ. Econ. 112, 106108. https://doi.org/10.1016/j.eneco.2022.106108

Baiman, S. 1990. Agency research in managerial accounting: A second look. Account. Org. Soc. 15 (4), 341–371. https://doi.org/10.1016/0361-3682(90)90023-N

Baker, M., Bergstresser, D., Serafeim, G., Wurgler, J. 2022. The pricing and ownership of US green bonds. Annu. Rev. Financ. Econ. 14 (1), 415–437. https://doi.org/10.1146/annurev-financial-111620-014802

Barua, S., Chiesa, M. 2019. Sustainable financing practices through green bonds: What affects the funding size? Bus. Strat. En. 28 (6), 1131–1147. https://doi.org/10.1002/bse.2307

Batra, S., Tiwari, A.K., Yadav, M., Danso, A. 2025. Connectedness among diverse financial assets: Evidence from cryptocurrency uncertainty indices. Technol. Forecast. Soc. 210. https://doi.org/10.1016/j.techfore.2024.123874

Bedendo, M., Nocera, G., Siming, L. 2023. Greening the financial sector: Evidence from bank green bonds. J. Bus. Ethics. https://doi.org/10.1007/s10551-022-05305-9
Bellucci, A., Borisov, A., Giombini, G., Zazzaro, A. 2023. Information asymmetry, external certification, and the cost of bank debt. J. Corp. Financ. 78. https://doi.org/10.1016/j.jcorpfin.2022.102336
Ben-Rephael, A., Da, Z., Israelsen, R.D. 2017. It depends on where you search: Institutional investor attention and underreaction to news. Rev. Financ. Stud. 30 (9), 3009–3047. https://doi.org/10.1093/rfs/hhx031
Benlemlih, M., Jaballah, J., Kermiche, L. 2023. Does financing strategy accelerate corporate energy transition? Evidence from green bonds. Bus. Strat. En. https://doi.org/10.1002/bse.3180
Berrone, P., Fosfuri, A., Gelabert, L. 2015. Does greenwashing pay off? Understanding the relationship between environmental actions and environmental legitimacy. J. Bus. Ethics 144 (2), 363–379. https://doi.org/10.1007/s10551-015-2816-9
Bhutta, U.S., Tariq, A., Farrukh, M., Raza, A., Iqbal, M.K. 2022. Green bonds for sustainable development: Review of literature on development and impact of green bonds. Technol. Forecast. Soc. 175. https://doi.org/10.1016/j.techfore.2021.121378
Billah, M., Elsayed, A.H., Hadhri, S. 2023. Asymmetric relationship between green bonds and Sukuk markets: The role of global risk factors. J. Int. Financ. Markets Inst. Money 83. https://doi.org/10.1016/j.intfin.2022.101728
Bongaerts, D., Schoenmaker, D. 2024. Liquidity and clientele effects in green debt markets. J. Corp. Financ. 86. https://doi.org/10.1016/j.jcorpfin.2024.102582
Bouazizi, T., Galariotis, E., Guesmi, K., Makrychoriti, P. 2023. Investigating the nature of interaction between crypto-currency and commodity markets. Int. Rev. Financ. Anal. 88. https://doi.org/10.1016/j.irfa.2023.102690
Bouri, E., Rognone, L., Sokhanvar, A., Wang, Z. 2023. From climate risk to the returns and volatility of energy assets and green bonds: A predictability analysis under various conditions. Technol. Forecast. Soc. 194. https://doi.org/10.1016/j.techfore.2023.122682
Boutabba, M.A., Rannou, Y. 2022. Investor strategies in the green bond market: The influence of liquidity risks, economic factors and clientele effects. Int. Rev. Financ. Anal. 81, 102071. https://doi.org/10.1016/j.irfa.2022.102071
Braga, J.P., Semmler, W., Grass, D. 2021. De-risking of green investments through a green bond market – Empirics and a dynamic model. J. Econ. Dyn. Control 131, 104201. https://doi.org/10.1016/j.jedc.2021.104201
Caldara, D., Iacoviello, M. 2022. Measuring geopolitical risk. Am. Econ. Rev. 112 (4), 1194–1225. https://doi.org/10.1257/aer.20191823
Cao, J., Titman, S., Zhan, X., Zhang, W. 2022. ESG preference, institutional trading, and stock return patterns. J. Financ. Quant. Anal. 58 (5), 1843–1877. https://doi.org/10.1017/s0022109022000916
Castañer, X., Oliveira, N. 2020. Collaboration, coordination, and cooperation among organizations: Establishing the distinctive meanings of these terms through a systematic literature review. Journal of Management 46 (6), 965–1001. https://doi.org/10.1177/0149206320901565
Cengiz, D., Dube, A., Lindner, A., Zipperer, B. 2019. The effect of minimum wages on low-wage jobs. Q. J. Econ. 134 (3), 1405–1454. https://doi.org/10.1093/qje/qjz014
Cepni, O., Demirer, R., Pham, L., Rognone, L. 2023. Climate uncertainty and information transmissions across the conventional and ESG assets. J. Int. Financ. Markets Inst. Money 83. https://doi.org/10.1016/j.intfin.2022.101730

Cepni, O., Demirer, R., Rognone, L. 2022. Hedging climate risks with green assets. Econ. Lett. 212, 110312. https://doi.org/10.1016/j.econlet.2022.110312
Cestau, D., Hollifield, B., Li, D., Schürhoff, N. 2019. Municipal bond markets. Annu. Rev. Financ. Econ. 11 (1), 65–84. https://doi.org/10.1146/annurev-financial-110118-123034
Chai, S., Chu, W., Zhang, Z., Li, Z., Abedin, M.Z. 2022. Dynamic nonlinear connectedness between the green bonds, clean energy, and stock price: the impact of the COVID-19 pandemic. Ann. Oper. Res., 1–28. https://doi.org/10.1007/s10479-021-04452-y
Chang, L., Taghizadeh-Hesary, F., Chen, H., Mohsin, M. 2022. Do green bonds have environmental benefits? Energ. Econ. 115, 106356. https://doi.org/10.1016/j.eneco.2022.106356
Chen, Y., Ping, L., Liang, F.H. 2023. Industry reputation crisis and firm certification: A co-evolution perspective. J. Bus. Ethics 186 (4), 761–780. https://doi.org/10.1007/s10551-023-05438-5
Cheng, L.T.W., Sharma, P., Broadstock, D.C. 2023. Interactive effects of brand reputation and ESG on green bond issues: A sustainable development perspective. Bus. Strat. En. https://doi.org/10.1002/bse.3161
Chiburis, R., Lokshin, M. 2007. Maximum likelihood and two-step estimation of an ordered-probit selection model. The Stata Journal 7 (2), 167–182. https://doi.org/10.1177/1536867X0700700202
Christophers, B. 2018. Risking value theory in the political economy of finance and nature. Prog. Hum. Geog. 42 (3), 330–349. https://doi.org/10.1177/0309132516679268
Costola, M., Lorusso, M. 2022. Spillovers among energy commodities and the Russian stock market. J. Commod. Mark. 28. https://doi.org/10.1016/j.jcomm.2022.100249
Cumming, D., Meoli, M., Vismara, S. 2019. Investors' choices between cash and voting rights: Evidence from dual-class equity crowdfunding. Res. Policy 48 (8). https://doi.org/10.1016/j.respol.2019.01.014
Dai, Z., Zhang, X., Yin, Z. 2023. Extreme time-varying spillovers between high carbon emission stocks, green bond and crude oil: Evidence from a quantile-based analysis. Int. Rev. Financ. Anal. 118. https://doi.org/10.1016/j.eneco.2023.106511
Daubanes, J.X., Mitali, S.F., Rochet, J.-C. 2021. Why do firms issue green bonds? Swiss Finance Institute Research Paper Series No. 21-97. https://doi.org/10.2139/ssrn.3996238
Daubechies, I. 1990. The wavelet transform, time-frequency localization and signal analysis. Ieee T. Inform. Theory 36 (5), 961–1005. https://doi.org/10.1109/18.57199
Díaz, A., Escribano, A. 2021. Sustainability premium in energy bonds. Energ. Econ. 95. https://doi.org/10.1016/j.eneco.2021.105113
Diebold, F.X., Yilmaz, K. 2009. Measuring financial asset return and volatility spillovers, with application to global equity markets. Econ. J. 119 (53), 158–177. https://doi.org/10.1111/j.1468-0297.2008.02208.x
Diebold, F.X., Yilmaz, K. 2012. Better to give than to receive: Predictive directional measurement of volatility spillovers. Int. J. Forecasting 28 (1), 57–66. https://doi.org/10.1016/j.ijforecast.2011.02.006
DiMaggio, P., Powell, W.W. 1983. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. American Sociological Review 84 (2), 147–160. https://doi.org/10.1515/9780691229270-005
Du, X., Weng, J., Zeng, Q., Chang, Y., Pei, H. 2017. Do lenders applaud corporate environmental performance? Evidence from Chinese private-pwned firms. J. Bus. Ethics 143 (1), 179–207. https://doi.org/10.1007/s10551-015-2758-2

Duchin, R., Gao, J., Xu, Q. 2024. Sustainability or greenwashing: Evidence from the asset market for industrial pollution. J. Financ. 80 (2), 699–754. https://doi.org/10.1111/jofi.13412

