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Sovereign Green Bonds: an overview and analysis of financial performance

Loïc Pages & Louise Lequeux-Sauvage

Under the supervision of Prof. Henrotte

President of the Jury: Prof. Derrien

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Sovereign Green Bonds: an overview and analysis of financial performance[1]

Written by students Loïc Pages and Louise Lequeux-Sauvage

Abstract

This paper examines the role and performance of sovereign green bonds (SGBs), combining a review of their institutional development with empirical analysis of their pricing behavior in primary and secondary markets. It first explores the evolution of the SGB market, regulatory frameworks, and strategic motivations of issuers. The quantitative analysis then shows that, after adjusting for liquidity, SGBs trade at slightly lower yields than conventional bonds, indicating a modest "greenium." The findings emphasize the importance of liquidity in determining green bond pricing and suggest that SGBs may offer a financial advantage for issuers, particularly in markets with strong ESG demand.

[1] Following HEC guidelines, we are hereby notifying that some paragraphs of this paper were rewritten using Large Language Models such as Chat GPT.

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1. Introduction

Over the past decade, green bonds have become a key instrument in the transition towards more sustainable financial systems. These debt securities, which commit the issuer to allocate proceeds to projects with explicit environmental benefits, have been widely adopted by corporate entities and multilateral development banks. In comparison, sovereign green bonds (SGBs), those issued by national governments, emerged later and still represent a smaller share of the global green bond market. Yet, their importance is growing rapidly. As sovereigns take on greater responsibility in financing climate transitions, understanding how these instruments operate and perform is essential both from a financial and public policy perspective.

To date, the academic literature has focused primarily on corporate green bonds, with a particular emphasis on pricing dynamics, investor preferences, and the risk of greenwashing. In contrast, sovereign issuers, despite their growing market share and unique role as both regulators and participants in the sustainable finance space, have received comparatively limited attention. This gap is significant: sovereign green bonds are structurally different from corporate issues in terms of credit risk, fiscal constraints, political accountability, and macroeconomic exposure. Moreover, their potential to shape market standards and influence corporate issuers makes them an important subject of study in their own right.

This paper addresses this gap through a two-phase analysis of sovereign green bonds. The first phase is qualitative and combines three sections (2,3 and 4) into a comprehensive review of the context in which sovereign green bonds have emerged, the frameworks that support their issuance, and the strategic motivations of the sovereigns that issue them. We begin by tracing the historical development of the SGB market, from the early supranational green bonds issued by the European Investment Bank in 2007 and the World Bank in 2008 to the gradual involvement of sovereigns following the Paris Agreement. Poland's issuance in 2016 marked the first sovereign green bond, quickly followed by France's landmark green bond in 2017, which helped establish SGBs as credible sovereign instruments. This was followed by increasing uptake across both advanced and emerging economies, including Chile, Indonesia, Nigeria, Germany, and Canada, often driven by the rising demand from institutional investors subject to ESG mandates and regulatory developments such as the EU's Sustainable Finance Disclosure Regulation (SFDR). After exploring the current market landscape, the paper then turns to the regulatory and certification frameworks that have shaped the SGB landscape, including the widespread use of the Green Bond Principles (GBP), external verification mechanisms such as Second Party Opinions (SPOs) and Climate Bonds Initiative certification, and more recent attempts at regulatory harmonization through the EU Taxonomy and the European Green Bond Standard. These instruments provide legitimacy and transparency but also introduce complexity and reporting burdens. Finally, we explore the strategic rationale for sovereign green bond issuance, highlighting both the opportunities and limitations they present. Benefits include diversification of the investor base, alignment with national climate targets, and long-term signalling of policy commitment. However, these bonds also impose restrictions on fiscal flexibility and require sustained institutional coordination. In addition, we assess whether sovereign issuance can stimulate domestic green bond markets, drawing on recent empirical studies that suggest a catalytic effect on corporate issuance, particularly in jurisdictions with strong climate policy frameworks.

The second phase of the paper focuses on a quantitative analysis of sovereign green bond pricing in both primary and secondary markets. This section builds upon the methodology developed by Doronzo et al. (2021) but extends it by using a broader and more recent dataset whilst maintaining a liquidity-adjusted framework. A sample of 26 SGBs is constructed, each paired with one or more conventional bonds from the same issuer with similar characteristics. In the primary market, we estimate yield differentials at issuance using interpolation techniques to identify pricing premiums or discounts. In the secondary market, we extract the zero-volatility spread (z-spread) of each bond and derive daily delta z-spreads (DZS), which capture the yield difference between green and conventional bonds while adjusting for maturity. A key aspect of this methodology is the use of a liquidity proxy, based on bid-ask spread differentials, allowing us to test whether pricing differences persist after accounting for market liquidity. Using panel regressions (OLS, fixed effects, and random effects) we estimate the influence of liquidity on the observed yield differences and assess whether SGBs exhibit a systematic "greenium" once liquidity is controlled for.

Taken together, this paper provides a comprehensive analysis of sovereign green bonds, combining historical, institutional, and empirical perspectives. It contributes to the literature by offering new evidence on the financial performance of SGBs, clarifying the regulatory and strategic factors that influence their issuance, and deepening our understanding of their role within the broader sustainable finance ecosystem.

2. History and evolution of the sovereign green bond market

Addressing climate change and achieving global sustainability goals demands urgent and large-scale investment across all regions. For instance, according to the European Commission, to achieve the European Union's climate target of reducing greenhouse gas emissions by 55% by 2030, an average of EUR 764B was invested annually between 2011 and 2020, representing about 5.1% of the EU's GDP in 2023. To meet the 2030 target, an additional EUR 477B of green investment will be needed each year, bringing the total to approximately EUR 1.2 trillion annually, equivalent to 8.3% of the EU's 2023 GDP (European Central Bank, 2025).

In that context, Green, Social, and Sustainability Bonds (GSSBs) are playing a pivotal role in mobilizing investors towards sustainable development. These financial instruments direct capital to sustainable infrastructure, essential services, and other areas critical to achieving climate and sustainability objectives (World Bank, 2024).

While our paper only covers Green Bonds, it is important to define the three types of GSSBs: according to the International Capital Market Association (2019), the leading institution providing guidelines on the matter, Green Bonds are any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance projects with clear environmental benefits, and which are aligned with the Green Bond Principles. Eligible green projects include, but are not limited to, renewable energy and energy efficiency, pollution prevention and control, green buildings, clean transportation etc. Social Bonds finance projects that directly aim to address or mitigate a specific social issue, such as providing affordable basic infrastructure, access to essential services, food security, or socioeconomic advancement and empowerment. Sustainability Bonds are any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance a combination of green and social projects, combining Green Bonds and Social Bonds.

2.1. Chronological development

2.1.1. First green bonds (EIB, World Bank)

The very first supranational green bond was issued in May 2007 by the European Investment Bank (EIB) (2007-2), an autonomous public institution granting loans and guarantees to finance investment projects promoting European objectives. The instrument, baptised "Climate Awareness Bond" (CAB), was a AAA-rated, 5-year zero coupon bond with a nominal value of EUR 600M. Its payoff at maturity included a full redemption of the bond's nominal value plus an additional amount at least equal to a 5% return and linked to an equity index, the FTSE4Good

Environmental Leaders Europe 40 Index, made up of European companies with outstanding environmental practices (Malta Financial Services Authority, 2019).

This bond stood out as a pioneering initiative: not only marking the first time an EIB bond was publicly offered across all 27 EU member states, but also through the earmarking of its proceeds exclusively for renewable energy investments. In 2006, the European Investment Bank (2007-1) had set sustainable energy as a core objective, with an annual target of EUR 600M to EUR 800M in lending for renewable energy projects, including solar, hydro and wind, as well as energy efficiency initiatives. The Climate Awareness Bond net proceeds were then earmarked and allocated by the EIB to a specially created portfolio to be used exclusively for such projects.

Amidst the growing awareness of climate change, other supranational institutions soon followed: in November 2008, after the launch of its "Strategic Framework for Development and Climate Change", the World Bank (2008) issued the first labelled "Green Bond" designed together with Skandinaviska Enskilda Banken (SEB) to address the demand from Scandinavian pension funds looking for climate-related investment opportunities. The SEK 3.35B, 3.5% coupon bond, was the first fixed-income product to introduce climate mitigation and adaptation objectives and the first World Bank bond to raise funds for a specific program (World Bank, 2015).

Throughout the 2007-2012 period, investors' appetite for such instruments rose sharply, well illustrated by the development of the International Finance Corporation (IFC)'s green bond activity (Climate Bonds Initiative, 2014). The IFC, a member of the World Bank Group which promotes development by focusing on the private sector in developing countries, initially issued a USD 200M bond in 2010. In 2013, it issued two record-breaking USD 1B bonds (International Finance Corporation, 2023).

From 2013 onwards, corporates entered the green bond market and rapidly became the largest issuers of climate-related fixed income instruments. However, multilateral and national development banks are still an important element of the green bond market: as of 2025, the EIB's total Climate Awareness Bond issuance has passed EUR 100B (European Investment Bank, n.d.), the World Bank's Green Bonds have reached USD 20B (World Bank Treasury, n.d.) and the IFC USD 15B (International Finance Corporation, n.d.).

2.1.2. The introduction of sovereign green bonds (France, Poland)

The 2016 Paris Agreement, following COP21, was a turning point for green finance: the agreement set three objectives to address the climate challenge related to the financial sector and limit the temperature rise to 2°C (Ministère de la Transition Écologique, n.d.). First, removing obstacles to green investments by adopting favourable regulations, encouraging innovative products like green bonds and mobilising public banks to catalyse private finance. Second, shifting capital away from carbon-intensive assets and industries by increasing environmental risk-related monitoring and transparency. Finally, implementing frameworks and principles to ensure that all financial flows are compatible with the aforementioned objectives.

The emphasis on the need for sustainable funding led to the creation of Green Bond Frameworks by several countries, notably France, and several announcements of future issuances for 2017. The very first SGB was issued by Poland in December 2016 to finance sustainable projects including renewable energy production, diverting from coal-based generation or developing clean transportation. The EUR 750M, five-year issuance with a coupon of 0.5% was twice oversubscribed, showing a strong interest in these products (Climate Bonds Initiative, 2016-2).

However, the pioneering of sovereign green bonds is generally attributed to France: in January 2017, the country set a record with the issuance of a EUR 7B green OAT[2] bond that was more than three times oversubscribed (Agence France Trésor, n.d.). With a maturity of 22 years and a 1.75% coupon, it was both the largest and longest-maturity benchmark green bond issued to date, attracting a highly diverse investor base, including asset managers (33%), banks (21%), pension funds (20%), insurers (19%), official institutions (4%) and hedge funds (3%) (GIZ, SEB, & ABM, 2018). The favourable financial and regulatory environments of France were responsible for that success: up to that point, France had been the second biggest country of issuance for labelled green bonds, as well as the first country to issue a municipal green bond in 2012. On the political front, the 2015 "Energy Transition" law encouraged sustainable investments by setting objectives for GHG emissions reduction, energy efficiency and the deployment of renewable energy, while "Article 173" introduced mandatory Climate Risk reporting, including disclosure from investors in green bonds (Climate Bonds Initiative, 2016-1).

2.1.3. 2020 and post development

After an initial phase of rapid growth in the SGB market between 2017 and 2020, marked by the first issuances of many countries from both developed and emerging economies (Fiji, Nigeria, Indonesia, Chile), the year 2020 was a major inflection point, driven by two main factors: the COVID-19 pandemic and the acceleration of climate policies. Following the pandemic and the increased government spending, many countries sought to align stimulus spending with sustainability objectives, integrating green finance into broader recovery programs. At the European level, the launch of the EUR 800B economic recovery package *NextGenerationEU* set a

[2] Obligation Assimilable du Trésor (French treasury bond)

precedent by committing at least 30% of funds to climate-related investments, partly financed through green bond issuance (European Commission, N.d.-1). This strategy was reinforced by the EU Green Deal and a new taxonomy aiming to shift investments toward sustainable assets.

2.1.4. *Growing demand from institutional investors*

In parallel, one of the key drivers described by Boffo & Patalano (2020) behind the development of SGBs has been the rising appetite of institutional investors, including asset managers, insurance companies, and pension funds, for sustainable debt instruments. As mentioned previously, institutional investors' appetite had been the catalyst for the creation of the very first green bond issued by the World Bank in 2008. As ESG considerations have become a key factor in portfolio construction, these past years have shown a shift toward aligning investment strategies with environmental and social goals (Ground, 2022). In this context, SGBs offer an attractive opportunity: they combine the high credit quality typically associated with government debt with the added value of measurable environmental impact. For institutional investors with sustainability mandates, SGBs are especially appealing due to their very large scale, transparency, and the role they play in funding public climate strategies (Lindner & Chung, 2023). Moreover, for long-term investors like insurance companies, the long maturity of those bonds is an additional advantage.

In Europe, this trend has been bolstered by the new fiscal and regulatory policies such as the EU's Sustainable Finance Disclosure Regulation (SFDR) and the EU Taxonomy framework, which promotes the reallocation of capital flows toward green assets and away from high-carbon industries. Under the SFDR, funds belong to one of three categories: "Article 6" funds which do not integrate ESG considerations into their investment strategies, "Article 8" or "light green" funds which simply promote some ESG features and "Article 9" or "dark green" for the funds that are fully aligned with and aim to achieve sustainable objectives. Investing in SGBs helps meet sustainable targets to obtain a favourable classification as Article 8 or 9 funds, which in turn enhances their attractiveness to clients and beneficiaries (Ernst & Young Luxembourg, 2024).