Dutordoir, M., Li, S., Neto, J.Q.F. 2023. Issuer motivations for corporate green bond offerings. Brit. J. Manage. https://doi.org/10.1111/1467-8551.12747

El Ghoul, S., Guedhami, O., Kim, H., Park, K. 2018. Corporate environmental responsibility and the cost of capital: International evidence. J. Bus. Ethics 149 (2), 335–361. https://doi.org/10.1007/s10551-015-3005-6

El Ghoul, S., Guedhami, O., Kwok, C.C.Y., Mishra, D.R. 2011. Does corporate social responsibility affect the cost of capital? J. Bank. Financ. 35 (9), 2388–2406. https://doi.org/10.1016/j.jbankfin.2011.02.007

Elsayed, A.H., Khalfaoui, R., Nasreen, S., Gabauer, D. 2024. The impact of oil shocks on green, clean, and socially responsible markets. Energ. Econ. 136. https://doi.org/10.1016/j.eneco.2024.107729

Elsayed, A.H., Naifar, N., Nasreen, S., Tiwari, A.K. 2022. Dependence structure and dynamic connectedness between green bonds and financial markets: Fresh insights from time-frequency analysis before and during COVID-19 pandemic. Energ. Econ. 107, 105842. https://doi.org/10.1016/j.eneco.2022.105842

Fama, E.F., French, K.R. 2007. Disagreement, tastes, and asset prices. J. Financ. Econ. 83 (3), 667–689. https://doi.org/10.1016/j.jfineco.2006.01.003

Fatica, S., Panzica, R. 2021. Green bonds as a tool against climate change? Bus. Strat. En. 30 (5), 2688–2701. https://doi.org/10.1002/bse.2771

Fatica, S., Panzica, R. 2024. Sustainable investing in times of crisis: Evidence from bond holdings and the COVID-19 pandemic. J. Bank. Financ. 166. https://doi.org/10.1016/j.jbankfin.2024.107238

Fatica, S., Panzica, R., Rancan, M. 2021. The pricing of green bonds: Are financial institutions special? J. Financ. Stabil. 54, 100873. https://doi.org/10.1016/j.jfs.2021.100873

Ferriani, F. 2023. Issuing bonds during the Covid-19 pandemic: Was there an ESG premium? Int. Rev. Financ. Anal. 88, 102653. https://doi.org/10.1016/j.irfa.2023.102653

Flammer, C. 2021. Corporate green bonds. J. Financ. Econ. 142 (2), 499–516. https://doi.org/10.1016/j.jfineco.2021.01.010

García, C.J., Herrero, B., Miralles-Quirós, J.L., del Mar Miralles-Quirós, M. 2023. Exploring the determinants of corporate green bond issuance and its environmental implication: The role of corporate board. Technol. Forecast. Soc. 189, 122379. https://doi.org/10.1016/j.techfore.2023.122379

Ghitti, M., Gianfrate, G., Lopez-de-Silanes, F., Spinelli, M. 2023. What's in a shade? The market relevance of green bonds' external reviews. Brit. Account. Rev. https://doi.org/10.1016/j.bar.2023.101271

Gigante, G., Manglaviti, D. 2022. The ESG effect on the cost of debt financing: A sharp RD analysis. Int. Rev. Financ. Anal. 84, 102382. https://doi.org/10.1016/j.irfa.2022.102382

Gounopoulos, D., Wu, H., Zhao, B. 2023. Talk vs. walk: Lessons from silent sustainable investing of mutual funds. SSRN Work. Pap. https://doi.org/10.2139/ssrn.4602285

Grinsted, A., Moore, J.C., Jevrejeva, S. 2004. Application of the cross wavelet transform and wavelet coherence to geophysical time series. Nonlin. Processes Geophys. 11, 561–566. https://doi.org/10.5194/npg-11-561-2004

Guo, D., Zhou, P. 2021. Green bonds as hedging assets before and after COVID: A comparative study between the US and China. Energ. Econ. 104, 105696. https://doi.org/10.1016/j.eneco.2021.105696

Halim, Z.A., How, J., Verhoeven, P., Hassan, M.K. 2019. The value of certification in Islamic bond offerings. J. Corp. Financ. 55, 141–161. https://doi.org/10.1016/j.jcorpfin.2018.09.002
Hammoudeh, S., Ajmi, A.N., Mokni, K. 2020. Relationship between green bonds and financial and environmental variables: A novel time-varying causality. Energ. Econ. 92, 104941. https://doi.org/10.1016/j.eneco.2020.104941
Han, Y., Li, J. 2022. Should investors include green bonds in their portfolios? Evidence for the USA and Europe. Int. Rev. Financ. Anal. 80, 101998. https://doi.org/10.1016/j.irfa.2021.101998
Hart, O., Moore, J. 1999. Foundations of incomplete contracts. The Review of Economic Studies 66 (1), 115.
Henide, K. 2022. Voluntary disclosure and adverse selection: Bayesian game theoretical inference for green bond labelling regimes. Int. Rev. Financ. Anal. 83, 102248. https://doi.org/10.1016/j.irfa.2022.102248
Hilbrandt, H., Grubbauer, M. 2020. Standards and SSOs in the contested widening and deepening of financial markets: The arrival of green municipal bonds in Mexico city. Environ. Plann. A. 52 (7), 1415–1433. https://doi.org/10.1177/0308518x20909391
Huang, Y.S., Bui, D.G., Lin, C.Y., Robin. 2022. The effect of abnormal institutional attention on bank loans. J. Int. Financ. Markets Inst. Money 76. https://doi.org/10.1016/j.intfin.2021.101458
Huynh, T.D., Xia, Y. 2020. Climate change news risk and corporate bond returns. J. Financ. Quant. Anal. 56 (6), 1985–2009. https://doi.org/10.1017/s0022109020000757
Huynh, T.L.D., Hille, E., Nasir, M.A. 2020. Diversification in the age of the 4th industrial revolution: The role of artificial intelligence, green bonds and cryptocurrencies. Technol. Forecast. Soc. 159, 120188. https://doi.org/10.1016/j.techfore.2020.120188
Jankovic, I., Vasic, V., Kovacevic, V. 2022. Does transparency matter? Evidence from panel analysis of the EU government green bonds. Energ. Econ. 114. https://doi.org/10.1016/j.eneco.2022.106325
Jia, Q. 2023. The impact of green finance on the level of decarbonization of the economies: An analysis of the United States', China's, and Russia's current agenda. Bus. Strat. En. https://doi.org/10.1002/bse.3120
Jin, J., Han, L., Wu, L., Zeng, H. 2020. The hedging effect of green bonds on carbon market risk. Int. Rev. Financ. Anal. 71, 101509. https://doi.org/10.1016/j.irfa.2020.101509
Jin, Y., Zhao, H., Bu, L., Zhang, D. 2023. Geopolitical risk, climate risk and energy markets: A dynamic spillover analysis. Int. Rev. Financ. Anal. 87, 102597. https://doi.org/10.1016/j.irfa.2023.102597
Kanamura, T. 2020. Are green bonds environmentally friendly and good performing assets? Energ. Econ. 88, 104767. https://doi.org/10.1016/j.eneco.2020.104767
Khalfaoui, R., Mefteh-Wali, S., Dogan, B., Ghosh, S. 2023. Extreme spillover effect of COVID-19 pandemic-related news and cryptocurrencies on green bond markets: A quantile connectedness analysis. Int. Rev. Financ. Anal. 86, 102496. https://doi.org/10.1016/j.irfa.2023.102496
Kilian, L. 2009. Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. Am. Econ. Rev. 99 (3), 1053–1069. https://doi.org/10.1257/aer.99.3.1053
Kim, S., Yoonb, A. 2023. Analyzing active fund managers' commitment to ESG: Evidence from the United Nations Principles for responsible investment. Manage. Sci. 69 (2), 741–758. https://doi.org/10.1287/mnsc.2022.4394

Kocaarslan, B., Soytas, U. 2023. The role of major markets in predicting the U.S. municipal green bond market performance: New evidence from machine learning models. Technol. Forecast. Soc. 196. https://doi.org/10.1016/j.techfore.2023.122820

Krüger, P. 2015. Corporate goodness and shareholder wealth. J. Financ. Econ. 115 (2), 304–329. https://doi.org/10.1016/j.jfineco.2014.09.008

Ku, Y.H.H., Chen, H.C., Chen, K.H. 2007. On the application of the dynamic conditional correlation model in estimating optimal time-varying hedge ratios. Appl. Econ. Lett. 14 (7), 503–509. https://doi.org/10.1080/13504850500447331

Larcker, D.F., Watts, E.M. 2020. Where's the greenium? J. Account. Econ. 69 (2-3), 101312. https://doi.org/10.1016/j.jacceco.2020.101312

Lau, P., Sze, A., Wan, W., Wong, A. 2022. The economics of the greenium: How much is the world willing to pay to save the earth? Environ. Resour. Econ. 81 (2), 379–408. https://doi.org/10.1007/s10640-021-00630-5