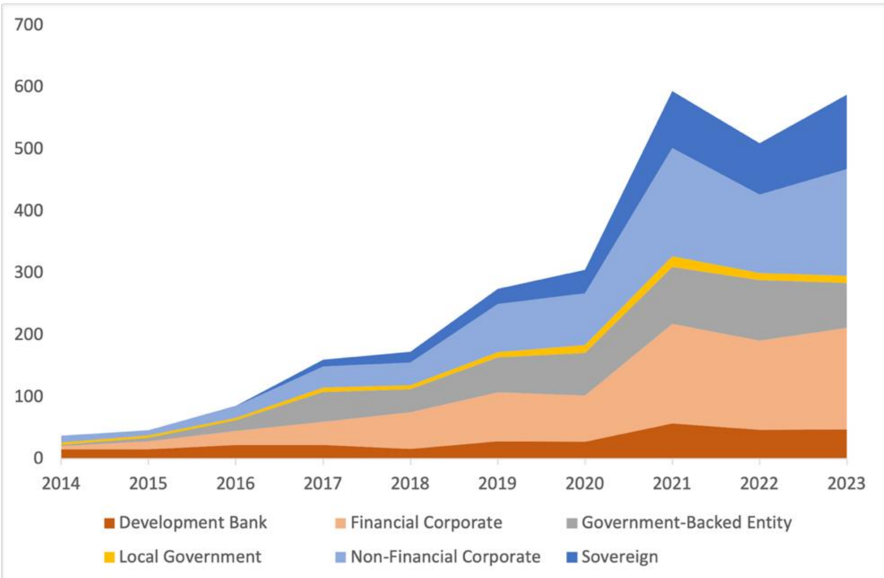
Additionally, the fast growth of the corporate green bond market in the 2010s served as precedent for investors, demonstrating both the feasibility of earmarking bond proceeds and the scalability of green finance. Consequently, institutional investors who had grown accustomed to corporate green bonds were comfortable allocating capital to sovereign green bonds as they emerged.

2.2. Current Market Landscape

This section builds upon "Sovereigns and Sustainable Bonds: Challenges and New Options" by Cheng et al. (2022) in the Bank for International Settlement (BIS) Quarterly Review that used green bond data from the Climate Bond Initiative. Unfortunately, the data we had access to did not cover the year 2024 and was less granular than the BIS paper, due to changes in the CBI data sharing policy. Nonetheless, we can complement our analysis with the Climate Bond Initiative (2024-2) Market Intelligence Report, the World Bank (2024) Sustainable Development Bond Impact Report, as well as the World Bank (2025) Labeled Bond Quarterly newsletter from February 2025, for a more recent, albeit superficial perspective.

Using the CBI platform, we can see on Figure 1 below that the share of sovereign issuers in the green bond market has strengthened since the first issuance in 2016: in 2023, sovereigns stood at USD120B and represented 20.4% of total green bond issuances, up from 16.3% in 2022. This increase is driven by the strong activity of the three main issuers: France (USD81B issued as of 2024), Germany (USD80B) and the United Kingdom (USD71B), illustrating the pan European initiative to develop green finance and sovereign green bonds (Climate Bonds Initiative, 2024-2).

Figure 1: Green bond issuances by issuer type (2014-2023), USD Bn



Per the CBI (2024-2) report, the cumulative amount of sovereign green bond issuance in Q3 2024 reached USD 504B (80% of all sovereign GSS bonds), a 29% increase year-to-date. However, although not visible on the graph, sovereign issuances in Q4 2024 dropped sharply, decreasing by 87.5% when compared to issuances Q4 2023, and by 72.2% with respect to the previous quarter. This should not be interpreted as a global slowdown: first, issuances usually taper in the final quarter. In addition, as put forward by Gill (2024), governments and investors seem to have anticipated ahead of U.S. elections in fear of market volatility by issuing earlier in the year. Finally, eight countries, including several emerging economies, launched their first GSS bonds: Australia, Dominican Republic, Honduras, Iceland, Ivory Coast, Japan, Qatar, and Romania.

Using the latest World Bank (2025) newsletter, based on Bloomberg Terminal data, we find more detailed information on emerging countries: they have issued a cumulative USD148B of labelled sustainable bonds (covering GSS and Sustainability-Linked Bonds[3]), which represents 24% of the total amount of USD623B. The market is very heterogenous across the 27 emerging countries that have already issued these instruments; Chile makes up 34% of emerging country issuances, then Mexico, Thailand, Indonesia and Peru represent 36%, with the 22 other countries issuing the final 30%. As we can see on Figure 2, while the sovereign green bond market can seem weaker in emerging economies, it should be noted that the main instrument issued by governments in those countries is Sustainable bonds (USD69B, or 46% of cumulative amounts issued as of 2024 against 23% for green bonds), whose proceeds can be used for both environmental and social investments, reflecting their increased social development needs compared to developed countries.

Figure 2: Breakdown of sovereign issued sustainable instruments as of 2024, for all countries versus emerging economies, %

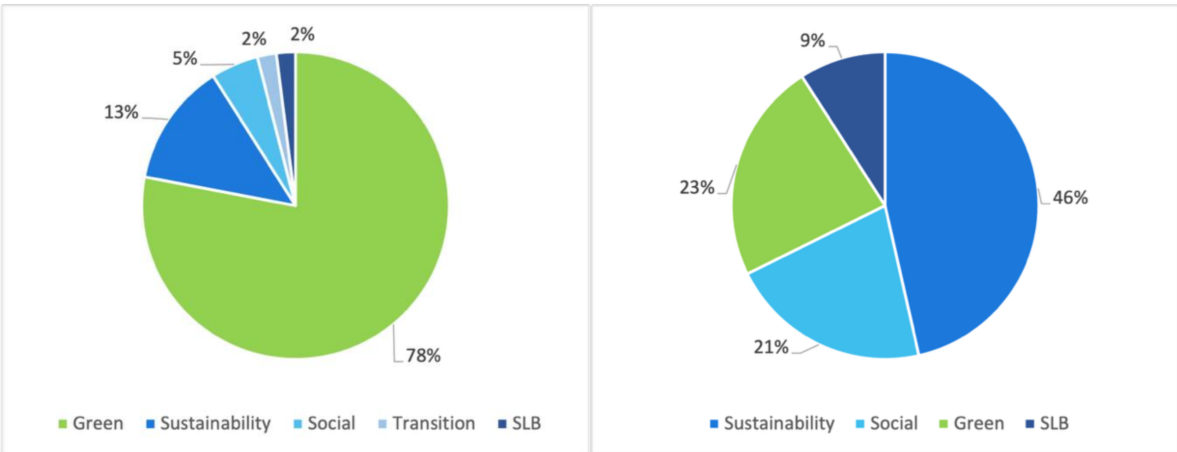
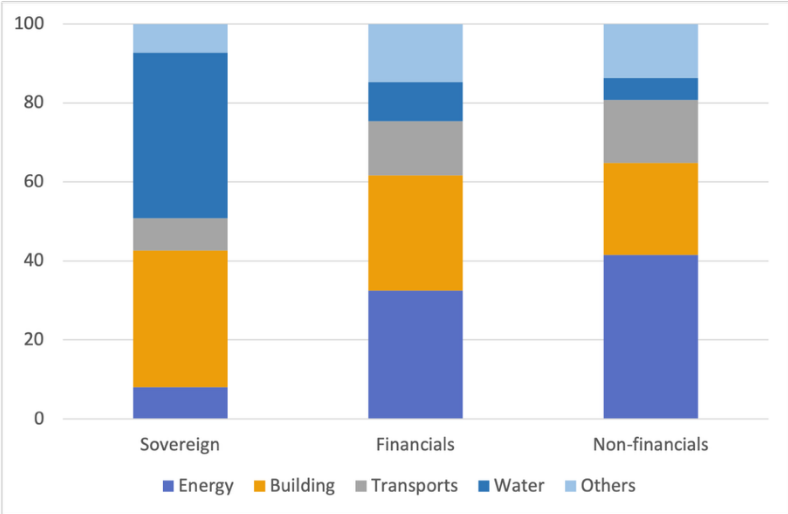


Figure 3 highlights that the green bond Use-of-Proceeds allocation by sector varies substantially depending on issuer type: financial corporates contribute to the energy transition by funding portfolios of smaller projects, maintaining a relatively balanced mix of sectors. Non-financial corporates focus on decarbonating their own operations and improving energy efficiency through investing in greener buildings. On the other hand, sovereigns channel most of their green bond proceeds into water infrastructure and buildings, which is consistent with the goal of funding large-scale public infrastructure projects to adapt and mitigate climate risk.

[3] A sustainability-linked bond is a type of debt instrument where the bond's financial or structural characteristics are tied to the issuer's achievement of predefined ESG performance targets. Unlike green bonds, SLB proceeds can be used for general corporate purposes.

Figure 3: Green Bond Use-of-Proceeds Sectoral Breakdown by Issuer Type, 2022, in percent



3. Certification and regulation

As we have seen before, the key feature of SGBs, as opposed to conventional bonds, is the Use-of-Proceeds mechanism: net proceeds from these issuances are required to be invested exclusively in "green" projects. This has led to a pressing need for robust regulatory and certification mechanisms to ensure their environmental integrity, investor confidence, and consistency with national climate goals. Issuers must establish a clear and verifiable link between raised capital and measurable environmental outcomes. This requires a coherent set of international standards, reliable certification tools, and transparent reporting practices. This section outlines the regulatory architecture that underpins the issuance of sovereign green bonds, focusing on international norms and standards, regional taxonomies, and reporting obligations and verification mechanisms.

3.1. International norms and standards

3.1.1. The role of ICMA and the Green Bond Principles (GBP)

The Green Bond Principles, developed by the International Capital Market Association (ICMA) (2022-2), are a set of guidelines for the global green bond market. While non-binding, the GBP serve as a reference on transparency and disclosure and are widely adopted by both public and private issuers. Originally drafted in 2014 during the rapid expansion of the green bond market, the GBP have been updated several times since, most recently in 2022, to account for the changes in the market.

The Green Bond Principles rest on four core components (International Capital Market Association, 2022-2): "Use of Proceeds", emphasising the need for issuers to clearly define the Green Projects proceeds will be invested in the legal documentation of the security. The GBP provide an indicative list of eligible areas of investments, including categories such as energy efficiency, renewable energy, clean transportation and biodiversity conservation. The second pillar is "Process for Project Evaluation and Selection": the issuer must describe the environmental sustainability objectives, the decision-making processes to determine project eligibility, clearly identify all the associated risks and whether projects align with existing taxonomy. "Management of Proceeds" means that issuers are expected to track and allocate green bond net proceeds to eligible green expenditures using a transparent and traceable system, often involving internal accounts or sub-portfolios. Finally, the Green Bond Principles highlight the need for "Reporting": issuers should publish at least annual updates on the allocation of proceeds and, whenever possible, on the environmental outcomes of the financed projects. Impact reporting should rely on both qualitative and quantitative performance indicators, if possible.

The Green Bond Principles encourage a high level of transparency and have been instrumental in harmonizing market practices. While not legally enforceable, they are considered market best practice and serve as the basis for most sovereign green bond frameworks, including those issued by EU countries, Canada, and Indonesia (International Bar Association, 2023). However, when issuing a green bond, the issuer is expected to develop its own Green Bond Framework, which offers further disclosures and outlines procedures geared at reassuring investors, particularly regarding the green use of proceeds (Bank for International Settlements, 2022).

3.1.2. Certification by the Climate Bond Initiative (CBI)

Although green bonds are generally governed by the same regulations and legal frameworks conventional bonds in most jurisdictions, there are – with the exceptions of India and China – no official regulatory authorities that legally assess their "green-ness" (Kaminker & Majowski, 2018). In the absence of uniform legal standards, external review providers are essential in upholding the green bond market's environmental integrity and its trustworthiness. By improving both transparency and the credibility of a bond's environmental claims, these reviews help mitigate concerns over 'greenwashing' – the risk that a green bond might fail to deliver its stated environmental benefits. Several types of external reviews exist, the main ones being Certifications and Second-Party Opinions (Climate Bonds Initiative, N.d.-2).

The "Climate Bonds Standard and Certification Scheme" is a labelling scheme introduced by the Climate Bonds Initiative (N.d.-1) for various climate-related financial instruments and assets, including green bonds. The CBI offers a more stringent, science-based certification scheme to ensure that bonds align with the objectives of the Paris Climate Agreement to limit global warming to 1.5°C. The scheme is internationally applied by issuers, governments, investors, and financial institutions to prioritise investments that meaningfully support climate change mitigation.

Under the Climate Bonds Standard (CBS), issuers seeking certification must align with the CBS taxonomy, which sets clear sub-sector-specific eligibility criteria (e.g., for solar energy, low-carbon transport, water infrastructure) that are stricter than the GBP (European Parliamentary Research Service, 2022). Regarding the management of proceeds, the CBS mandates that funds be either earmarked or ring-fenced to ensure they are allocated exclusively to eligible green projects and within a 24-month settlement period. The certification process includes a pre-issuance "readiness assessment" by an approved third-party verifier, as well as an "engagement assurance" review within one year of issuance to ensure the proceeds were allocated as planned. Finally, certified green bond issuers must provide annual reporting until full allocation of proceeds.

CBI certification is particularly valuable for attracting environmentally focused investors and enhancing credibility as it offers both issuers and investors a clear and technically specified catalogue outlining which activities and assets are considered environmentally sustainable. While some sovereign issuers (such as Nigeria and Chile) have obtained CBI certification, many others—including France—prefer a second-party opinion (SPO) model, often considered more flexible (Asian Development Bank, 2018).

When issuing a sovereign or conventional green bond, issuers must provide their own Green Bond Framework, usually built upon the Green Bond Principles and offering a more granular description of the eligible green projects, the selection mechanism and the reporting. This framework, such as the French Green OAT Framework, constitutes a first-party opinion of the green bond's "greenness" and governance features that needs to be reviewed by external consultants with environmental and climate expertise to ensure the accuracy and credibility of the issuer (République Française, 2017). Those independents reviewers are either ESG service providers (the main ones being Sustainalytics, Vigeo Eiris, DNV GL and Oekom) or scientific experts (such as CICERO or CECEP Consulting). The Second-Party Opinion (SPO), conducted before the issuance upon the issuer's request, aims to provide investors with the relevant information and a qualitative assessment of the bond's features.