Le, T.L., Abakah, E.J.A., Tiwari, A.K. 2021. Time and frequency domain connectedness and spill-over among fintech, green bonds and cryptocurrencies in the age of the fourth industrial revolution. Technol. Forecast. Soc. 162, 120382. https://doi.org/10.1016/j.techfore.2020.120382

Lee, C.C., Wang, F., Chang, Y.F. 2023. Towards net-zero emissions: Can green bond policy promote green innovation and green space? Energ. Econ. 121, 106675. https://doi.org/10.1016/j.eneco.2023.106675

Leitao, J., Ferreira, J., Santibanez-Gonzalez, E. 2021. Green bonds, sustainable development and environmental policy in the European Union carbon market. Bus. Strat. En. 30 (4), 2077–2090. https://doi.org/10.1002/bse.2733

Li, H., Li, Q., Huang, X., Guo, L. 2023. Do green bonds and economic policy uncertainty matter for carbon price? New insights from a TVP-VAR framework. Int. Rev. Financ. Anal. 86, 102502. https://doi.org/10.1016/j.irfa.2023.102502

Li, Q., Sharif, A., Razzaq, A., Yu, Y. 2022. Do climate technology, financialization, and sustainable finance impede environmental challenges? Evidence from G10 economies. Technol. Forecast. Soc. 185, 122095. https://doi.org/10.1016/j.techfore.2022.122095

Li, Y., Yu, C., Shi, J., Liu, Y. 2023. How does green bond issuance affect total factor productivity? Evidence from Chinese listed enterprises. Energ. Econ. 123. https://doi.org/10.1016/j.eneco.2023.106755

Lin, B., Su, T. 2022. Green bond vs conventional bond: Outline the rationale behind issuance choices in China. Int. Rev. Financ. Anal. 81, 102063. https://doi.org/10.1016/j.irfa.2022.102063

Liu, F., Qin, C., Qin, M., Stefea, P., Norena-Chavez, D. 2024. Geopolitical risk: An opportunity or a threat to the green bond market? Energ. Econ. 131. https://doi.org/10.1016/j.eneco.2024.107391

Liu, F.H.M., Lai, K.P.Y. 2021. Ecologies of green finance: Green sukuk and development of green Islamic finance in Malaysia. Environ. Plann. A. 53 (8), 1896–1914. https://doi.org/10.1177/0308518x211038349

Long, S., Tian, H., Li, Z. 2022. Dynamic spillovers between uncertainties and green bond markets in the US, Europe, and China: Evidence from the quantile VAR framework. Int. Rev. Financ. Anal. 84, 102416. https://doi.org/10.1016/j.irfa.2022.102416

Lu, X., Huang, N., Mo, J., Ye, Z. 2023. Dynamics of the return and volatility connectedness among green finance markets during the COVID-19 pandemic. Energ. Econ. 125. https://doi.org/10.1016/j.eneco.2023.106860

Lyon, T.P., Maxwell, J.W. 2011. Greenwash: Corporate environmental disclosure under threat of audit. J. Econ. Manage. Strat. 20 (1), 3–41. https://doi.org/10.1111/j.1530-9134.2010.00282.x
Lyon, T.P., Montgomery, A.W. 2015. The means and end of greenwash. Organ. Environ. 28 (2), 223–249. https://doi.org/10.1177/1086026615575332
Ma, D., Zhang, Y., Ji, Q., Zhao, W.L., Zhai, P. 2024. Heterogeneous impacts of climate change news on China's financial markets. Int. Rev. Financ. Anal. 91. https://doi.org/10.1016/j.irfa.2023.103007
Mahmood, F., Ben Zaied, Y., Abedin, M.Z. 2024. Role of green finance instruments in shaping economic cycles. Technol. Forecast. Soc. 209. https://doi.org/10.1016/j.techfore.2024.123792
Martimort, D., Pouyet, J. 2008. To build or not to build: Normative and positive theories of public–private partnerships. Int. J. Ind. Organ. 26 (2), 393–411. https://doi.org/10.1016/j.ijindorg.2006.10.004
Mensi, W., Rehman, M.U., Vo, X.V. 2022. Impacts of COVID-19 outbreak, macroeconomic and financial stress factors on price spillovers among green bond. Int. Rev. Financ. Anal. 81, 102125. https://doi.org/10.1016/j.irfa.2022.102125
Mertzanis, C., Tebourbi, I. 2024. Geopolitical risk and global green bond market growth. Eur. Financ. Manag. https://doi.org/10.1111/eufm.12484
Miles, M.P., Munilla, L.S. 2004. The potential impact of social accountability certification on marketing: A short note. J. Bus. Ethics 50, 1–11.
Mokni, K., Mensi, W., Hammoudeh, S., Ajmi, A.N. 2022. Green bonds and oil price shocks and uncertainty: A safe haven analysis. International Economics 172, 238–254. https://doi.org/10.1016/j.inteco.2022.11.003
Montiel, I., Christmann, P., Zink, T. 2016. The effect of sustainability standard uncertainty on certification decisions of firms in emerging economies. J. Bus. Ethics 154 (3), 667–681. https://doi.org/10.1007/s10551-016-3350-0
Naeem, M.A., Conlon, T., Cotter, J. 2022. Green bonds and other assets: Evidence from extreme risk transmission. J. Environ. Manage. 305, 114358. https://doi.org/10.1016/j.jenvman.2021.114358
Owusu-Manu, D.G., Mankata, L., Edwards, D., El-Gohary, H., Hussain, J. 2022. A cognizance of green bond features preferential to renewable energy project financing in Ghana. Ieee T. Eng. Manage., 1–12. https://doi.org/10.1109/tem.2021.3080630
Paeleman, I., Guenster, N., Vanacker, T., Siqueira, A.C.O. 2024. The consequences of financial leverage: Certified B corporations' advantages compared to common commercial firms. J. Bus. Ethics, 1–17. https://doi.org/10.1007/s10551-023-05349-5
Parmar, B.L., Freeman, R.E., Harrison, J.S., Wicks, A.C., Purnell, L., De Colle, S. 2010. Stakeholder theory: The state of the art. Academy of Management Annals 4 (1), 403–445. https://doi.org/10.5465/19416520.2010.495581
Pástor, Ľ., Stambaugh, R.F., Taylor, L.A. 2022. Dissecting green returns. J. Financ. Econ. 146 (2), 403–424. https://doi.org/10.1016/j.jfineco.2022.07.007
Pham, L. 2021. Frequency connectedness and cross-quantile dependence between green bond and green equity markets. Energ. Econ. 98, 105257. https://doi.org/10.1016/j.eneco.2021.105257
Pham, L., Do, H.X. 2022. Green bonds and implied volatilities: Dynamic causality, spillovers, and implications for portfolio management. Energ. Econ. 112, 106106. https://doi.org/10.1016/j.eneco.2022.106106
Pham, L., Huynh, T.L.D. 2020. How does investor attention influence the green bond market? Financ. Res. Lett. 35. https://doi.org/10.1016/j.frl.2020.101533

Piñeiro-Chousa, J., López-Cabarcos, M.Á., Šević, A. 2022. Green bond market and sentiment: Is there a switching behaviour. J. Bus. Res. 141, 520–527. https://doi.org/10.1016/j.jbusres.2021.11.048
Raghunandan, A., Rajgopal, S. 2022. Do ESG funds make stakeholder-friendly investments? Review of Accounting Studies 27, 822–863. https://doi.org/10.1007/s11142-022-09693-1
Rannou, Y., Boutabba, M.A., Barneto, P. 2021. Are green bond and carbon markets in Europe complements or substitutes? Insights from the activity of power firms. Energ. Econ. 104, 105651. https://doi.org/10.1016/j.eneco.2021.105651
Raza, S.A., Khan, K.A., Benkraiem, R., Guesmi, K. 2024. The importance of climate policy uncertainty in forecasting the green, clean and sustainable financial markets volatility. Int. Rev. Financ. Anal. 91. https://doi.org/10.1016/j.irfa.2023.102984
Ready, R.C. 2018. Oil prices and the stock market. Rev. Financ. 22 (1), 155–176. https://doi.org/10.1093/rof/rfw071
Reboredo, J.C. 2018. Green bond and financial markets: Co-movement, diversification and price spillover effects. Energ. Econ. 74, 38–50. https://doi.org/10.1016/j.eneco.2018.05.030
Reboredo, J.C., Ugolini, A., Aiube, F.A.L. 2020. Network connectedness of green bonds and asset classes. Energ. Econ. 86, 104629. https://doi.org/10.1016/j.eneco.2019.104629
Rehman, M.U., Raheem, I.D., Zeitun, R., Vo, X.V., Ahmad, N. 2023. Do oil shocks affect the green bond market? Energ. Econ. 117. https://doi.org/10.1016/j.eneco.2022.106429
Ren, X., Li, Y., Yan, C., Wen, F., Lu, Z. 2022. The interrelationship between the carbon market and the green bonds market: Evidence from wavelet quantile-on-quantile method. Technol. Forecast. Soc. 179, 121611. https://doi.org/10.1016/j.techfore.2022.121611
Ren, X., Xiao, Y., He, F., Gozgor, G. 2024. The contagion of extreme risks between fossil and green energy markets: evidence from China. Quant. Financ. 24 (5), 627–642. https://doi.org/10.1080/14697688.2024.2339374
Riley, J.G. 1979. Informational equilibrium. Econometrica 47 (2).
Rizvi, S.K.A., Naqvi, B., Mirza, N., Umar, M. 2022. Safe haven properties of green, Islamic, and crypto assets and investor's proclivity towards treasury and gold. Energ. Econ. 115, 106396. https://doi.org/10.1016/j.eneco.2022.106396
Russo, A., Mariani, M., Caragnano, A. 2020. Exploring the determinants of green bond issuance: Going beyond the long-lasting debate on performance consequences. Bus. Strat. En. 30 (1), 38–59. https://doi.org/10.1002/bse.2608
Saeed, T., Bouri, E., Alsulami, H. 2021. Extreme return connectedness and its determinants between clean/green and dirty energy investments. Energ. Econ. 96, 105017. https://doi.org/10.1016/j.eneco.2020.105017
Sangiorgi, I., Schopohl, L. 2021. Why do institutional investors buy green bonds: Evidence from a survey of European asset managers. Int. Rev. Financ. Anal. 75, 101738. https://doi.org/10.1016/j.irfa.2021.101738
Sangiorgi, I., Schopohl, L. 2023. Explaining green bond issuance using survey evidence: Beyond the greenium. Brit. Account. Rev. 55 (1). https://doi.org/10.1016/j.bar.2021.101071
Sharif, A., Aloui, C., Yarovaya, L. 2020. COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: Fresh evidence from the wavelet-based approach. Int. Rev. Financ. Anal. 70, 101496. https://doi.org/10.1016/j.irfa.2020.101496
Shi, X., Ma, J., Jiang, A., Wei, S., Yue, L. 2023. Green bonds: Green investments or greenwashing? Int. Rev. Financ. Anal. 90. https://doi.org/10.1016/j.irfa.2023.102850