Like certification, SPOs are not required by regulators, only recommended, but having the approval of specialised consultants plays a critical role when it comes to gaining the investors' trust. However, even though SPOs are used by the majority of issuers, the system has its limitations: Second Party Opinion providers often advise issuers when drafting their initial Green Bond Framework, leading to potential conflicts of interests.

3.1.3. Reporting Standards and Methodologies

Reporting and monitoring mechanisms are fundamental pillars of SGBs that ensure transparency and accountability regarding the use of proceeds on the issuer's side as well as reinforcing investors' confidence that the environmental objectives are being met. While regulatory requirements differ across jurisdictions, sovereign issuers have gradually aligned with a set of emerging best practices combining post-issuance allocation disclosures, and environmental impact assessments.

After the green bond issuance, net proceeds must be placed in an earmarked sub-portfolio that will be managed according to the practices defined in the framework to ensure that funds are only allocated to eligible projects (International Capital Market Association, 2022-2). Issuers must then report on allocation to provide transparency on how bond proceeds have been invested, including the project description, along with information on the share of funds allocated versus remaining. For the sake of transparency, many governments commission external auditors to verify that allocations are consistent with the commitments set out in the original framework.

In addition to post-issuance allocation reporting, impact reporting is a key pillar of the green bond architecture (International Capital Market Association, 2022-3): issuers are expected to monitor the environmental impact of their investment, based on qualitative and quantitative metrics such as renewable energy capacity installed or GHG emissions avoided and to report those outcomes to investors, typically on an annual basis. Governments have increasingly adopted standardized reporting procedures based on ICMA's Harmonized Framework for Impact Reporting to improve the reliability and comparability of those reports; although not a sovereign issuer, the World Bank Impact Report for Sustainable Development Bonds and Green Bonds can be considered as a best practice example. In recent years, the European Commission (N.d.-3) has introduced the European Green Bond Standard, a voluntary Standard that could apply to both sovereign and corporate green bonds and establishes detailed reporting requirements.

3.2. Regional Taxonomy and Regulatory Approach

3.2.1. The European Union Taxonomy and European Bond Standard

As aforementioned, the European Union pioneered sustainable financial instruments in 2007, when the European Investment Bank issued the first bond with a clear use-of-proceeds mechanism to fund renewable energy investments. The European Union has continued to play a leading role in the green bond market and more broadly in the fight against climate change: in 2020, the European Commission (N.d.-2) launched the ambitious European Green Deal, a comprehensive package of climate policies designed to achieve the EU's goal of reaching climate neutrality by 2050. Those initiatives include the EU Taxonomy for Sustainable Activities, one of the most influential developments in green finance regulation. The taxonomy is a complex classification system designed to combat greenwashing and guide investors toward informed decision-making by determining whether an economic activity is environmentally sustainable, based on six environmental objectives: “climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, protection and restoration of biodiversity and ecosystems” (European Parliament & Council of the European Union., 2020). For an activity to be recognized as environmentally sustainable under the Taxonomy, it must make a significant contribution to one of these six objectives, while not adversely impacting the other five – this is called the “Do No Significant Harm” principle - and must comply with minimum social safeguards and technical screening criteria. Additionally, the EU Taxonomy requires large companies to report to investors about the environmental impact of their assets and to determine the share of their economic activities that are related to environmentally sustainable activities, per the Taxonomy definition. More importantly, in the context of our paper, Article 7(4) of the Disclosure Delegated Act under Article 8 of EU Taxonomy Regulation states that “environmentally sustainable bonds or debt securities with the purpose of financing specific identified activities that are issued by an investee undertaking shall be included”, encouraging investment in SGBs (European Commission, 2021).

Building on the EU Taxonomy, the European Parliament & Council of the European Union (2023) introduced a new framework named “European Green Bond Standard”, a voluntary certification scheme for sovereign and corporate issuers alike. The rationale for this standard is given in Regulation (EU) 2023/2631 “On European Green Bonds and optional disclosures for bonds marketed as environmentally sustainable and for sustainability-linked bonds”:

“Specifying quality requirements for European Green Bonds in the form of a regulation should ensure that there are uniform conditions for the issuance of such bonds by preventing diverging national requirements that could result from the transposition of a directive, and should also ensure that those conditions are directly applicable to issuers of such bonds. Issuers that wish to use the designation ‘European Green Bond’ or ‘EuGB’ should follow the same rules across the Union in order to increase market efficiency by reducing discrepancies and thereby also reducing the costs for investors of assessing such bonds. To facilitate comparison and address greenwashing, optional sustainability disclosure templates should be provided both for bonds marketed as environmentally sustainable and for sustainability-linked bonds.”

The core components of the Standard are as follows: eligible green projects must be defined as environmentally sustainable under the EU Taxonomy, issuers must all use the same EU

Framework - describing projects, objectives, processes and methodologies on allocation, reporting and impact calculation. Under that Standard, issuers must produce allocation and impact reports, while the framework and allocation report must undergo verification by an accredited third party. However, the verification of impact reports is not mandatory, only recommended.

While not yet mandatory, this standard could become the default for sovereign green bond issuers in the EU. This would have notable consequences on the verification process: sovereign issuers currently rely on Second Party Opinion providers, consultants who also advise them on the design of their framework. The EU Green Bond Standard would remove this possibility and replace it with external reviewers accredited by the EU who would only audit the issuers (Natixis Green & Sustainable Hub, 2019).

3.2.2. The Chinese Taxonomy

Parallel to the European Union's regulatory efforts, several other major economies have developed their own green bond taxonomies, often seeking to align them with international norms. China stands out, having taken significant steps to reform its domestic green finance framework throughout the past few years (Interesse, 2024). While China has been the largest green bond market for several years, with USD131B of issuances originating from Chinese entities in 2023 (Climate Bonds Initiative, 2024-1), its green bond framework used to have loose criteria compared to international standards, leading to investor confusion and potential greenwashing as clean coal was allowed by some regulators. China did not have one set of guidelines but several, each issued by different regulatory bodies. In 2021, facing market and political pressure, the People's Bank of China (2021), the China Securities Regulatory Commission and the National Development and Reform Commission published the harmonised "Green Bond Catalogue" to align their definition of what would constitute an eligible green project

In 2022, China introduced its own Green Bond Principles, partly based on the ICMA GBP, adopting the international standard of using 100% of bond proceeds on green investments – the previous Chinese regulation only required 50% or 70%, depending on instruments (International Capital Market Association, 2022-1). In February 2025, China issued its Sovereign Green Bond Framework, demonstrating the country's commitment to supporting green and sustainable development. The framework relies on the "Green Bond Catalogue" to identify sustainable industries and will adopt a third-party verification system for its annual reporting (Ministry of Finance of the People's Republic of China, 2025).

Another particularly notable development showing China's strategy of aligning itself with international standards is the 2021 China-EU Common Ground Taxonomy (CGT), a collaborative initiative launched under the International Platform on Sustainable Finance (2022), a network of policymakers launched by the EU aiming to increase international cooperation on sustainable finance matters. The CGT highlights the similarities and differences between the green finance taxonomies of China and the European Union. While the CGT in itself is not a legally binding taxonomy, it reflects a growing willingness among leading issuers to coordinate their approaches and promote interoperability of green financial instruments to scale-up the global green bond market (Gong, 2022).

To conclude, the global trend toward standardization and transparency has significant implications for the development of the green bond market by increasing cross-border capital flows. Harmonizing reporting processes and criteria makes frameworks easier to compare and facilitates investors' due diligence. Finally, the convergence in reporting and eligibility criteria strengthens investor confidence and would strongly benefit emerging economies by attracting foreign investments.

4. Rationale of green bond issuance for sovereign issuers and impact on the corporate market

4.1. Advantages and drawbacks for sovereign issuers

4.1.1. Advantages for issuers

Sovereign green bonds offer governments a strategic financing instrument to support climate and environmental objectives while realizing broader economic, financial, and reputational benefits. At their core, these bonds allow countries to align public borrowing with national and international sustainability commitments, usually the United Nations Sustainable Development Goals (SDGs) or the Paris Agreement. By issuing green bonds, governments can demonstrate their climate leadership and embed environmental goals into public financial management.

From a financing strategy perspective, sovereign green bonds diversify government funding sources beyond traditional taxation or conventional debt instruments (International Monetary Fund, 2023-1). By tapping into growing pools of ESG-conscious investors, governments can raise funds for green investments without resorting to new taxes or reallocating limited budgetary resources (Climate Bonds Initiative, 2021). This is particularly attractive at a time when many countries face pressure to accelerate their energy transitions while managing post-pandemic fiscal constraints. The ability to issue debt earmarked for green expenditures offers an alternative to climate-related tax increases on fossil fuels, making the SGB an efficient and socially acceptable mechanism to fund environmental policy (Columbia Center on Sustainable Investment, 2025).

Green bonds also broaden the investor base by attracting dedicated ESG and impact investors, including institutions with mandates to finance environmentally sustainable projects. This deepens market liquidity and may lead to more favourable demand conditions. France's Green OATs, for instance, consistently attract strong interest from long-term investors and have become a reference point in the SGB market. For emerging economies, this investor diversification is particularly valuable. Countries such as Chile, Indonesia, and Nigeria have issued SGBs or sustainable bonds not only to fund climate projects but also to expand access to international capital markets and attract long-term financing partners with sustainability mandates (Madeira & Pérez, 2023).

Issuing green bonds also reinforces the credibility and transparency of a country's sustainability strategy. The development of a Green Bond Framework, which consists in defining eligible expenditures, governance, and reporting practices, requires internal coordination and institutional capacity-building. France's framework, for example, encompasses a wide range of green public expenditures, from clean transport to biodiversity, and is monitored by the independent Green OAT Evaluation Council, composed of eight independent experts from international organisations and academia (Agence France Trésor, n.d.). The level of governance and discipline required sends a strong signal to markets and stakeholders about the government's long-term environmental commitments, while also improving investor confidence through structured and verifiable reporting.

An additional advantage of sovereign green bond issuance lies in the potential to extend the average maturity of public debt portfolios. Many green bonds are issued with long tenors, often 10, 20, or even 30 years (MSCI, 2023), allowing governments to secure funding for capital-intensive green projects with long time horizons. By issuing longer-dated instruments, governments can align their financing strategies with the long-term nature of environmental investments while reducing short-term refinancing risk (Banque de France, 2024).

For emerging markets, SGBs also offer an opportunity to strengthen institutional frameworks and enhance access to concessional or blended finance. Instruments such as sustainability-linked bonds or bonds aligned with the International Development Finance Club (IDFC) principles have enabled countries like Benin and Colombia to attract international development partners and catalyse private sector participation in national climate agendas. Green bonds can therefore serve as a platform to improve governance, promote transparency in public investment, and build credibility among international donors and investors (De la Orden & De Calonje, 2022).

4.1.2. Drawbacks for issuers

Despite their growing appeal in a context where addressing climate change has become a crucial matter for many governments, sovereign green bonds come with several challenges that can limit their effectiveness or deter some governments from using them. The main challenges stem from the key difference between conventional sovereign bonds and green ones, that is the exclusive allocation of funds for environmental projects.

First and foremost, net proceeds are not fungible and must be tied to predefined eligible expenditures, so they offer less fiscal flexibility than conventional debt. The increased rigidity in government spending can be especially constraining in times of economic stress or shifting policy priorities. Government must then balance their objectives of scaling-up sustainable investments with the need to fund broader budgetary priorities. Nigeria, for instance, has faced difficulties in identifying a consistent pipeline of green projects to sustain its program, which has limited its ability to scale issuance. Moreover, earmarking budget items for green bonds may introduce inefficiencies or distort investment planning if not well integrated with existing fiscal processes (Lindner & Chung, 2023).

In addition, issuers are required by the Green Bond Principles and by their own frameworks to closely monitor the allocation of funds and publish the achieved environmental benefits, which requires complex and costly impact reports, often on an annual basis. Those reports must be based on quantitative and verifiable data, the gathering of which can be resource-intensive, and are usually reviewed by external organisations. France, for example, commits to publishing detailed annual allocation and impact reports for its Green OAT, supported by an independent evaluation council. While this enhances credibility, it also increases transaction and operational costs: in emerging countries, establishing reliable reporting processes can be a barrier to entry (Raghu Raman et al., 2024)

Another major issue is the risk of falling short of green commitments, which can expose governments to reputational or political backlash, both domestic and international (Ferrer, 2023). Although green bonds typically do not carry legal penalties for non-compliance, failure to align the use of proceeds with promised objectives or to adhere to the green framework may trigger accusations of greenwashing (International Capital Market Association, 2023). This may lead to market volatility, decreased investor confidence or even exclusion from ESG funds (Agence France Trésor., 2017). This risk is particularly sensitive for countries trying to position themselves as climate leaders, such as Chile or Germany, which have made green transparency a pillar of their sovereign bond strategies.

Issuing a sovereign green bond also requires close coordination across ministries and public agencies, from the framework design to the choice of eligible projects to the implementation of monitoring protocols. This can be challenging to orchestrate in an environment with fragmented institutional structures. In France, the successful implementation of the Green OAT in 2017 was supported by strong interministerial cooperation and high-level political commitment: Agence France Trésor (2017) was responsible for issuing and managing the Green OAT, the Ministry for the Ecological Transition defined the eligibility criteria and ensured that the allocation of proceeds was in line with the government's goals, the Ministry for the Economy and Finances oversaw the structuring of the bond, while the independent Evaluation Council assessed the environmental impact of the Green OAT. However, this level of coordination is not always replicable.

Finally, for some emerging economies, particularly those with less developed capital markets, sovereign green bond demand may be limited without strong ESG investor appetite or credit enhancement mechanisms.