Singhania, M., Chadha, G., Prasad, R. 2023. Sustainable finance research: Review and agenda. Int. J. Financ. Econ., 1–36. https://doi.org/10.1002/ijfe.2854

Sinha, A., Mishra, S., Sharif, A., Yarovaya, L. 2021. Does green financing help to improve environmental & social responsibility? Designing SDG framework through advanced quantile modelling. J. Environ. Manage. 292, 112751. https://doi.org/10.1016/j.jenvman.2021.112751

Sohag, K., Hammoudeh, S., Elsayed, A.H., Mariev, O., Safonova, Y. 2022. Do geopolitical events transmit opportunity or threat to green markets? Decomposed measures of geopolitical risks. Energ. Econ. 111, 106068. https://doi.org/10.1016/j.eneco.2022.106068

Sohag, K., Hassan, M.K., Bakhteyev, S., Mariev, O. 2023. Do green and dirty investments hedge each other? Energ. Econ. 120, 106573. https://doi.org/10.1016/j.eneco.2023.106573

Su, T., Zhang, Z., Lin, B. 2022. Green bonds and conventional financial markets in China: A tale of three transmission modes. Energ. Econ. 113, 106200. https://doi.org/10.1016/j.eneco.2022.106200

Su, Y.H., Rizvi, S.K.A., Umar, M., Chang, H. 2023. Unveiling the relationship between oil and green bonds: Spillover dynamics and implications. Energ. Econ. 127. https://doi.org/10.1016/j.eneco.2023.107043

Suroso, D.S.A., Setiawan, B., Pradono, P., Iskandar, Z.S., Hastari, M.A. 2022. Revisiting the role of international climate finance (ICF) towards achieving the nationally determined contribution (NDC) target: A case study of the Indonesian energy sector. Environ. Sci. Policy 131, 188–195. https://doi.org/10.1016/j.envsci.2022.01.022

Tang, D.Y., Zhang, Y. 2020. Do shareholders benefit from green bonds? J. Corp. Financ. 61, 101427. https://doi.org/10.1016/j.jcorpfin.2018.12.001

Tang, Y., Chen, X.H., Sarker, P.K., Baroudi, S. 2023. Asymmetric effects of geopolitical risks and uncertainties on green bond markets. Technol. Forecast. Soc. 189, 122348. https://doi.org/10.1016/j.techfore.2023.122348

Tao, H., Zhuang, S., Xue, R., Cao, W., Tian, J., Shan, Y. 2022. Environmental finance: An interdisciplinary review. Technol. Forecast. Soc. 179. https://doi.org/10.1016/j.techfore.2022.121639

Tiwari, A.K., Abakah, E.J.A., Shao, X., Le, T.N.L., Gyamfi, M.N. 2023. Financial technology stocks, green financial assets, and energy markets: A quantile causality and dependence analysis. Energ. Econ. 118. https://doi.org/10.1016/j.eneco.2022.106498

Tolliver, C., Keeley, A.R., Managi, S. 2020. Policy targets behind green bonds for renewable energy: Do climate commitments matter? Technol. Forecast. Soc. 157. https://doi.org/10.1016/j.techfore.2020.120051

Torrence, C., Compo, G.P. 1998. A practical guide to wavelet analysis. B. Am. Meteorol. Soc. 79 (1), 61–78. https://doi.org/10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2

Torrence, C., Webster, P.J. 1999. Interdecadal changes in the ENSO–monsoon system. J. Climate 12 (8), 2679–2690. https://doi.org/10.1175/1520-0442(1999)012<2679:ICITEM>2.0.CO;2

Tranfield, D., Denyer, D., Smart, P. 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Brit. J. Manage. 14 (3), 207–222. https://doi.org/10.1111/1467-8551.00375

Umar, Z., Abrar, A., Hadhri, S., Sokolova, T. 2023. The connectedness of oil shocks, green bonds, sukuks and conventional bonds. Energ. Econ. https://doi.org/10.1016/j.eneco.2023.106562

Wang, C.W., Wu, Y.C., Hsieh, H.Y., Huang, P.H., Lin, M.C. 2022. Does green bond issuance have an impact on climate risk concerns? Energ. Econ. 111, 106066. https://doi.org/10.1016/j.eneco.2022.106066

Wang, K.H., Wang, Z.S., Yunis, M., Kchouri, B. 2023. Spillovers and connectedness among climate policy uncertainty, energy, green bond and carbon markets: A global perspective. Energ. Econ. 128. https://doi.org/10.1016/j.eneco.2023.107170

Wang, X., Li, J., Ren, X. 2022. Asymmetric causality of economic policy uncertainty and oil volatility index on time-varying nexus of the clean energy, carbon and green bond. Int. Rev. Financ. Anal. 83, 102306. https://doi.org/10.1016/j.irfa.2022.102306

Wang, Y., Taghizadeh-Hesary, F. 2023. Green bonds markets and renewable energy development: Policy integration for achieving carbon neutrality. Energ. Econ. 123, 106725. https://doi.org/10.1016/j.eneco.2023.106725

Wei, P., Qi, Y., Ren, X., Gozgor, G. 2023. The role of the COVID-19 pandemic in time-frequency connectedness between oil market shocks and green bond markets: Evidence from the wavelet-based quantile approaches. Energ. Econ. 121, 106657. https://doi.org/10.1016/j.eneco.2023.106657

Xi, Y., Zeng, Q., Lu, X., Huynh, T.L.D. 2022. Oil and renewable energy stock markets: Unique role of extreme shocks. Energ. Econ. 109, 105995. https://doi.org/10.1016/j.eneco.2022.105995

Xu, Y., Han, L., Wan, L., Yin, L. 2019. Dynamic link between oil prices and exchange rates: A non-linear approach. Energ. Econ. 84, 104488. https://doi.org/10.1016/j.eneco.2019.104488

Yousaf, I., Suleman, M.T., Demirer, R. 2022. Green investments: A luxury good or a financial necessity? Energ. Econ. 105, 105745. https://doi.org/10.1016/j.eneco.2021.105745

Yu, Q., Hui, E.C.M., Shen, J. 2024. The real impacts of third-party certification on green bond issuances: Evidence from the Chinese green bond market. J. Corp. Financ. 89. https://doi.org/10.1016/j.jcorpfin.2024.102694

Zeng, H., Abedin, M.Z., Lucey, B., Ma, S. 2025. Tail risk contagion and multiscale spillovers in the green finance index and large US technology stocks. Int. Rev. Financ. Anal. 97. https://doi.org/10.1016/j.irfa.2024.103865

Zerbib, O.D. 2019. The effect of pro-environmental preferences on bond prices: Evidence from green bonds. J. Bank. Financ. 98, 39–60. https://doi.org/10.1016/j.jbankfin.2018.10.012

Zhang, D., Chen, X.H., Lau, C.K.M., Cai, Y. 2023. The causal relationship between green finance and geopolitical risk: Implications for environmental management. J. Environ. Manage. 327, 116949. https://doi.org/10.1016/j.jenvman.2022.116949

Zhang, W., He, X., Hamori, S. 2022. Volatility spillover and investment strategies among sustainability-related financial indexes: Evidence from the DCC-GARCH-based dynamic connectedness and DCC-GARCH t-copula approach. Int. Rev. Financ. Anal. 83, 102223. https://doi.org/10.1016/j.irfa.2022.102223