4.2. A catalyst for the corporate green bond market?

As mentioned in section 2, the green bond market is unusual in the sense that corporates paved the way for sovereign issuers, who only started issuing those instruments several years later, when investors' appetite had become strong. In the history of conventional bond markets, especially in emerging economies, sovereign issuances have laid the foundations for corporate bonds and have had a positive impact on the development of corporate bond markets (Dittmar & Yuan, 2008) (Yuan, 2005). It is then worth wondering if this mechanism is still observed even when the chronology is different and whether those countries' SGB issuances have had an impact on the corporate market. An IMF working paper by Cheng et al. (2024) titled "Sovereign green bonds: a catalyst for sustainable debt market development?" studied the evolution of the corporate green bond market to evaluate the impact of sovereign issuances from three angles: the size of the corporate green bond market, the pricing and liquidity effect and the green reporting and verification quality effect.

According to this paper "Some sovereign issuers [...] interviewed for this study explicitly mentioned they expect SGBs to set the benchmark for green standards in the market, even though corporate green bonds issuance in many cases has preceded that by their governments."

The analysis was based on more than 2,700 corporate green bond issuances across 63 jurisdictions, from 2012 to 2022, comparing each market before and after the date of the first SGB issuance. The working paper shows improvement across all three categories considered: the introduction of

SGBs has a statistically significant positive effect on both the issuance amount and the number of corporate green bonds, especially in emerging economies. More importantly, the research indicates that this effect depends on the country's climate policy, as measured by CCPI: the stronger the policy, the greater the impact of a sovereign debut on the number of corporate green bond issuances, though not on the amount issued, illustrating the positive signalling effect of green bond issuance.

The working paper also shows an improvement in corporate green bond verification and reporting after the first sovereign issuance: a higher percentage of corporate green bonds were verified, either by means of a second party opinion or through green bond certification. This is in line with the hypothesis that sovereign issuers – all of whom have implemented a green bond framework prescribing high level of reporting and verification – encourage the use of third-party green reviews and establish standards for the allocation of proceeds and impact reporting.

Finally, when studying the impact of sovereign issuances on corporate green bond liquidity and yields, the paper finds that the sovereign debut on the green bond market does increase liquidity, reducing the bid-ask spread by up to 1 basis point and diminishes yield spreads by 2 to 9 basis points. However, those results are not replicated for subsequent sovereign issuances: if anything, they have the opposite effect, with a statistically significant decrease in liquidity and increasing yield spreads. This is consistent with the theory that the first issuance serves as a benchmark from which corporate issuers benefit.

To conclude, by entering the green bond market, governments signal their strong commitment to green policies, which can help shift investors towards sustainable instruments and stimulate the growth in the corporate market, as well as improving market liquidity and pricing. The next section of this paper moves to an empirical analysis of SGB financial performance in primary and secondary markets.

5. Financial performance of sovereign green bonds

We begin this section by noting that our quantitative work builds upon, updates and extends the paper of Doronzo et al. (2021), which examined the existence of a greenium for SGBs in both primary and secondary markets. Given the similarity in methodology and data collection, some overlap in terminology is inevitable. However, the conclusions of our paper differ significantly, reflecting the substantial growth in sovereign participation in the green bond market over the past years. This section will begin with a forward of theory, before providing a literature review and moving to the selection of our bond sample and primary and secondary market analyses.

5.1. Possible explanations for yield differences between SGBs and SBs

To frame the analysis, let us begin with a theoretical premise: SGBs and their conventional, non-green counterparts are issued by the same sovereign entity and should, in theory, be priced similarly. Since both types of bonds carry identical credit risk, being backed by the same government, any difference in pricing cannot be attributed to default risk. Even if investors perceive an issuer's commitment to sustainability as indicative of lower long-term credit risk, such a perception should logically extend to all its liabilities, not just its green-labelled debt.

Yet, in practice, SGBs may be subject to additional forces that influence their market pricing. One key factor is investor demand driven by sustainability preferences. A growing base of ESG-focused investors may be willing to pay a premium, that is accepting lower bond yields, for assets that align with their mandates, especially when the supply of green-labelled sovereign debt is relatively constrained, creating a scarcity premium. We found this effect to be documented by Pietsch & Salakhova (2022). Another mechanism at play is the investor composition effect. SGBs often attract institutional investors with very long-term investment horizons, such as pension funds, insurers, and sovereign wealth funds, that may be less prone to short-term trading. This buy-and-hold behaviour can enhance price stability, particularly during periods of market stress. However, pricing disparities could also reflect differences in market liquidity. Green bonds may suffer from thinner secondary markets due to lower trading volumes or be more tightly held, which can either widen or compress spreads depending on prevailing market dynamics (Stephan et al., 2018). We will investigate and account for this liquidity component more rigorously in the empirical section. So, while theory posits that SGBs should be priced equivalently to non-green sovereign bonds, several real-world frictions could justify a pricing differential. The academic literature to date remains relatively ambiguous and is detailed in the following section.

5.2. Literature review

The academic literature on the pricing differential of sovereign green bonds has expanded rapidly in recent years, reflecting both the growth of the market and the complexity of isolating the environmental premium from other drivers such as liquidity. Early empirical studies laid the foundation for this field by matching green and conventional sovereign bonds with similar characteristics to estimate the existence and magnitude of a greenium. Grzegorczyk and Wolff (2022) were among the first to systematically analyse euro area sovereign green bonds, using exact matching of green and conventional pairs to reveal an average yield discount of -3.6 bps for Germany and -16 bps for Spain. Their findings suggested that reputational incentives and behavioural factors, rather than differences in credit risk, were key drivers of the observed greenium, challenging traditional asset pricing models that assume sovereign bonds from the same issuer are otherwise identical. Building on this, Amstad et al. (2023) expanded the analysis to a broader set of sovereign issuers, employing a twin-bond methodology with Danish and German green bonds and a panel regression including 14 sovereigns.[4] They found a modest greenium of around -3 bps in the twin-bond analysis, with a notable variation between advanced economies and emerging markets. This variation was interpreted as evidence that investor perceptions of climate commitment can amplify the greenium, particularly in markets with strong ESG mandates.

A significant methodological advance in the literature has been the use of z-spread analysis to control for term structure and interest rate risk. This methodology will be further developed as we begin our empirical analysis. The European Central Bank (2022) demonstrated that, after matching on duration and credit risk, SGBs traded at z-spreads that were on average -6.6 bps lower than their conventional counterparts. This approach was further refined by Bianchini and Nicodano (2024), who combined z-spread analysis with the construction of synthetic bonds to isolate the impact of liquidity. Their results showed a residual greenium of -15.9 bps after accounting for liquidity, suggesting that while liquidity is a major factor, an environmental premium persists.

The role of liquidity has been a recurring theme in the literature, with several studies emphasizing its importance in explaining greenium estimates. Doronzo et al. (2021) were among the first to incorporate bid-ask spread differentials into fixed-effects regression model. Their analysis indicated that liquidity explained much of the observed pricing differences, particularly for less frequently traded sovereign green bonds. This finding prompted a reassessment of earlier claims about the size and universality of the greenium, especially for issuers with smaller or less liquid

[4] A "twin bond" is a green bond issued with identical financial characteristics-such as maturity and coupon-to a conventional bond from the same issuer, differing only in the use of proceeds.

green bond programs. Subsequent research has revealed more nuanced liquidity dynamics. ESMA (2021) documented SGBs tend to have wider bid-ask spreads, by about 0.01 EUR on average, than conventional bonds, reflecting lower liquidity. However, Robeco (2024) observed that this illiquidity premium diminishes for large, frequently reopened green bond lines such as the German Bund, where the greenium can be as low as -1.8 bps. This suggests a "liquidity threshold effect," whereby a minimum level of market depth is necessary for a greenium to emerge. The experience of early sovereign issuers such as Poland, which initially showed no greenium despite strong demand, supports this interpretation.

Another important dimension explored in the literature is the maturity structure of greenium effects. A Bruegel (2022) study found that short-dated green bonds (less than five years to maturity) exhibited a greenium more than twice as large as that of longer-dated bonds, a pattern not observed in the corporate green bond market. This was attributed to regulatory capital requirements that favour short-term ESG assets among institutional investors, creating excess demand at the short end of the curve. Longitudinal studies have documented the evolution of the greenium over time. Banque de France (2024) reported that the greenium for French SGBs widened from -1.2 bps in 2021 to -3.1 bps in 2023, coinciding with the cumulative green issuance surpassing 15% of total sovereign debt. In contrast, the IMF (2023-2) found that greenium volatility increased during periods of monetary tightening, with the German 10-year green bond yield briefly exceeding that of its conventional counterpart by 2.1 bps in 2022. Data from the Climate Bonds Initiative (2023) indicates that the gap between primary and secondary market greenium has narrowed over time, with average bookbuilding discounts for new sovereign green bonds falling from 2.1 bps in 2020 to just 0.8 bps in 2023, suggesting improved price discovery and reduced reliance on "green concessions" to attract investors.

Despite these advances, there are ongoing debates about the interpretation and persistence of the greenium. Baker et al. (2022) argue that the greenium is primarily a function of supply-demand imbalances and disappears when green bond issuance exceeds a certain threshold. Zerbib (2019) raises the question of whether the greenium really reflects investor preferences for environmental impact or is driven by regulatory arbitrage, noting that a significant portion of the observed premium occurs in jurisdictions with mandatory ESG investment guidelines. Taken together, the literature converges on the existence of a modest greenium for sovereign green bonds, typically in the range of -1.5 to -4 bps, though this premium is highly sensitive to liquidity conditions. The use of z-spreads and liquidity-adjusted regressions has improved the precision of greenium estimates, but questions remain about the persistence of this premium as the market matures.

5.3. Selection of sample bonds and their closest non-green peers

To construct the sample of SGBs for this quantitative analysis, we relied on Refinitiv Workspace. As of the time of writing, there were 105 active, plain vanilla, fixed-coupon, investment-grade SGBs in issuance, each with multiple reopenings and reissuances. The sample includes bonds issued by various countries and denominated in multiple currencies, and we opted not to exclude any SGB based on these criteria. However, to ensure sufficient secondary market trading data for our analysis, we considered a minimum of one year of data to be adequate and restricted the sample to bonds issued before 2024, reducing the dataset to 66 bonds. The next step in the selection process was more complex. As we will detail in the following section, our methodology involves linear interpolation in both primary and secondary markets. This process is tedious, as it requires identifying one or two highly comparable non-green bonds from the issuer's yield curve for each SGB at the time of issuance. Specifically, these reference bonds must have the same ticker, similar maturities, and the same currency as the green bond. Identifying such comparables is nontrivial, as green bonds are mostly issued on the long-end segment of the yield curve, and many sovereign issuers operate across multiple currencies. For numerus bonds, particularly in the countries of Colombia, Denmark and Germany, Sovereigns issued on the same day as our studied SGB another non-green Sovereign bond. This makes for a particularly interesting and precise analysis. Applying the above-mentioned selection criterion further reduced the final sample to 26 SGBs, which are detailed in Table 1 in appendix. These bonds were issued by Canada, Colombia, Denmark, France, Germany, Hungary, Indonesia, Ireland, New Zealand, Poland, Switzerland, and the United Kingdom. The final dataset comprises a total of 152 observations in the primary market, including both initial issuances and reopenings.

5.4. Primary market analysis

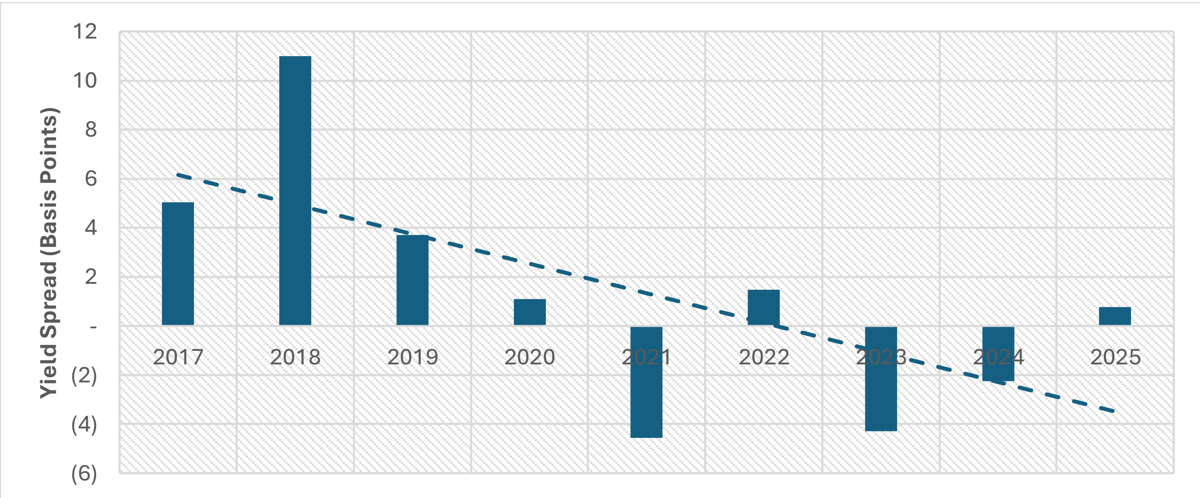
We begin by analysing the pricing of our sample of SGBs at issuance, before they begin trading in the secondary market. This approach allows us to determine whether SGBs are initially priced at a premium or discount relative to conventional bonds from the same issuer. To assess this pricing differential, we employ linear interpolation, a method widely used in academic literature such as by Bertelli et al. (2021) and featured in periodic reports from the Climate Bonds initiative (2024). Our methodology involves comparing the yield at issuance of each SGB with the yield of a fitted non-green sovereign bond from the same issuer. Since we are analysing the primary market, we use the average break-even yield of the green bonds, which reflects the issuer's actual cost of borrowing. In contrast, the non-green bonds used for comparison are already trading in the secondary market, where break-even yields are not applicable. For these, we use bid yields, as they represent the price at which dealers are willing to buy, offering a more relevant measure for the issuer than ask yields, which reflect selling prices. Initially, we considered fitting a cubic curve to the issuer's entire yield curve at the time of each SGB issuance to serve as the benchmark for interpolation. However, this method presented several limitations. Many SGBs are issued at the long end of the yield curve, where there are few comparable bonds, making the interpolation unreliable. Moreover, shorter-dated bonds are often not appropriate comparators for long-term SGBs. To address these limitations, we adopted a manual selection process, commonly used in the literature (Bertelli et al., 2021), to identify the two closest non-green bonds for each SGB at issuance, one maturing before and one after. These bonds were selected based on maturity, outstanding amount, issuer, ticker, coupon structure, payment frequency, and currency, differing only in their use of proceeds (i.e., non-green). This filtering process reduced our sample from 66 to 26 SGBs, as detailed in the previous section, but ensured a more robust and accurate benchmark for assessing yields at issuance.