Zhang, Y., Tavalaei, M.M., Parry, G., Zhou, P. 2024. Evolution or involution? A systematic literature review of organisations' blockchain adoption factors. Technol. Forecast. Soc. 208. https://doi.org/10.1016/j.techfore.2024.123710

Zhou, P., Gai, Y., Wang, C. 2025. Determination of urban land value: A systematic literature review. Journal of Accounting Literature. https://doi.org/10.1108/jal-10-2024-0272

Zhou, P., Jin, S., Mazouz, K., Ding, W. 2025. Choices and effects of different green labels in the EU bond market. J. Bus. Ethics 200. https://doi.org/10.1007/s10551-024-05847-0

# Appendix

**Table A 3.1.** Key literature on the connectedness between green bonds and different assets.

**Panel (a).** Key literature on the connectedness between green bonds and non-energy assets.

| Theme | Market | Article | Data |
|---|---|---|---|
| equity | US | Yousaf et al. (2022) | S&P 500 Index |
| | US; EU | Reboredo et al. (2020) | MSCI USA Price Return USD Index<br>MSCI Europe Index |
| | US; China | Guo and Zhou (2021) | Dow Jones Index<br>Shanghai Security Exchange Composite Index |
| | US; EU; China | Long et al. (2022) | CBOE Volatility Index |
| | China | Su et al. (2022) | MSCI China index<br>Shanghai Composite Index |
| | Global | Reboredo (2018) | MSCI World Index |
| | | Chai et al. (2022) | MSCI ACWI Index |
| | | Elsayed et al. (2022) | MSCI World Index |
| | | Pham and Do (2022) | US VIX Index<br>EU VSTOXX Index<br>China VXFXI Index<br>Emerging Markets VXXEM Index |
| | | Zhang et al. (2022) | MSCI World ESG Leaders Index<br>NEX WilderHill New Energy Global Innovation Index<br>SPGB S&P Green Bond Index Total Return<br>DJS Dow Jones Sustainability World Composite |
| | | Sohag et al. (2023) | Green Equity Index<br>Oil Equity Index |
| green equity | Global | Pham (2021) | NASDAQ OMX Clean Energy Focused Index<br>NASDAQ OMX Green Building Index<br>NASDAQ OMX Green Transportation Index<br>NASDAQ OMX Global Water Index |
| | | Lu et al. (2023) | S&P Global 1200 ESG Index<br>S&P Global 1200 Carbon Efficient Index<br>S&P Global 1200 Fossil Fuel Free Index |
| bond | US | Hammoudeh et al. (2020) | US 10-year Treasury Bond Index |
| | | Abakah, Tiwari, Ghosh, et al. (2023) | S&P US Treasury Bond Index |
| | US; EU | Reboredo et al. (2020) | Bloomberg Barclays US Treasury Total Return Index<br>Bloomberg Barclays US Corporate Total Return Value Index<br>Bloomberg Barclays US Corporate High Yield Total Return Index<br>Bloomberg Barclays Euro Aggregate Treasury Total Return Index<br>Bloomberg Barclays Euro Aggregate Corporate Total Return Index<br>Bloomberg Barclays Pan-European High Yield Total Return Index |
| | | Han and Li (2022) | Bloomberg Barclays US Aggregate Total Return Index<br>Barclays Euro Aggregate Total Return Index |
| | US; China | Guo and Zhou (2021) | 10-year US Government Bond Index<br>10-year Chinese Government Bond Index |
| | China | Su et al. (2022) | China Bond Treasury Bond Index<br>China Bond Corporate Bond Index |
| | Global | Elsayed et al. (2022) | Bloomberg Barclays Global Treasury Index<br>Bloomberg Barclays Global Corporate Index |
| | | Reboredo (2018) | Barclays Global Aggregate Corporate Index<br>Bloomberg Barclays Global Treasury Total Return Index |
| | | Rizvi et al. (2022) | USD 5-Year Treasury Yield |
| | | Abakah, Tiwari, Ghosh, et al. (2023) | S&P 500 Composite Price Index<br>Dow Jones Islamic Market World Index |
| | | Billah et al. (2023) | 15 Sukuk markets |
| green bond | Global | Long et al. (2022) | Bloomberg US Green Bond Index<br>Bloomberg European Green Bond Index<br>China Bond Green Bond Index |
| | | Mensi et al. (2022) | Green Building<br>Green Industrial<br>Green Financial<br>Green Utility |
| gold | Global | Rizvi et al. (2022) | Philadelphia SE Gold Silver Index |
| | | Yousaf et al. (2022) | S&P GSCI Gold Spot Price Index |

**Table A 3.1.** Key literature on the connectedness between green bonds and different assets (continued).

**Panel (b).** Key literature on the connectedness between green bonds and energy assets.

| Theme | Market | Article | Data |
|---|---|---|---|
| carbon emission trade | US | Hammoudeh et al. (2020) | CO2 emission allowances |
| | EU | Rannou et al. (2021) | EUA Futures Contract |
| | | Ren et al. (2022) | ECX EUA carbon futures |
| | China | Dai et al. (2023) | high-carbon-emission stocks |
| | Global | Jin et al. (2020) | EUA Futures Contract |
| | | Leitao et al. (2021) | EUA Futures Contract |
| | | Ren et al. (2022) | EUA Futures Contract |
| | | Wang, Li, et al. (2022) | S&P GSCI Carbon Emission Allowances |
| | | Wang et al. (2023) | ICE EUA future price |
| | | Zhang et al. (2022) | Carbon Emissions Futures |
| oil | US; EU; China | Long et al. (2022) | CBOE Crude Oil ETF Volatility Index |
| | US; China | Guo and Zhou (2021) | West Texas Intermediate Crude Oil Index<br>Brent Crude Oil |
| | | Dai et al. (2023) | West Texas Intermediate Crude Oil Index |
| | China | Ren et al. (2024) | South China Sea crude oil spot<br>steam coal futures |
| | Global | Saeed et al. (2021) | Crude oil prices |
| | | Pham and Do (2022) | Brent Crude Oil |
| | | Wang, Li, et al. (2022) | CBOE Crude Oil ETF Volatility Index |
| | | Wang et al. (2023) | Newcastle coal future price<br>Average of WTI, Brent, and Dubai crude oil future prices |
| | | Rehman et al. (2023) | World Integrated Oil and Gas Producer Index |
| | | Umar et al. (2023) | World Integrated Oil and Gas Producer Index |
| | | Wei et al. (2023) | NYMEX Oil Futures Contract |
| energy | US; EU | Reboredo et al. (2020) | Thomson Reuters United States Energy Index<br>Thomson Reuters Europe Energy Index |
| | Global | Reboredo (2018) | S&P GSCI Energy Spot CME Index |
| | | Saeed et al. (2021) | iShares U.S. Oil & Gas Exploration & Production ETF |
| | | Elsayed et al. (2022) | MSCI World Energy Price Index |
| | | Pham and Do (2022) | Energy VXXLE Index |
| clean energy | US | Hammoudeh et al. (2020) | WilderHill's Clean Energy Price Index |
| | China | Ren et al. (2024) | New energy index<br>Green investment index<br>Green power index |
| | Global | Saeed et al. (2021) | WilderHill's Clean Energy Price Index |
| | | Chai et al. (2022) | S&P Global Clean Energy Index |
| | | Wang, Li, et al. (2022) | S&P Global Clean Energy Index |
| | | Abakah, Tiwari, Ghosh, et al. (2023) | S&P Global Clean Energy Index |
| | | Arfaoui et al. (2023) | S&P Global Clean Energy Index |
| | | Lu et al. (2023) | S&P Global Clean Energy Index |
| gas | China | Ren et al. (2024) | Natural Gas Index |
| | Global | Abakah, Tiwari, Adekoya, et al. (2023) | Shale Gas Price Index<br>Henry Hub Natural Gas Price Index |
| | | Wang et al. (2023) | Average of the European Union and the US Henry Hub natural gas future prices |

**Table A 3.1.** Key literature on the connectedness between green bonds and different assets (continued).

**Panel (c).** Key literature on the connectedness between green bonds and emerging indices.

| **Theme** | **Market** | **Article** | **Data** |
|---|---|---|---|
| crypto-currency | Global; US; EU | Khalfaoui et al. (2023) | Bitcoin; Ethereum; Litecoin; Ripple |
| | Global | Huynh et al. (2020) | Bitcoin |
| | | Le et al. (2021) | Bitcoin |
| | | Rizvi et al. (2022) | Bitwise 10 Large Cap Crypto Index |
| | | Abakah, Tiwari, Ghosh, et al. (2023) | Bitcoin |
| | | Arfaoui et al. (2023) | Bitcoin; Cardano; Ethereum; Ripple |
| AI robotics | Global | Huynh et al. (2020) | NASDAQ Artificial Intelligence Index |
| | | Abakah, Tiwari, Ghosh, et al. (2023) | NASDAQ CTA Artificial Intelligence and Robotics Index |
| FinTech | Global | Le et al. (2021) | KBW NASDAQ Technology Index |
| | | Abakah, Tiwari, Ghosh, et al. (2023) | KBW NASDAQ Technology Index |
| | | Tiwari et al. (2023) | KBW NASDAQ Technology Index |
| Forex | US; China | Guo and Zhou (2021) | US Dollar Index<br>returns of the USD/CNY exchange rate |
| commodity | Global | Pham and Do (2022) | Gold GVZ Index<br>Silver VXSLV Index |
| | | Cepni et al. (2022)<br>Cepni et al. (2023) | Physical Risk Index<br>Transition Risk Index |
| climate risk | US | Bouri et al. (2023) | Physical Risk Index<br>Transition Risk Index |
| | EU | Ma et al. (2024) | Climate change news indexes |
| | Global | Tang et al. (2023) | US Economic Policy Uncertainty Index<br>Geopolitical Threats Index<br>Geopolitical Acts Index |
| political uncertainty | US | Li, Li, et al. (2023) | China Economic Policy Uncertainty Index |
| | China | Sohag et al. (2022) | Geopolitical Risk Index<br>Geopolitical Threats Index<br>Geopolitical Acts Index<br>Geopolitical Risks Broad Index |
| | Global | Wang, Li, et al. (2022) | US Economic Policy Uncertainty Index |
| | | Wang et al. (2023) | Climate Policy Uncertainty Index |
| | | Zhang et al. (2023) | Geopolitical Risk Index |
| | | Raza et al. (2024) | Climate Policy Uncertainty Index |
| | | Adekoya et al. (2021) | S&P 500 Bond Price Index |
| investor sentiment | US | Piñeiro-Chousa et al. (2022) | Twitter sentiment |

**Table A 3.2.** Key literature on corporate finance topics on green bonds.

| Theme | Market | Article | Data |
|---|---|---|---|
| issuance | China | Lin and Su (2022); | Green Bonds Issuance (0 or 1) |
| | | Wang, Wu, et al. (2022); | Climate Risk Concerns in Ratios;<br>Ratios of Climate Risks |
| | | García et al. (2023) | The Likelihood of Green Bonds Issuance |
| | Global | Barua and Chiesa (2019); | Amount Issued |
| | | Azhgaliyeva et al. (2022); | Green Bonds Issuance (0 or 1);<br>Market Share of Green Bond |
| | | Cheng et al. (2023) | Green Bonds Issuance (0 or 1);<br>Conventional bonds Issuance (0 or 1) |
| | | Sangiorgi and Schopohl (2023) | survey of green bond issuers |
| yield | US | Baker et al. (2022) | Offering Yield |
| | EU | Agliardi and Agliardi (2021); | Green Bonds Premium (based on daily yield) |
| | | Agliardi and Agliardi (2021) | |
| | | Gigante and Manglaviti (2022) | Offering Yield |
| | German | Pástor et al. (2022) | Daily Yield |
| | Global | Zerbib (2019); | Green Bonds Premium (based on daily yield) |
| | | Kanamura (2020); | Green Bonds Premium (based on daily yield) |
| | | Larcker and Watts (2020); | Green Bonds Premium (based on offering yield) |
| | | Russo et al. (2020); | Green Bonds Performance |
| | | Tang and Zhang (2020); | Green Bonds Premium (based on offering yield) |
| | | Braga et al. (2021); | Daily Yield;<br>Beta Price |
| | | Fatica et al. (2021); | Offering Yield |
| | | Flammer (2021); | Offering Yield |
| liquidity | EU | Boutabba and Rannou (2022) | Liquidity Premium |
| investor behaviour | US | Baker et al. (2022) | Herfindahl-Hirschman Index of ownership concentration |
| | Global | Larcker and Watts (2020); | Herfindahl-Hirschman Index of ownership concentration;<br>Institutional Ownership |
| | | Tang and Zhang (2020); | Cumulative Abnormal Return;<br>Institutional Ownership;<br>Stock Liquidity |
| | | Flammer (2021); | Cumulative Abnormal Return;<br>Institutional Ownership;<br>State-level Green Preference |
| | | Sangiorgi and Schopohl (2021) | Green Bonds Investment Activities |

**Table A 3.3.** Key literature on the environmental effects of green bonds.

| Theme | Market | Article | Data |
|---|---|---|---|
| sustainability | US; Russian Federation; China | Jia (2023) | political steps and initiatives taken in the field of green finance, and initiatives of international actors in the field of decarbonization |
| | OECD countries | Wang and Taghizadeh-Hesary (2023) | Wind Energy; Solar Energy; Hydro Energy |
| | G10 countries | Li et al. (2022) | $CO_2$ Emissions; |
| | China | Li, Yu, et al. (2023) | total factor productivity |
| | | Shi et al. (2023) | number of green patents |
| | Indonesia | Suroso et al. (2022) | nationally determined contribution target |
| | Malaysia | Liu and Lai (2021) | policy documents, non-governmental organization publications, corporate reports, and interviews |
| | Global | Fatica and Panzica (2021); | Total Greenhouse Gas Emissions; Direct (Scope 1) Emissions |
| | | Flammer (2021); | $CO_2$ Emissions; Environment Rating |
| | | Benlemlih et al. (2023); | Resource Use Grade; Environmental Innovation Grade; $CO_2$ Emission Grade; $CO_2$ Intensity |
| | | Chang et al. (2022); | Environmental quality; Ecological Footprint |
| | | Alharbi et al. (2023); | net generation of renewable energy from biomass and non-biomass sources |
| | | Bedendo et al. (2023) | bank environmental footprint |
| | | García et al. (2023) | Environmental Pillar Score; Emission Score; Resource Use Score; Environmental Innovation Score; CO2 emissions relative to total sales |
| policy | Mexico | Hilbrandt and Grubbauer (2020) | Regulatory Shifts |
| | Global | Tolliver et al. (2020) | Nationally Determined Contributions Index |
| | China | Lee et al. (2023) | Green Bonds Policy |

**Table A 3.4.** ICMA and CBI requirements on green bonds.

**Panel A:** Prior-issuance requirement of ICMA and CBI

| Stage | Documents | | ICMA | CBI |
|---|---|---|---|---|
| pre-issuance | green bond framework | use of proceeds | In the event that all or a proportion of the proceeds are or may be used for refinancing, it is recommended that issuers provide an estimate of the share of financing vs. re-financing, and where appropriate, also clarify which investments or project portfolios may be refinanced, and, to the extent relevant, the expected look-back period for refinanced eligible Green Projects. | The Issuer shall document the Nominated Projects & Assets which are proposed to be associated with the Bond and which have been assessed as likely to be Eligible Projects & Assets. The Issuer shall establish a list of Nominated Projects & Assets that can be kept up-to-date during the term of the Bond.<br>The expected Net Proceeds of the Bond shall be no greater than the Issuer's total investment exposure to the proposed Nominated Projects & Assets, or the relevant proportion of the total Market Value of the proposed Nominated Projects & Assets that are owned or funded by the Issuer. |
| | | process for project evaluation and selection | The issuer of a Green Bond should clearly communicate to investors:<br>1. The environmental sustainability objectives of the eligible Green Projects;<br>2. The process by which the issuer determines how the projects fit within the eligible Green Projects categories (examples are identified above); and<br>3. Complementary information on processes by which the issuer identifies and manages perceived social and environmental risks associated with the relevant project(s). | The issuer shall establish, document, and maintain a decision-making process that it uses to determine the eligibility of the Nominated Projects & Assets. The decision-making process shall include, without limitation:<br>1. A statement on the climate-related objectives of the Bond;<br>2. How the climate-related objectives of the Bond are positioned within the context of the Issuer's overarching objectives, strategy, policy, and/or processes relating to environmental sustainability;<br>3. The Issuer's rationale for issuing the Bond;<br>4. A process to determine whether the Nominated Projects & Assets meet the eligibility requirements specified in the Climate Bonds Standard. |
| | | management of proceeds | The net proceeds of the Green Bond (GBP), or an amount equal to these net proceeds, should be credited to a sub-account, moved to a sub-portfolio or otherwise tracked by the issuer in an appropriate manner, and attested to by the issuer in a formal internal process linked to the issuer's lending and investment operations for eligible Green Projects.<br>So long as the Green Bond is outstanding, the balance of the tracked net proceeds should be periodically adjusted to match allocations to eligible Green Projects made during that period. The issuer should make known to investors the intended types of temporary placement for the balance of unallocated net proceeds.<br>The Green Bond Principles encourage a high level of transparency and recommend that an issuer's management of proceeds be supplemented by the use of an external auditor, or other third parties, to verify the internal tracking method and the allocation of funds from the Green Bond proceeds. | The systems, policies, and processes to be used for management of the Net Proceeds shall be documented by the Issuer and disclosed to the Verifier, and shall include arrangements for the following activities:<br>1. Tracking of Proceeds: The Net Proceeds of the Bond can be credited to a sub-account, moved to a sub-portfolio, or otherwise tracked by the Issuer in an appropriate manner and documented.<br>2. Managing unallocated proceeds: The balance of unallocated Net Proceeds can be managed as per the requirements in Clause 7.3.<br>3. Earmarking funds to Nominated Projects & Assets: An earmarking process can be used to manage and account for funding to the Nominated Projects & Assets and enables estimation of the share of the Net Proceeds being used for |
| | | reporting | Issuers should make, and keep, readily available up-to-date information on the use of proceeds to be renewed annually until full allocation, and on a timely basis in case of material developments. | The Issuer shall prepare a Green Bond Framework and make it publicly available prior to Issuance or at the time of Issuance.<br>The Issuer shall prepare an Update Report at least annually while the Bond remains outstanding. |