Our primary analysis offers mixed results. Among 152 observations across 26 bonds, we find 63 instances of positive yield spreads at issuance and 89 instances of negative spreads. The average spread across all observations is –1.54 bps (Table 3 in appendix). Although the observed mean spread suggests a potential lower yield for green bonds, the result is not statistically significant at the 5% level ($t = -1.469$, $p \approx 0.144$, 95% CI = [–3.72, 0.63]). Therefore, we cannot conclude that the average spread differs significantly from zero. However, the direction of the mean and the marginal one-tailed p-value (~0.072) provide some evidence of a negative spread, statistically significant only at the 10% level. Notably, Switzerland, the United Kingdom, Ireland, Poland, and Hungary exhibit positive spreads, while Canada, Colombia, Germany, Denmark, France, Indonesia, and New Zealand exhibit negative spreads. A key finding is the progressive decline in average yield spreads over time. Early issuances tend to show positive spreads, whereas more recent issuances increasingly display negative spreads. This trend is consistent with the findings of Doronzo et al. (2021), which suggests a strengthening "greenium" over time, as investors become more willing to accept lower yields for green instruments. Doronzo et al. (2021) documented a positive, yet declining yield spread; our findings confirm this downward trajectory, with the average spread now reaching negative figures. Figure 4 illustrates this trend. Three outliers stand out in the dataset: two Indonesian bonds with unusually high negative spreads (averaging –42 bps), and a Hungarian bond with an exceptionally high positive spread at issuance (65.1 bps). Excluding these outliers slightly increases the average spread to –1.45 bps, though the result remains statistically insignificant.

Historically, positive yield spreads for green bonds have been attributed to the need for an illiquidity premium (Stephan et al., 2018), which we will further analyse in the secondary market.

For now, our results suggest that green bonds are gradually losing their positive yield spread, making SGBs increasingly cost-effective for issuers. Given the statistical insignificance of the primary market yield spread, liquidity conditions are not examined at this stage but will be addressed in our secondary market analysis. It is important to note that our findings are still based on a relatively small dataset. While sovereign issuance of green bonds is growing, it remains a niche segment of the overall bond market. These bonds also vary widely in terms of issuance currency, frequency, and method. Some sovereigns, such as Germany, France, Denmark, the United Kingdom, and New Zealand, have reopened their green bonds multiple times (New Zealand has done so a record 34 times), while others, such as Canada, Poland, Indonesia, and Hungary, have not. Our analysis suggests that one-off issuances show much greater variability in yield spreads than reopened ones, possibly due to novelty effects or investor fear of missing out. Furthermore, differences in issuance methods (e.g., auctions vs. bank syndication) add further complexity. These considerations warrant caution when drawing definitive conclusions about yield spreads at issuance.

Figure 4: Average yield spread at issuance (basis points per year)



5.5. Secondary market analysis

We now investigate whether such a spread emerges in the secondary market. As previously mentioned, the trading history for the selected bonds must be sufficiently long to allow for meaningful secondary market analysis. The selection of bonds was conducted accordingly, ensuring that we have data from at least the beginning of 2024 for all selected instruments. We begin with some preliminary observations by examining the progression of bid yield to maturity in order to detect any anomalies or notable patterns.

Illustrated in this section and appendix are six of the 26 sample SGBs, each from a different country. While all bonds in the sample were analysed quantitatively, only a subset is displayed for space considerations. This subset was selected at random and does not alter the statistical conclusions of the analysis, which are made on all data points. At first glance, when examining bid yield to maturity, it appears that SGBs generally trade in line with their conventional peers (Figure 6 in appendix). In cases where the green bond lies somewhere in the middle in terms of maturity relative to its comparables (e.g., New Zealand, France, Switzerland, UK and Indonesia), it exhibits similar directional movements and remains within the yield bounds of its peers. This behaviour is expected and simply reflects maturity differences between the bonds. German SGBs, each issued on the same date as a comparable conventional peer, move exactly in line with their peers. We also observe that bid-ask spreads are either comparable to or slightly higher than those of similar conventional bonds (Figure 7 in appendix). Specifically, the bid-ask spreads of the French, British and New Zealand SGBs lie in the middle range of their respective peer groups, whereas the German, Swiss, and Indonesian SGBs exhibit wider bid-ask spreads than their comparables. We will analyse this observation in greater detail later in this section, as we isolate liquidity as a factor to determine whether a greenium can be identified.

Looking solely at yield to maturity is insufficient to assess the presence of a greenium. As mentioned in our literature review, the more standard methodology in the literature for evaluating pricing differences between SGBs and their conventional counterparts is the use of the zero-volatility spread. The z-spread represents the constant spread that must be added to each point on the government (risk-free) spot rate curve so that the present value of a bond's cash flows equals its market price. It is termed "zero-volatility" because it assumes deterministic interest rates and, therefore, excludes adjustments for interest rate volatility or embedded options. Although we are comparing government bonds, where the issuer is the same as the reference curve, it remains meaningful to compute the z-spread. This is because sovereign issuers typically have multiple outstanding bonds with varying maturities, coupon structures, and liquidity profiles. Consequently, not all sovereign bonds trade precisely on the theoretical risk-free curve. The z-spread captures these deviations, reflecting relative richness or cheapness across bonds issued by the same sovereign. In particular, the z-spread incorporates factors such as demand imbalances, and market microstructure effects that are not explained by the yield curve alone. Employing z-spreads thus allows us to isolate pricing differentials in a manner that adjusts for maturity and ensures consistency in duration. This is particularly important in our context, as SGBs often have significantly longer/ shorter durations than their closest benchmarks.

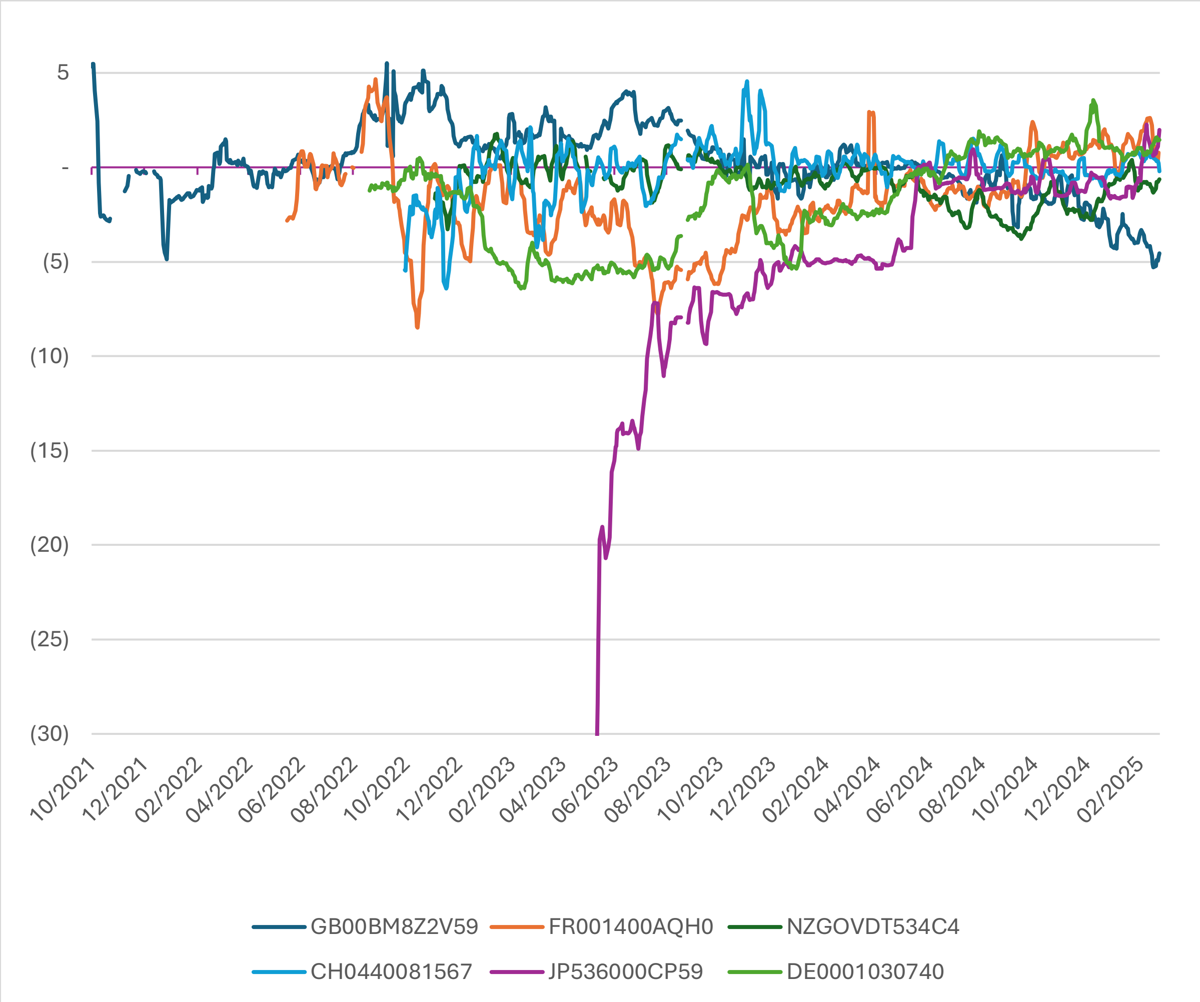
In practical terms, we retrieve daily z-spread data $(ZS\_SGB_{i,t})$ from Refinitiv Workspace for our selected set of SGBs. For each bond, we also obtain the daily z-spreads of the two conventional sovereign bonds issued by the same country with the nearest higher and lower residual maturities.[5] We then linearly interpolate between these two z-spreads to estimate a synthetic conventional bond z-spread $(ZS\_SCB_{i,t})$ that matches the SGB's maturity on each trading day. This synthetic spread represents the expected pricing of a hypothetical non-green sovereign bond with identical characteristics and residual maturity. The difference between the green bond's z-spread and the interpolated conventional z-spread forms the basis of our daily greenium estimate, which we denote as $DZS_{i,t}$. A negative DZS implies that the SGB yields less than the CB, and therefore the existence of a greenium, ceteris paribus.

$$DZS_{i,t} = ZS\_SGB_{i,t} - ZS\_SCB_{i,t}\ (Equation\ 1)$$

The analysis reveals a small, yet statistically significant, negative average DZS of approximately -1.26 *** bps, indicating the presence of a modest greenium (table 3 in appendix)[6]. Figure 7 in the appendix displays the density function of the DZS data, provides a clear visual representation of this negative greenium and illustrates that the majority of DZS values lie between -10 and 10 bps. Interestingly, the data also highlight a general convergence in the market valuations of SGBs and conventional bonds: over time, the pricing of SGBSs has increasingly aligned with that of conventional bonds and their peers in the market, lowering the DZS and suggesting that the greenium is gradually diminishing (cf. Figure 5 below). This convergence trend is likely reflective of the growing acceptance of green bonds in the broader financial market, with their pricing becoming more competitive and aligned with traditional bonds.

[5] Or only one conventional sovereign bond if it was issued on the same day as the SGB with the same maturity, see table 1.
[6] Legend: *-statistically significant at the 10% level, **-statistically significant at the 5% level, ***-statistically significant at the 1% level.

Figure 5: DZS since issuance of 6 bonds in our sample (bps)



5.5.1. Regression Model and introduction of liquidity

Given the small magnitude of the greenium suggested by the DZS descriptive statistics and the substantial difference in bid-ask spreads between green and conventional bonds, we now conduct an empirical analysis that investigates two key questions: Does liquidity influence the yield differential (DZS) between green and conventional bonds? After controlling for liquidity, do green bonds still exhibit a systematic yield discount (i.e., a greenium)? To answer these questions, we apply the methodology used in prior literature, which estimates the premium of a Green Bond over a conventional bond, while controlling for liquidity differences (Doronzo et al., 2021) (Zerbib, 2019). By comparing bonds from the same issuer, with similar maturities and identical credit ratings, we limit the influence of factors unrelated to liquidity.

A crucial challenge in this analysis is the selection of an appropriate liquidity proxy. Since reliable traded volume data is unavailable, and variables like outstanding bond amount ratios do not vary frequently in the secondary market, we adopt a widely used liquidity measure ($L_{i,t}$) (Fong et a., 2017): the quoted bid-ask spread. We define relative liquidity as the difference between the bid-ask spread of our studied green bond ($BA\_SGB_{i,t}$) and the average bid-ask spread of our two closest non-green conventional bonds ($BA\_ACB_{i,t}$)[7].

$$L_{i,t} = BA\_SGB_{i,t} - BA\_ACB_{i,t} \text{ , } (Equation\ 2)\ where$$

$$BA\_ACB_{i,t} = \frac{BA\_Conventional\_bond\_1_{i,t} + BA\_Conventional\_bond\_2_{i,t}}{2} \quad (Equation\ 3)$$

A positive value of L would imply that the SGB is less liquid than its conventional counterpart and vice versa. Since liquidity is a key determinant of bond yields, we include it as a control variable to isolate the true pricing difference between green and non-green bonds. To quantify the impact of liquidity on yield differentials and test for the presence of a greenium, we estimate the following regression model:

$$DZS_{i,t} = \rho_i + \beta L_{i,t} + \epsilon_{i,t}\ (Equation\ 4)$$

Where ρ_i will captures the residual difference in yields after controlling for liquidity, and $\epsilon_{i,t}$ is the error term.