**Table A 3.4.** ICMA and CBI requirements on green bonds (continued).

**Panel B:** Post-issuance requirement from ICMA and CBI

| Stage | Documents | ICMA | CBI |
|---|---|---|---|
| post-issuance | asset allocation report | The annual report should include a list of the projects to which Green Bond proceeds have been allocated, as well as a brief description of the projects, the amounts allocated, and their expected impact. Where confidentiality agreements, competitive considerations, or a large number of underlying projects limit the amount of detail that can be made available, the Green Bond Principles (GBP) recommends that information be presented in generic terms or on an aggregated portfolio basis. | The Allocation Reporting shall include, without limitation:<br>1. Confirmation that the Bonds issued under the Green Bond Framework are aligned with the Climate Bonds Standard. This may include statements of alignment with other applicable standards;<br>2. A statement on the climate-related objectives of the Bond;<br>3. The list of Nominated Projects & Assets to which Net Proceeds have been allocated (or re-allocated);<br>4. The amounts allocated to the Nominated Projects & Assets;<br>5. An estimate of the share of the Net Proceeds used for financing and refinancing, and which Nominated Projects & Assets have been refinanced.<br>6. The geographical distribution of the Nominated Projects & Assets. |
| | impact report | Transparency is of particular value in communicating the expected and/or achieved impact of projects. The GBP recommends the use of qualitative performance indicators and, where feasible, quantitative performance measures and disclosure of the key underlying methodology and/or assumptions used in the quantitative determination. Issuers should refer to and adopt, where possible, the guidance and impact reporting templates provided in the Harmonized Framework for Impact Reporting. | The Impact Reporting shall, without limitation:<br>1. Provide the expected or actual outcomes or impacts of the Nominated Projects & Assets with respect to the climate-related objectives of the Bond;<br>2. Use qualitative performance indicators and, where feasible, quantitative performance measures of the outcomes or impacts of the Nominated Projects & Assets with respect to the climate-related objectives of the Bond;<br>3. Provide the methods and the key underlying assumptions used in the preparation of the performance indicators and metrics. |
| | eligibility report | | The Eligibility Reporting shall include, without limitation:<br>1. Confirmation that the Nominated Projects & Assets continue to meet the relevant eligibility requirements specified in Part C of the Climate Bonds Standard;<br>2. Information on the environmental characteristics or performance of Nominated Projects & Assets which is prescribed by the relevant Sector Eligibility Criteria. |
| others | additional costs related to the label/certification | ICMA has varied membership fees for tier 1, 2A, 2B, and 3 members. The membership fee for tier 3 is CHF 17,500 per year for full and associate membership. (Tier 3 is basic membership: Subsidiaries of all international/regional/domestic firms, all public institutions, associate members (non-full members), and firms similar to domestic firms but with a smaller revenue base.) | A Minimum Fee of USD$2,000 (two thousand US dollars) for Issuers in developed countries and USD$1,000 (one thousand US dollars) for Issuers in developing countries will be charged by the Climate Bonds Initiative upon awarding the Certification label. Following the issuance of any certified bond (or a series of bonds in a Programmatic Certification process) a Variable fee of 1/10th of a basis point (i.e., x 0.00001) of the bond issuance amount will be calculated. (For example, on a USD$500 million bond, the certification fee is USD$5,000 [five-thousand US dollars].)<br>For Programmatic Issuers, the Minimum Fee will only apply to the first bond issued under the program; the Variable fee for each subsequent programmatic issuance will be calculated based on the aggregate issuance amounts under the program and any fees previously billed (including the Minimum fee) will be deducted from the cumulative Variable Fee. |

This table lists and compares ICMA and CBI's requirements to issuers after the issuance of green bonds.

**Table A 3.5.** Variable definitions.

| Variable Name | Description | Data Source |
|---|---|---|
| **Dependent variables:** | | |
| *Yield* | Bond daily yield from the issuance date to the end of 2022 | Bloomberg |
| *GoogleTrends* | Issuers' monthly Google search index. | GoogleTrends |
| *NewsHeat* | The monthly average of daily abnormal institutional investor attention(*AIA*). *AIA* is a dummy variable that equals 1 when the issuers' Bloomberg news heat score is 3 or 4, and 0 otherwise . | Bloomberg |
| **Control variables:** | | |
| *SDG* | The issuer located the country's overall sustainable score in the year before the bond issuance | SDG Index and Dashboards |
| *ParisAgreement* | A dummy variable equals 1 when the green bond is issued after April/2016. | |
| *GreenBond* | A dummy variable equals 1 when the bond is labelled as green. | Documents disclosed by issuers. |
| *Self-labelled* | A dummy variable equals 1 when the green bond does not follow external green bond standards. | Documents disclosed by issuers. |
| *Externally-labelled* | A dummy variable equals 1 when the green bond has a label from third parties (ICMA or/and CBI). | Documents disclosed by issuers. |
| *ICMA* | A dummy variable equals 1 when the issuer declares to follow ICMA's Green Bond Principles in disclosed documents. | Documents disclosed by issuers. |
| *CBI* | A dummy variable equals 1 when the issuer declares to follow CBI's Climate Bond Standard in disclosed documents. | Documents disclosed by issuers. |
| *Greenness* | An ordinal variable that uses 0, 1, and 2 to represent conventional bonds, self-label green bonds, and externally-labelled green bonds, respectively. | |
| *FirstGreen* | A dummy variable equals 1 when it is the issuer's first time issuing green bonds. | Refinitiv |
| *Amount ($million)* | The total dollar amounts outstanding of the bond at issuance. | Refinitiv |
| *Coupon* | Annualized coupon rate of the bond (measured in %). | Refinitiv |
| *Yrs2Maturity* | Years to maturity since bond issuance. | Refinitiv |
| *Puttable* | A dummy variable equals 1 when the bond has a put option. | Refinitiv |
| *Callable* | A dummy variable equals 1 when the bond has a call option. | Refinitiv |
| *Financials* | A dummy variable equals 1 when the issuer belongs to the financial sector defined by the Refinitiv Business Classification Sector. | Refinitiv |
| *BrownIssuer* | A dummy variable equals 1 when the issuer belongs to high-emission sectors (e.g., Oil and Gas, Transportation, Utilities). | Refinitiv |
| *Listed* | A dummy variable equals 1 when the issuer is a listed company. | Refinitiv |
| *CleanTransport* | A dummy variable equals 1 when bond proceeds are financed from green projects in clean transport. | Refinitiv |
| *IssuePrice* | Bond first-day price. | Refinitiv |
| *YieldIssue* | First-day yield estimated by issue price and annualized coupon rate. | Refinitiv |
| *RatingScale* | An ordinal variable based on Moody's rating ranging from 1 to 20, with the lower value indicating higher Moody's rating. | Refinitiv |
| *BA_Spread* | Bond daily bid-ask spread. | Bloomberg |
| *DefaultProbability* | Issuers' default probability in the next 5 years | Bloomberg |
| *HigherDefaultProbability* | A dummy variable equals 1 when the issuers' default probability is higher than the average level. | |
| *MainMarket* | A dummy variable equals 1 if the issuer's location is Netherlands, Germany, Luxembourg, United Kingdom, or Hong Kong (EU green bonds issued by issuers from these five markets account for 42% of total green bonds issued in the EU during 2012-2021). | |
| *InvestorSentiment* | The categorized value of Sentix Economic Indices: Euro Aggregate Overall Index | Bloomberg |
| *ECB_PolicyRate* | European Central Bank's interest rate on the main refinancing operations. | European Central Bank |
| *Inflation* | The categorized value of the EU inflation rate. | Eurostat |

This table provides a detailed description and data source for test variables in this paper.

**Table A 3.6.** Use of bond proceeds.

| **Use of Proceeds** | **Freq.** | **Percent** |
|---|---|---|
| **Panel A:** Green bonds | | |
| Clean Transport | **377** | **34.88** |
| Energy Efficiency | 248 | 22.94 |
| Eligible Green Projects | 106 | 9.81 |
| Climate Change Adaptation | 94 | 8.7 |
| Green Construction/Buildings | 75 | 6.94 |
| Renewable Energy Projects | 44 | 4.07 |
| Circular Economy Adapted/Eco-efficient Products, Production Technologies/Processes | 27 | 2.5 |
| General Purpose | 23 | 2.13 |
| Aquatic Biodiversity Conservation | 17 | 1.57 |
| Alternative Energy | 16 | 1.48 |
| Sustainable Water or Wastewater management | 13 | 1.2 |
| Pollution Prevention & Control | 8 | 0.74 |
| Refinance/Financing expenses | 7 | 0.65 |
| Access to Essential Services | 5 | 0.46 |
| Carbon reduction through reforestation and avoided deforestation | 4 | 0.37 |
| The Belt and Road Initiative | 4 | 0.37 |
| Acquisition | 3 | 0.28 |
| Others | <=2 | 0.91 |
| | | |
| **Panel B:** Conventional bonds | | |
| General Purpose | 592 | 74.28 |
| Acquisition | 46 | 5.77 |
| Repay Bank Loan or Bridge Financing | 28 | 3.51 |
| Redeem Existing Bonds or Securities | 22 | 2.76 |
| Refinance/Financing expenses | 22 | 2.76 |
| China Urban Construction | 11 | 1.38 |
| Access to Essential Services | 10 | 1.25 |
| Purchase of Funding Agreement | 9 | 1.13 |
| Budgetary Purpose | 7 | 0.88 |
| General Purpose/Refinance | 6 | 0.75 |
| Climate Change Adaptation | 4 | 0.5 |
| Dividend or Distribution to Shareholders | 3 | 0.38 |
| Other Education | 3 | 0.38 |
| Pandemic | 3 | 0.38 |
| Social Housing/Affordable Housing | 3 | 0.38 |
| Tender Offer | 3 | 0.38 |
| Working capital | 3 | 0.38 |
| Others | <=2 | 2.75 |

Bond use of proceeds recorded in Refinitiv.