5.5.2. Ordinary Least Squares (OLS) regression model

All results of regressions are outlined in table 5 in the appendix. Our analysis begins with a standard OLS regression, which reveal an intercept estimate of approximately -1.27 ***, suggesting that when liquidity is not a factor, a greenium remains. This result provides initial evidence that, on average, green bonds still exhibit lower yields than their conventional counterparts, ceteris paribus. The coefficient on liquidity is estimated at around 0.01, but its lack of statistical significance indicates that liquidity does not appear to have a meaningful effect on the DZS within this first model. Moreover, the R-squared value is extremely low (0.00), suggesting that the model explains virtually none of the variation in the greenium. This poor explanatory power implies that the OLS approach may not be well-suited for capturing the relationship between green bond yields and liquidity, possibly due to omitted variables or unobserved heterogeneity in the data.

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[7] Or only one conventional sovereign bond if it was issued on the same day as the SGB with the same maturity.

To assess whether the OLS model suffers from misspecification, a Ramsey RESET test is conducted (see table 6 in appendix). The test strongly rejects the null hypothesis of correct functional form, with a test statistic of 86.315 ***. This suggests that the model likely omits important explanatory variables or fails to capture the appropriate functional relationship between liquidity and the greenium. Given this result, it is necessary to consider more advanced econometric models that can account for unobserved heterogeneity, such as the Fixed Effects and Random Effects models.

5.5.3. Fixed effects regression model

To control for bond-specific heterogeneity, a Fixed Effects model is estimated. This approach allows for the inclusion of individual bond-specific intercepts, thereby accounting for time-invariant characteristics that may influence the greenium. The results indicate a more pronounced negative greenium, with an intercept of approximately -1.86 ***. This suggests that after controlling for unobserved heterogeneity, the estimated greenium is even larger in absolute magnitude than what was found under OLS. More importantly, the coefficient on liquidity is estimated at approximately 6.01 ***, now highly statistically significant. This result indicates a strong positive relationship between liquidity and the greenium, meaning that as liquidity increases (i.e., bid-ask spreads of the SGB narrow), the yield differential between green and conventional bonds increases. Put differently, more liquid green bonds tend to trade at lower yields, whereas less liquid green bonds tend to trade at higher yields relative to their conventional counterparts. The R-squared value of the Fixed Effects model is 0.13, which, while still modest, represents a really significant improvement over the OLS model.

To determine whether the Fixed Effects or Random Effects model is more appropriate, a Hausman test is performed (see table 7 in appendix). The test strongly rejects the null hypothesis that the Random Effects model provides consistent estimates, with a test statistic of 15.97 ***. This result indicates that the unobserved bond-specific factors are correlated with the explanatory variables, making the Fixed Effects model the preferred specification.

5.5.4. Random effects GLS regression model and robust s.e.

Despite the Hausman test favouring the Fixed Effects approach, a Random Effects model is estimated for comparison. The results largely confirm the findings from the Fixed Effects regression, with an intercept of approximately -1.31 * and a liquidity coefficient of around 5.72 ***. The coefficient on liquidity remains highly statistically significant, supporting the conclusion that liquidity plays a meaningful role in determining the greenium. However, given the rejection of the Random Effects assumption in the Hausman test, this model is less reliable than the Fixed Effects specification.

Finally, a robust Random Effects model is estimated using heteroscedasticity-robust standard errors to account for potential heteroscedasticity in the data. The coefficient on liquidity remains positive and close in magnitude to the previous estimates, though its statistical significance is reduced. This suggests that while the relationship between liquidity and the greenium is robust, heteroscedasticity may play a role in influencing the precision of the estimated coefficients.

5.5.5. Best model and regression conclusions

Overall, the Fixed Effects model emerges as the most reliable specification for analysing the greenium. The results indicate that green bonds exhibit a small, negative yield differential relative to conventional bonds of -1.86 ***, confirming the presence of a greenium, after accounting for liquidity differences. This is in line with current academic literature converging on the existence of a modest greenium for SGBs, typically in the range of -1.5 to -4 bps as detailed in the literature review. From the issuer's perspective, this negative yield differential constitutes a tangible advantage, as it enables sovereigns to finance themselves at a marginally lower cost compared to issuing conventional bonds. This provides an additional incentive for governments to pursue sovereign green bond programmes, aligning environmental objectives with financial benefits. Furthermore, liquidity has a coefficient of 6.01 *** and is found to be a significant factor in explaining variations in the greenium, with less liquid green bonds (those with wider bid-ask spreads) displaying a larger DZS spreads, and vice versa. This finding suggests that investors demand higher yields for holding illiquid green bonds, while more liquid green bonds trade at a smaller yield differential relative to their conventional counterparts. This result is a known phenomenon in the fixed income literature but was not widely documented in the context of sovereign green bonds and not reported by the research of Doronzo et al. (2021),which we are building upon and extending. Our results highlight the importance of considering liquidity when analysing the pricing of SGBs, as market frictions appear to play a key role in shaping yield differences.

6. Conclusion

This paper set out to analyse the role and performance of sovereign green bonds (SGBs), combining a review of their institutional development and regulatory foundations with a detailed empirical investigation of their pricing behaviour. The objective was to understand whether these instruments, increasingly used by governments to finance climate priorities, offer a financial advantage relative to conventional debt, and what factors contribute to any such advantage.

The first part of the paper provided the broader context in which SGBs have emerged. Although corporate green bonds have been extensively researched, sovereign green issuance remains underexplored in the academic literature, despite its increasing share of the labelled debt market. Our review highlighted how the SGB market has evolved since 2016, shaped by investor demand, international climate commitments, and the development of regulatory frameworks such as the Green Bond Principles and the EU Taxonomy. We also identified the main motivations and constraints faced by sovereign issuers. Green bonds allow governments to access ESG-oriented capital, reinforce their climate credibility, and support market development. But they also introduce stricter earmarking, elevated reporting burdens, and reputational risks, factors particularly relevant for countries with less institutional capacity.

The second part of the paper focused on the financial performance of sovereign green bonds in both primary and secondary markets. Drawing on a sample of 26 SGBs and their closest conventional peers, we first investigated primary market pricing by comparing yields at issuance through interpolation. The results were mixed: the average spread was -1.54 bps, indicating a potential greenium, but the effect was not statistically significant at the 5% level. The distribution of spreads also revealed high heterogeneity across issuers and issuance dates. However, the direction of the average and the marginal significance suggest that the greenium may have become more pronounced in more recent issuances, a trend that aligns with findings in earlier literature. We then turned to the secondary market, where a more robust signal emerged. By retrieving z-spreads for each SGB and comparing them with maturity-adjusted synthetic benchmarks, we derived a daily delta z-spread (DZS) as our greenium estimate. The analysis showed a statistically significant negative mean DZS of -1.26 *** bps, confirming that, on average, sovereign green bonds trade at lower yields than their conventional counterparts. This finding implies that green bonds are not only accepted by investors without requiring a yield premium but may actually benefit from slightly lower borrowing costs over time. A central aspect of the empirical work was then to assess the influence of liquidity on observed yield differentials. Using bid-ask spread differentials as a proxy, we tested whether green bonds are priced differently once liquidity is considered. Several panel regression models were estimated, beginning with a baseline OLS specification and followed by fixed effects and random effects models. The OLS model, while showing a negative intercept, explained little variation and failed diagnostic tests. In contrast, the fixed effects model, which controls for unobserved, time-invariant bond-specific traits, yielded a larger negative intercept of –1.86 bps and a highly significant positive coefficient on liquidity of 6.01 bps. This implies that more liquid green bonds are associated with a larger negative greenium, while less liquid ones tend to trade closer to or above their conventional peers. Whilst the random effects model yielded close results, the Hausman test confirmed that the fixed effects was preferred.

Several key implications follow from these findings. First, the existence of a small but statistically significant greenium in secondary markets, after adjusting for liquidity, suggests that sovereign issuers may benefit from a financial advantage when issuing green-labelled bonds. This can improve the attractiveness of SGBs as a funding tool, particularly in jurisdictions with established frameworks and strong demand from ESG-oriented investors. Second, the analysis reveals that liquidity plays a critical role in green bond pricing, and that variation in liquidity can partially explain why some SGBs trade at tighter spreads than others. Issuers and public debt managers seeking to maximize the benefits of SGBs should therefore consider factors and methods that support market liquidity, such as bond syndication methods and reopening strategies. The findings highlight the limits of simplistic greenium analyses that ignore structural variables like liquidity.

The results also point to several avenues for future research. First, expanding the dataset to include more recent issuances and new sovereign entrants would allow for time-series analysis of how the greenium evolves as the market matures. Second, integrating data on investor composition, such as the share of holdings by ESG funds, could help explain differences in pricing across jurisdictions. Third, future work could assess the interaction between sovereign green bonds and monetary policy tools, such as collateral eligibility in central bank operations or purchases under green quantitative easing programs. Finally, as new instruments such as sovereign sustainability-linked bonds are introduced, comparative studies will be needed to evaluate their effectiveness relative to traditional use-of-proceeds structures.

In conclusion, this paper has shown that sovereign green bonds are not only important political and strategic tools but also instruments with specific and observable financial characteristics. While their pricing advantage remains relatively modest, it is consistent, significant, and influenced by identifiable factors, especially liquidity. With the ongoing expansion of the sovereign green bond market, its design, transparency, and market functioning will remain essential areas of inquiry for scholars, investors, and policymakers alike.

7. Bibliography

Agence France Trésor. (n.d.). *Green OATs*. Retrieved from https://applis.finances.gouv.fr/en/green-oat

Agence France Trésor. (2017, December 11). *Green OAT: First meeting of the Evaluation Council.* Retrieved from https://www.aft.gouv.fr/en/publications/communiques-presse/20171211-green-oat-first-meeting

Amstad, M., Packer, F., & Schmitz, M. (2023). How Large is the Sovereign Greenium? *IMF Working Paper WP, 23*(80).

Asian Development Bank. (2018). *How to issue green bonds, social bonds and sustainability bonds*. Retrieved from https://asianbondsonline.adb.org/green-bonds/pdf/How%20to%20Issue%20Guide%20English%20FINAL%20PRINT.pdf

Baker, M., Bergstresser, D., Serafeim, G., & Wurgler, J. (2022). The Pricing and Ownership of U.S. Green Bonds. *Annual Review of Financial Economics*(14), 339-362.

Bank for International Settlements. (2022, September). *Sovereign green bonds: The start of a new wave?* Retrieved from BIS Quarterly Review: https://www.bis.org/publ/qtrpdf/r_qt2209d.htm

Banque de France. (2024). Do Green Sovereign Bonds Benefit from a Green Premium? *Financial Stability Review*(380).

Bertelli, B., Boero, G., & Torricelli, C. (2021). The market price of greenness: A factor pricing approach for Green Bonds. *Netspar.*

Bianchini, L., & Nicodano, G. (2024). Uncovering the Greenium: Yield Spreads and Liquidity Effects. *SSRN Working Paper*(4788877).

Boffo, R., & Patalano, R. (2020). *ESG investing: Practices, progress and challenges.* Retrieved from https://doi.org/10.1787/b4f71091-en

Bruegel. (2022). Greeniums in Sovereign Bond Markets. *Bruegel Working Paper*(17).

Cheng, G., Ehlers, T., & Packer, F. (2022, September 19). *Sovereigns and sustainable bonds: Challenges and new options.* Retrieved from Bank for International Settlements: https://www.bis.org/publ/qtrpdf/r_qt2209d.htm

Cheng, G., Ehlers, T., Packer, F., & Xiao, Y. (2024). Sovereign green bonds: A catalyst for sustainable debt market development? *Bank for International Settlements*.

Climate Bonds Initiative. (2014, February 13). *2013 overview: The dawn of the age of green bonds.* Retrieved from https://www.climatebonds.net/2014/02/2013-overview-dawn-age-green-bonds

Climate Bonds Initiative. (2016-1). *Bonds and climate change: The state of the market – France overview 2016. Commissioned by HSBC.* Retrieved from https://www.climatebonds.net/files/files/CB-HSBC-2016-Paris-Eng-02A%20JW.pdf

Climate Bonds Initiative. (2016-2, December 15). *Poland wins race to issue first green sovereign bond: A new era for Polish climate policy?* Retrieved from https://www.climatebonds.net/2016/12/poland-wins-race-issue-first-green-sovereign-bond-new-era-polish-climate-policy

Climate Bonds Initiative. (2021). *Sovereign Green, Social, and Sustainability Bond Survey*. Retrieved from https://www.climatebonds.net/files/reports/cbi-sovereign-green-social-sustainability-bond-survey-jan2021.pdf

Climate Bonds Initiative. (2023). Sovereign Green, Social, and Sustainability Bond Survey: The State of Play. *CBI Report.*

Climate Bonds Initiative. (2024-1, May 17). *China solidifies leadership in green finance for 2023*. Retrieved from https://www.climatebonds.net/resources/press-releases/2024/05/china-solidifies-leadership-green-finance-2023

Climate Bonds Initiative. (2024-2). *Market intelligence report: Q3 2024.* Climate Bonds Initiative.

Climate Bonds Initiative. (N.d.-1). *Climate Bonds guide to certification: Guidance for use of proceeds.* Retrieved from https://www.climatebonds.net/files/page/files/certification_guidance_for_use_of_proceeds.pdf

Climate Bonds Initiative. (N.d.-2). *External review*. Retrieved from https://www.climatebonds.net/market/second-opinion

Columbia Center on Sustainable Investment. (2025). *Sovereign Green, Social, Sustainability, and Sustainability-Linked Bonds: Evaluation of Promises and Prospects for Developing Countries*. Retrieved from https://ccsi.columbia.edu/sites/default/files/content/docs/publications/sovereign-green-social-sustainability-linked-bonds-evaluation-promises-prospects-developing-countries-report.pdf

De la Orden, R., & De Calonje, I. (2022). *Sustainability-linked finance: Mobilizing capital for sustainability in emerging markets*. Retrieved from International Finance Corporation: https://www.ifc.org/en/insights-reports/2022/sustainability-linked-finance

Dittmar, R., & Yuan, K. (2008). Do sovereign bonds benefit corporate bonds in emerging markets? *The Review of Financial Studies, 21*(5), 1983-2014.

Doronzo, R., Siracusa, V., & Antonelli, S. (2021). Green Bonds: the Sovereign Issuers' Perspective. *Mercati, infrastrutture, sistemi di pagamento (Markets, Infrastructures, Payment Systems), 3*.

Ernst & Young Luxembourg. (2024, January 17). *SFDR funds: The power of voluntary assurance*. Retrieved from EY Insights – Wealth & Asset Management:

https://www.ey.com/en_lu/insights/wealth-asset-management/sfdr-funds-the-power-of-voluntary-assurance

European Central Bank. (2022). Pricing of Green Bonds: Drivers and Dynamics of the Greenium. *ECB Working Paper Series*(2728).

European Central Bank. (2025, February 13). Green investment needs in the EU and their funding. *ECB Economic Bulletin*(1).

European Commission. (2021, July 6). Commission Delegated Regulation (EU) 2021/4987 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by specifying the content, methodology, and presentation of the information to be disclosed by undertakings subject to Arti.

European Commission. (N.d.-1). *NextGenerationEU Green Bonds*. Retrieved from https://commission.europa.eu/strategy-and-policy/eu-budget/eu-borrower-investor-relations/nextgenerationeu-green-bonds_en

European Commission. (N.d.-2). *The European Green Deal*. Retrieved from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission. (N.d.-3). *The European green bond standard – Supporting the transition*. Retrieved from https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/european-green-bond-standard-supporting-transition_en

European Investment Bank. (2007-1). *Clean energy for a sustainable future: The EIB and renewable energy Briefing note*. Retrieved from https://www.eib.org/files/publications/general/briefing_bg2007_clean_energy_en.pdf

European Investment Bank. (2007-2, June 5). *EPOS II – Obligation sensible au climat: la BEI œuvre à la protection du climat par le biais de son émission à l'échelle de l'UE*. Retrieved from https://www.eib.org/en/investor-relations/press/all/2007-042-epos-ii-obligation-sensible-au-climat-la-bei-oeuvre-a-la-protection-du-climat-par-le-biais-de-son-emission-a-l-echelle-de-l-ue

European Investment Bank. (n.d.). *Sustainable finance. European Investment Bank*. Retrieved from https://www.eib.org/en/investor-relations/sustainable-finance/index

European Parliament & Council of the European Union. (2023, November 22). Regulation (EU) 2023/2631 on European Green Bonds and optional disclosures for bonds marketed as environmentally sustainable and for sustainability-linked bonds. Official Journal of the European Union, L 2631, 1–43.

European Parliament & Council of the European Union. (2020). Regulation (EU) 2020/852 on the establishment of a framework to facilitate sustainable investment. Official Journal of the European Union, L 198, 13–43.

European Parliamentary Research Service. (2022). *Green bonds: An introduction to the EU's green bond standard*. Retrieved from https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698870/EPRS_BRI(2022)698870_EN.pdf

European Securities and Markets Authority. (2021). Report on Trends, Risks and Vulnerabilities in Financial Markets.

Ferrer, R. C. (2023). *Identifying green bonds' impact on company reputation and risk*. Retrieved from https://www.researchgate.net/publication/384656134_Identifying_Green_Bonds_Impact_on_Company_Reputation_and_Risk

Fong, K., Holden, C., & Trzcinka, C. (2017). What are the best liquidity proxies for global research. *Rev. Finance, 21*(4), 1355-1401.

Fritz, L. d. (2025, March 27). *ABN AMRO Economisch Bureau*. Retrieved from ESG - Green bonds exhibit lower volatility and higher liquidity than non-green bonds: https://www.abnamro.com/research/en/our-research/esg-green-bonds-exhibit-lower-volatility-and-higher-liquidity-than-non-green

Gill, N. (2024, December 3). *Sustainable bond sales hit 11-month low as issuers retreat.* Retrieved from Bloomberg: https://www.bloomberg.com/news/articles/2024-12-03/sustainable-bond-sales-hit-11-month-low-as-issuers-retreat

GIZ, SEB, & ABM. (2018). *Green bonds: Ecosystem, issuance process and regional perspectives – Mexico edition. Emerging Markets Dialogue on Finance.* Retrieved from https://www.emergingmarketsdialogue.org/wp-content/uploads/2018/04/GIZ-SEB-ABM_Green-Bonds_Mexico-Edition.pdf

Gong, Y. (2022, August 5). *Updated Common Ground Taxonomy, the crowbar of international green capital flows?* . Retrieved from Natixis Green & Sustainable Hub: https://gsh.cib.natixis.com/our-center-of-expertise/articles/updated-common-ground-taxonomy-the-crowbar-of-international-green-capital-flows

Ground, J. (2022, June 17). *ESG Global Study 2022.* Retrieved from Harvard Law School Forum on Corporate Governance: https://corpgov.law.harvard.edu/2022/06/17/esg-global-study-2022/

Grzegorczyk, M., & Wolff, G. (2022). Greeniums in Sovereign Bond Markets. *Bruegel Working Paper*(17).

Initiative, C. B. (2024, November). *Climate Bonds Initiative.* Retrieved from Sustainable Debt Market Summary Q3 2024: https://www.climatebonds.net/resources/reports/sustainable-debt-market-summary-q3-2024

Interesse, G. (2024, March 27). *Decoding China's 2024 Green Industry Catalogue: Key takeaways*. Retrieved from China Briefing: https://www.china-briefing.com/news/decoding-china-2024-green-industry-catalogue-key-takeaways/

International Bar Association. (2023). *The rise and rise of green bonds: From niche to norm*. Retrieved from https://www.ibanet.org/article/F43B78F6-59D7-4B29-A332-E10CCC9FF0BE

International Capital Market Association. (2019). *Mapping the SDGs: A working paper on how SDGs relate to green, social and sustainability bonds.* Retrieved from https://www.icmagroup.org/assets/documents/regulatory/green-bonds/june-2019/mapping-sdgs-to-green-social-and-sustainability-bonds06-2019-100619.pdf

International Capital Market Association. (2022-1, September). *Analysis of China's Green Bond Principles.* Retrieved from https://www.icmagroup.org/assets/Analysis-of-Chinas-Green-Bond-Principles.pdf

International Capital Market Association. (2022-2, June). *Green Bond Principles (GBP).* Retrieved from https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles-June-2022-060623.pdf

International Capital Market Association. (2022-3, June). *Handbook – Harmonised Framework for Impact Reporting.* Retrieved from https://www.icmagroup.org/assets/documents/sustainable-finance/2022-updates/harmonised-framework-for-impact-reporting-green-bonds_june-2022-280622.pdf

International Capital Market Association. (2023). *Market integrity and greenwashing risks in sustainable finance.* Retrieved from https://www.icmagroup.org/assets/documents/Sustainable-finance/Market-integrity-and-greenwashing-risks-in-sustainable-finance-October-2023.pdf

International Finance Corporation. (2023). *IFC green bond framework (January 2023).* Retrieved from https://www.ifc.org/content/dam/ifc/doc/2023/IFC-Green-Bond-Framework-Jan-2023.pdf

International Finance Corporation. (n.d.). *Green bonds.* Retrieved from https://www.ifc.org/en/about/investor-relations/green-bonds

International Monetary Fund. (2023-1). Sovereign ESG Bond Issuance: A Guide for Emerging Market and Developing Economies. *IMF Working Paper, 23*(58).

International Monetary Fund. (2023-2). Sovereign Green Bonds: Market Developments and Implications. *IMF Global Financial Stability Report.*

International Platform on Sustainable Finance. (2022, June 3). *Common Ground Taxonomy – Climate Change Mitigation: Instruction report.* Retrieved from https://gsh.cib.natixis.com/our-center-of-expertise/articles/updated-common-ground-taxonomy-the-crowbar-of-international-green-capital-flows

Kaminker, C., & Majowski, C. (2018). *Green bonds: Ecosystem, issuance process and regional perspectives – Mexico edition.* . Retrieved from Emerging Markets Dialogue on Finance: https://www.emergingmarketsdialogue.org/wp-content/uploads/2018/04/GIZ-SEB-ABM_Green-Bonds_Mexico-Edition.pdf

Lindner, P., & Chung, K. (2023). Sovereign ESG bond issuance: A guidance note for sovereign debt managers. *IMF Working Paper*(058).

Madeira, C., & Pérez, A. (2023, October 16). The role of sovereign green bonds in Chile's development. *Georgetown Journal of International Affairs*.

Malta Financial Services Authority. (2019). *Prospectus approved in accordance with the Prospectus Directive.* Retrieved from https://www.mfsa.mt/wp-content/uploads/2019/01/Prospectus-approved.pdf

Ministère de la Transition Écologique. (n.d.). *Les obligations vertes*. Retrieved from www.ecologie.gouv.fr/sites/default/files/publications/17006-EN_Les%20obligations%20vertes_DEF_Web_Page-%C3%A0-page.pdf

Ministry of Finance of the People's Republic of China. (2025, February). *The People's Republic of China Sovereign Green Bond Framework*. Retrieved from https://www.szgfa.com/Private/Files/20250221/638757477861349127506l209.pdf

MSCI. (2023). *Sovereign sustainability: How duration impacts returns in labeled sovereign bonds*. Retrieved from https://www.msci.com/www/quick-take/sovereign-sustainability-how/04970305750

Natixis Green & Sustainable Hub. (2019). *TEG 101 – The EU Green Bond Standard.* Retrieved from https://gsh.cib.natixis.com/site/T_rRFifyaz6SK8y7TKR4rw/api-website-feature/files/download/7971/eu_green_bond_standard_special_report_natixis_green_and_sustainable_hub.pdf

People's Bank of China. (2021, September 16). *Green Bond Endorsed Projects Catalogue (2021 Edition).* Retrieved from http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/4342400/2021091617180089879.pdf

Pietsch, A., & Salakhova, D. (2022). Pricing of green bonds: drivers and dynamics of the greenium. *European Central Bank Working Paper Series.*

Raghu Raman, S., Ray, S., Das, D., & Nedungadi, P. (2024). Innovations and barriers in sustainable and green finance for advancing sustainable development goals. *Frontiers in Environmental Science, 12*(1513204).

République Française. (2017, January 10). *Framework for the Green OAT.* Retrieved from https://applis.finances.gouv.fr/files/archives/attachments/25562.pdf

Robeco. (2024). The Greenium in High-Rated Euro Bonds. *Fixed Income Research Report.*

World Bank. (2008, November 6). *World Bank and SEB partner with Scandinavian institutional investors to finance green projects.* Retrieved from https://www.worldbank.org/en/news/press-release/2008/11/06/world-bank-and-seb-partner-with-scandinavian-institutional-investors-to-finance-green-projects

World Bank. (2015). *Green bond: Working towards a sustainable future (Revised edition).* Retrieved from https://documents1.worldbank.org/curated/en/400251468187810398/pdf/99662-REVISED-WB-Green-Bond-Box393208B-PUBLIC.pdf

World Bank. (2024). *IBRD sustainable development bond: FY23 impact report.* Retrieved from https://thedocs.worldbank.org/en/doc/667f95939700497452d00a1544ba2d01-0340022024/original/World-Bank-IBRD-FY23-IMPACT-REPORT.pdf

World Bank. (2025). Labeled bond quarterly newsletter. *World Bank*(10).

World Bank Treasury. (n.d.). *IBRD Green Bonds.* Retrieved from https://treasury.worldbank.org/en/about/unit/treasury/ibrd/ibrd-green-bonds

Wulandari, F., Schäfer, D., Stephan, A., & Sun, C. (2018). The impact of liquidity risk on the yield spread of green bonds. *Finance Research Letters*(27).

Yuan, K. (2005). The liquidity service of benchmark securities. *Journal of European Economic Association*(3), 1156–1180.

Zerbib, O. (2019). The effect of pro-environmental preferences on bond prices: Evidence from green bonds. *Journal of Banking and Finance*(98), 39-60.