**Table A 3.7.** Marginal effects in issuers' label selection process.

Average marginal effects Number of obs. = 1,915,743
Model VCE: Robust
1._predict: Pr(LabelGreenness==0), predict(pr outcome(0))
2._predict: Pr(LabelGreenness==1), predict(pr outcome(1))
3._predict: Pr(LabelGreenness==2), predict(pr outcome(2))
Delta-method

| | **dy/dx** | std. err. | z | P>z | [95% conf. interval] | |
|---|---|---|---|---|---|---|
| DefaultProbability | | | | | | |
| _predict | | | | | | |
| 1 | -0.619 | 0.008 | -73.470 | 0.000 | -0.636 | -0.603 |
| 2 | **0.012** | 0.000 | 63.360 | 0.000 | 0.012 | 0.012 |
| 3 | **0.607** | 0.008 | 73.430 | 0.000 | 0.591 | 0.623 |
| CleanTransport | | | | | | |
| _predict | | | | | | |
| 1 | -0.550 | 0.001 | -628.610 | 0.000 | -0.551 | -0.548 |
| 2 | **0.011** | 0.000 | 107.780 | 0.000 | 0.011 | 0.011 |
| 3 | **0.539** | 0.001 | 658.970 | 0.000 | 0.537 | 0.540 |
| Financials | | | | | | |
| _predict | | | | | | |
| 1 | -0.099 | 0.001 | -142.290 | 0.000 | -0.101 | -0.098 |
| 2 | **0.002** | 0.000 | 95.110 | 0.000 | 0.002 | 0.002 |
| 3 | **0.097** | 0.001 | 141.970 | 0.000 | 0.096 | 0.099 |
| ParisAgreement | | | | | | |
| _predict | | | | | | |
| 1 | -0.096 | 0.001 | -99.390 | 0.000 | -0.098 | -0.094 |
| 2 | **0.002** | 0.000 | 83.830 | 0.000 | 0.002 | 0.002 |
| 3 | **0.094** | 0.001 | 99.090 | 0.000 | 0.092 | 0.096 |
| BA_Spread | | | | | | |
| _predict | | | | | | |
| 1 | -0.043 | 0.001 | -50.870 | 0.000 | -0.045 | -0.042 |
| 2 | 0.001 | 0.000 | 47.310 | 0.000 | 0.001 | 0.001 |
| 3 | 0.042 | 0.001 | 50.850 | 0.000 | 0.041 | 0.044 |
| Listed | | | | | | |
| _predict | | | | | | |
| 1 | -0.026 | 0.002 | -12.000 | 0.000 | -0.030 | -0.021 |
| 2 | 0.000 | 0.000 | 11.940 | 0.000 | 0.000 | 0.001 |
| 3 | 0.025 | 0.002 | 12.000 | 0.000 | 0.021 | 0.029 |
| Callable | | | | | | |
| _predict | | | | | | |
| 1 | 0.009 | 0.001 | 12.310 | 0.000 | 0.008 | 0.011 |
| 2 | -0.000 | 0.000 | -12.150 | 0.000 | -0.000 | -0.000 |
| 3 | -0.009 | 0.001 | -12.310 | 0.000 | -0.011 | -0.008 |
| SDG | | | | | | |
| _predict | | | | | | |
| 1 | -0.004 | 0.000 | -64.200 | 0.000 | -0.004 | -0.004 |
| 2 | 0.000 | 0.000 | 57.350 | 0.000 | 0.000 | 0.000 |
| 3 | 0.004 | 0.000 | 64.170 | 0.000 | 0.004 | 0.004 |

This table reports the marginal effects of variables in the ordered probit model (Panel A of **Table 3.7**). In which the column *dy/dx* shows each variable's marginal effects in the issuer's bond label selection process.

**Table A 3.8.** The estimation results of the outcome equation.

| Yield | (1) Green vs. conventional | (2) Self-labelled vs. conventional | (3) Externally-labelled vs. conventional | (4) Externally-labelled vs. self-labelled |
|---|---|---|---|---|
| *D* = GreenLabel | -1.988*** | | | |
| | (-3.996) | | | |
| *D* = Self-label | | -0.539 | | |
| | | (-0.551) | | |
| *D* = External-label | | | -2.123*** | -1.875** |
| | | | (-4.249) | (-2.121) |
| IMR | 1.073*** | 0.298 | 1.139*** | 0.785* |
| | (3.865) | (0.563) | (4.062) | (1.719) |
| Callable | 0.643*** | 0.601*** | 0.715*** | 0.824*** |
| | (4.427) | (2.935) | (4.986) | (3.022) |
| DefaultProbability | 21.893*** | 25.748*** | 20.545*** | 18.698*** |
| | (8.760) | (6.801) | (8.103) | (5.522) |
| BA_Spread | 2.464*** | 2.031*** | 2.466*** | 3.046*** |
| | (10.380) | (5.782) | (9.776) | (9.889) |
| Listed | -0.652*** | -0.930*** | -0.662*** | -0.570* |
| | (-3.348) | (-3.395) | (-3.354) | (-1.752) |
| Financials | 0.530*** | 0.386* | 0.532*** | 0.118 |
| | (3.271) | (1.943) | (3.412) | (0.527) |
| CleanTransport | 0.663** | 0.095 | 0.777** | -0.072 |
| | (2.112) | (0.124) | (2.415) | (-0.429) |
| Constant | 6.379*** | 1.481* | 6.958*** | 4.489*** |
| | (8.928) | (1.913) | (10.053) | (3.970) |
| Fixed Effects | Yes | Yes | Yes | Yes |
| Adjusted $R^2$ | 0.547 | 0.512 | 0.547 | 0.549 |
| Observations | 1,915,677 | 764,007 | 1,799,347 | 879,650 |

Estimation results from the 2nd stage of the treatment effect model with a different market condition measure: I repeat estimations in
**Table *3.6*** but replace the ECB policy rate with the inflation rate. Two-way fixed effects (issuer, time) are included. Robust *t* statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Table A 3.9.** The impact of bond issuance on investor attention.

| **Panel A:** Impact on issuers' Google Trends | | | |
|---|---|---|---|
| Google Trends | (1)<br>Green<br>vs. conventional | (2)<br>Self-labelled<br>vs. conventional | (3)<br>Externally-labelled<br>vs. conventional |
| Month(-1): $D_{t-1}$ | 4.071 | 5.765 | 0.748 |
| | (1.42) | (0.96) | (0.24) |
| Month(0): $D_t$ | 7.951** | **7.611** | **6.473**** |
| | (2.27) | (1.57) | (1.99) |
| Month(+1): $D_{t+1}$ | 2.189 | 6.197 | 6.245 |
| | (0.89) | (1.01) | (1.40) |
| Adjusted R-squared | 0.083 | 0.090 | 0.082 |
| Observations | 53,332 | 48,776 | 51,992 |
| **Panel B:** Impact on issuer-related news readership heat | | | |
| NewsHeat | (1)<br>Green<br>vs. conventional | (2)<br>Self-labelled<br>vs. conventional | (3)<br>Externally-labelled<br>vs. conventional |
| Month(-1): $D_{t-1}$ | 0.0205 | 0.103 | 0.0007 |
| | (0.81) | (1.47) | (0.16) |
| Month(0): $D_t$ | -0.0009 | **0.155** | **0.0296**** |
| | (-0.29) | (1.07) | (2.09) |
| Month(+1): $D_{t+1}$ | -0.0205 | -0.0516 | 0.0003 |
| | (-1.00) | (-0.77) | (0.07) |
| Adjusted R-squared | 0.511 | 0.351 | 0.377 |
| Observations | 14,438 | 13,674 | 14,547 |
| Control ($\tilde{\mathbf{x}}$) | Yes | Yes | Yes |
| Fixed Effects | Yes | Yes | Yes |

Result from the PSM-DID estimation. I repeat the estimations in **Table 3.8** but but replace the ECB policy rate with the inflation rate. Control variables $\tilde{\mathbf{x}}$ includes *SDG*, *ParisAgree*, *Callable*, *Financials*, *Listed*, *CleanTransport*, bond size, maturity, rating, and market conditions. Two-way fixed effects (issuer, time) are included. Robust *t* statistics (in parentheses) are based on clustered standard errors at the issuer level. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$