8. Appendix

Table 1: List of all sample SGBs and their closest comparable peers

Bond	Issuer	Coupon	Maturity	Issue Date	ISIN	Principal Currency	Amount Issued (USD)	Comparable Befo	Maturity	Comparable After	Maturity
1	Canada (Government)	2.2500	01/12/2029	29/03/2022	CA135087N670	Canadian Dollar	3,464,523,281	CA135087J397	01/06/2029	CA135087K379	01/06/2030
2	Colombia, Republic of (Government)	7.0000	26/03/2031	29/09/2021	COL17CT03797	Colombian Peso	1,154,319,757	COL17CT03771	26/03/2031	-	-
3	Denmark, Kingdom of (Government)	0.0000	15/11/2031	21/01/2022	DK0009924375	Danish Krone	2,377,536,380	DK0009924102	15/11/2031	-	-
4	Denmark, Kingdom of (Government)	2.2500	15/11/2033	03/10/2023	DK0009924615	Danish Krone	2,659,356,425	DK0009924532	15/11/2033	-	-
5	France, Republic of (Government)	0.1000	25/07/2038	01/06/2022	FR001400AQH0	Euro	7,739,758,930	FR0013327491	25/07/2036	FR0010447367	25/07/2040
6	France, Republic of (Government)	1.7500	25/06/2039	31/01/2017	FR0013234333	Euro	39,636,649,489	FR0010371401	25/10/2038	FR0010773192	51616
7	France, Republic of (Government)	0.5000	25/06/2044	23/03/2021	FR0014002JM6	Euro	26,061,228,054	FR0010773192	25/04/2041	FR0011461037	25/05/2045
8	Germany, Federal Republic of (Government)	0.0000	10/10/2025	06/11/2020	DE0001030716	Euro	9,280,286,487	DE0001141828	10/10/2025	-	-
9	Germany, Federal Republic of (Government)	1.3000	15/10/2027	07/09/2022	DE0001030740	Euro	9,826,185,693	DE0001141869	15/10/2027	-	-
10	Germany, Federal Republic of (Government)	0.0000	15/08/2030	09/09/2020	DE0001030708	Euro	10,917,984,103	DE0001102507	15/08/2030	-	-
11	Germany, Federal Republic of (Government)	0.0000	15/08/2031	10/09/2021	DE0001030732	Euro	9,826,185,693	DE0001102564	15/08/2031	-	-
12	Germany, Federal Republic of (Government)	2.3000	15/02/2033	03/05/2023	DE000BU3Z005	Euro	12,009,782,513	DE000BU2Z007	15/02/2033	-	-
13	Germany, Federal Republic of (Government)	0.0000	15/08/2050	18/05/2021	DE0001030724	Euro	13,920,429,731	DE0001102481	15/08/2050	-	-
14	Germany, Federal Republic of (Government)	1.8000	15/08/2053	20/06/2023	DE0001030757	Euro	12,009,782,513	DE0001102614	15/08/2053	-	-
15	Hungary (Government)	5.0000	22/02/2027	21/11/2022	XS2558594391	Euro	1,091,798,410	XS2161992198	28/04/2026	XS1696445516	10/10/2027
16	Indonesia, Republic of (Government)	1.2000	24/05/2030	26/05/2023	JP536000CP59	Japanese Yen	99,478,919	JP536000CN69	08/06/2029	JP536000DL78	47672
17	Indonesia, Republic of (Government)	1.4300	26/05/2033	26/05/2023	JP536000DP58	Japanese Yen	40,603,640	JP536000DN68	09/06/2032	JP536000EK52	22/05/2034
18	Ireland (Government)	1.3500	18/03/2031	17/10/2018	IE00BFZRQ242	Euro	7,804,273,298	IE00BJ38CR43	15/05/2030	IE00BFZRPZ02	48714
19	Ireland (Government)	3.0000	18/10/2043	12/01/2023	IE000GVLBXU6	Euro	4,385,917,984	IE00B8RZMN07	20/05/2042	IE00BV8C9186	18/02/2045
20	New Zealand (Government)	4.2500	15/05/2034	22/11/2022	NZGOVDT534C4	New Zealand Dollar	5,456,862,218	NZGOVDT433C9	14/04/2033	NZGOVDT437C0	50145
21	Poland, Republic of (Government)	1.1250	07/08/2026	07/02/2018	XS1766612672	Euro	1,091,798,410	XS1346201616	19/01/2026	XS1209947271	10/05/2027
22	Poland, Republic of (Government)	1.0000	07/03/2029	07/03/2019	XS1958534528	Euro	1,637,697,615	XS1508566392	25/10/2028	XS0211389753	49342
23	Poland, Republic of (Government)	2.0000	08/03/2049	07/03/2019	XS1960361720	Euro	545,899,205	XS1508566558	25/10/2046	XS0224427160	20/07/2055
24	Switzerland, Confederation of (Government)	1.5000	26/10/2038	26/10/2022	CH0440081567	Swiss Franc	3,012,804,532	CH0127181193	27/06/2037	CH0440081401	50975
25	UK of GB and Northern Ireland (Government)	0.8750	31/07/2033	22/09/2021	GB00BM8Z2S21	British Pound	47,324,064,004	GB0004893086	07/06/2032	GB00B52WS153	07/09/2034
26	UK of GB and Northern Ireland (Government)	1.5000	31/07/2053	22/10/2021	GB00BM8Z2V59	British Pound	34,411,734,244	GB00B6RNH572	22/07/2052	GB00BJLR0J16	56544

Table 2: Primary market yield spread results (basis points)

	CAN	SWI	COL	GER							DEN		FRA			GBR		IRE		IND		NZE	POL			HUN	
Tranche	CA135087N670	CH0440081567	COL17CT03797	DE0001030708	DE0001030716	DE0001030724	DE0001030732	DE0001030740	DE0001030757	DE000BU3Z005	DK0009924375	DK0009924615	FR0013234333	FR0014002JM6	FR001400AQH0	GB00BM8Z2S21	GB00BM8Z2V59	IE000GVLBXU6	IE00BFZRQ242	JP536000CP59	JP536000DP58	NZGOVDT534C4	XS1766612672	XS1958534528	XS1960361720	XS2558594391	WA
Initial Issue	(12.9)	32.5	(27.4)	(0.0)	(5.1)	(6.4)	(3.3)	0.2	4.4	19.6	1.1			(2.2)	(11.3)	0.8	5.0	15.0	10.1	(35.4)	(48.6)	11.6	(1.8)	8.0	0.4	65.1	**0.8**
2		(11.4)	(12.4)	0.6	(10.9)	(19.9)	(7.0)	(3.0)	4.3	(24.0)	(0.6)	(12.2)	4.6	1.9	2.4			(7.9)	5.7			(17.2)					**(6.3)**
3		(12.0)	(16.3)	17.6	(13.0)	0.7	(16.8)	6.2	(1.6)	6.1	3.5	5.5	5.4	2.9	(4.7)	3.4			(1.4)			5.3					**(0.5)**
4		(4.6)	(22.5)	(2.7)	(5.2)	2.9	(17.4)	0.2	(8.9)	(11.6)	(14.1)	(10.9)	6.0	(11.2)	(2.5)		34.8		(1.3)			(7.7)					**(4.5)**
5			(1.1)			(2.9)			3.8	(1.1)	(5.2)	(0.8)	29.7	1.4	(10.5)				(4.1)			17.8					**2.4**
6						1.6				(1.8)	(12.6)	(7.5)	5.7	(13.0)	(14.8)	36.6	3.3					(20.4)					**(2.3)**
7										(4.2)		(3.0)	7.6	2.3	(3.1)	33.6	(5.1)					3.2					**3.9**
8													(5.4)	16.4		(10.5)	(5.3)					(14.0)					**(3.8)**
9													9.9			(2.6)	5.0					(11.1)					**0.3**
10													(1.1)			10.6	(4.3)					(6.7)					**(0.4)**
11													4.2			6.7						(11.0)					**(0.0)**
12													(1.4)				(4.7)					(6.9)					**(4.4)**
13													3.3			(7.2)	(1.0)					(18.2)					**(5.8)**
14													(13.3)			3.3						3.3					**(2.2)**
15													(7.5)									9.1					**0.8**
16													(3.1)									6.5					**1.7**
17																						(10.3)					**(10.3)**
18																						1.4					**1.4**
19																						(10.4)					**(10.4)**
20																						13.1					**13.1**
21																						(3.5)					**(3.5)**
22																						3.7					**3.7**
23																						16.7					**16.7**
24																						(7.6)					**(7.6)**
25																						1.7					**1.7**
26																						(7.6)					**(7.6)**
27																						(7.8)					**(7.8)**
28																						(3.0)					**(3.0)**
29																						(8.7)					**(8.7)**
30																						(10.7)					**(10.7)**
31																						(11.2)					**(11.2)**
32																						0.6					**0.6**
33																						(1.7)					**(1.7)**
34																						5.8					**5.8**
35																											
WA	**(12.9)**	**1.1**	**(15.9)**	**3.9**	**(8.5)**	**(4.0)**	**(11.1)**	**0.9**	**0.4**	**(2.4)**	**(4.6)**	**(4.8)**	**3.0**	**(0.2)**	**(6.3)**	**7.5**	**3.1**	**3.5**	**1.8**	**(35.4)**	**(48.6)**	**(2.8)**	**(1.8)**	**8.0**	**0.4**	**65.1**	**(1.5)**
WA	**(12.9)**	**1.1**	**(15.9)**	**(3.0)**							**(4.7)**		**(1.2)**			**5.3**		**2.7**		**(42.0)**		**(2.8)**	**2.2**			**65.1**	

Table 3: Yield spread descriptive statistics

N	152	*Variance*	*167.408*
Mean	-1.541	*Skewness*	1.014
Std. deviation	12.939	*Kurtosis*	5.875
S.e. mean	1.049	*Min*	-48.643
T-stat	-1.469	*Max*	65.07
p-value	0.144		

Table 4: Z-spread descriptive statistics

N	23017	*Variance*	*46.919*
Mean	-1.264	*Skewness*	3.059
Std. deviation	6.850	*Kurtosis*	49.072
S.e. mean	0.045	*Min*	-48.276
T-stat	-28.000	*Max*	126.797
p-value	0.000 ***		

Table 5: Results of regression

	OLS	*Fixed Effects*	*Random Effects GLS*	*Random Effects GLS (robust s.e.)*
Constant	-1.268 (0.052) ***	-1.863 (0.244) ***	-1.305 (0.513) *	-1.305 (0.800)
Liquidity	0.005 (0.120)	6.006 (0.323) ***	5.719 (0.315) ***	5.719 (3.367)
Residual s.e.	7.144	6.667		
Df	20699	20675	20699	20699
Multiple R^2	0.000	0.130	0.016	0.016
Adjusted R^2	-0.000	0.129	0.016	0.016
F stat	0.002	123.6 ***		
Chisq			330.245 ***	330.245 ***

Table 6: Ramsey RESET test for OLS model

RESET	*86.315*	*Df1*	*2*
p-value	0.000 ***	*Df2*	20697

Table 7: Hausman test (fixed effects vs random effects)

Chisq	*15.968*	*Df*	*1*
p-value	0.000 ***		

Table 8: Breusch-Pagan test for heteroscedasticity (random effects model)

BP	*237.34*	*Df*	*1*
p-value	0.000 ***		

Figure 65: YTM of 6 bonds in our sample and their non-green peers (percentage)

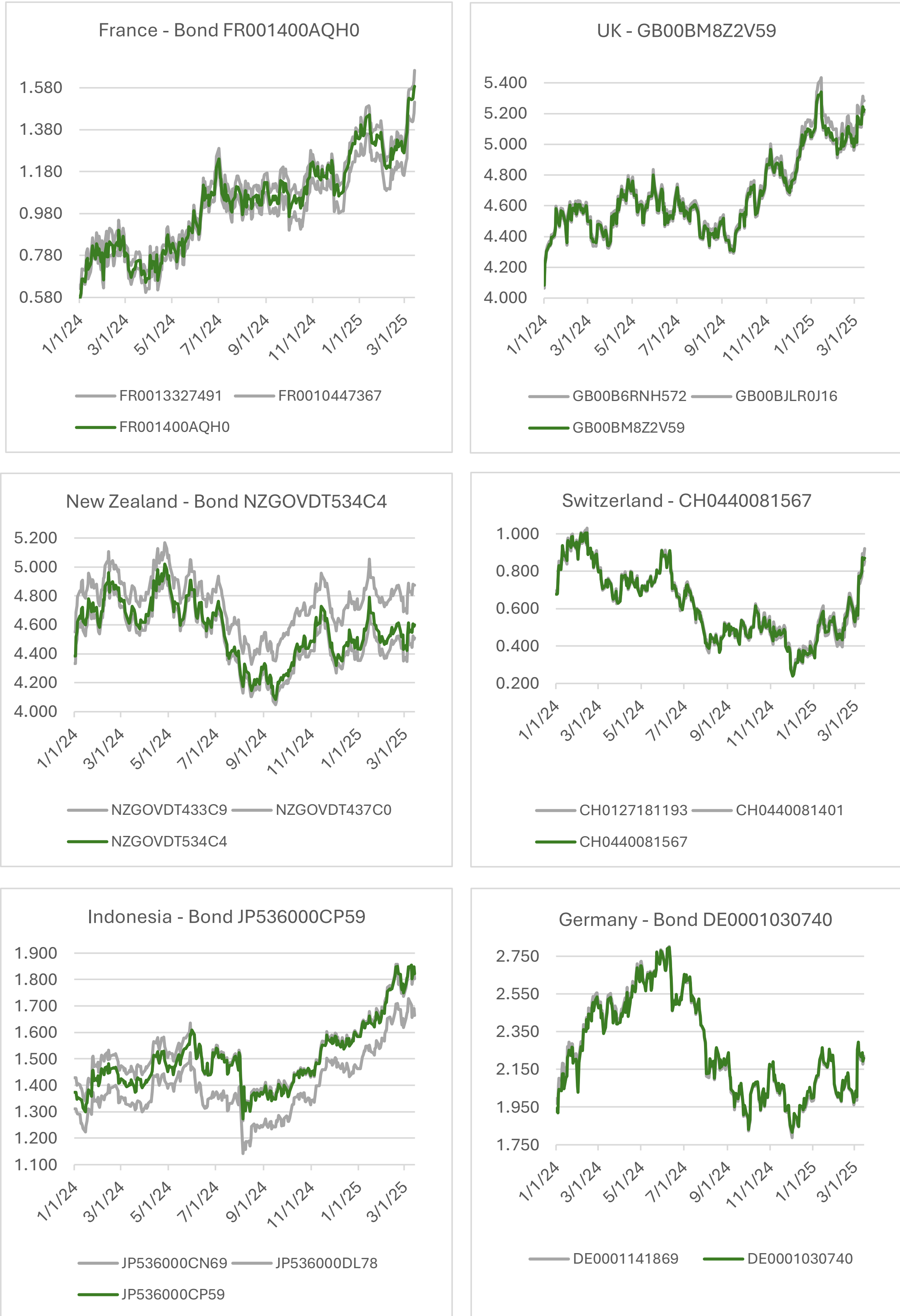

Figure 76: Bid-Ask Spreads of 6 bonds in our sample and their non-green peers

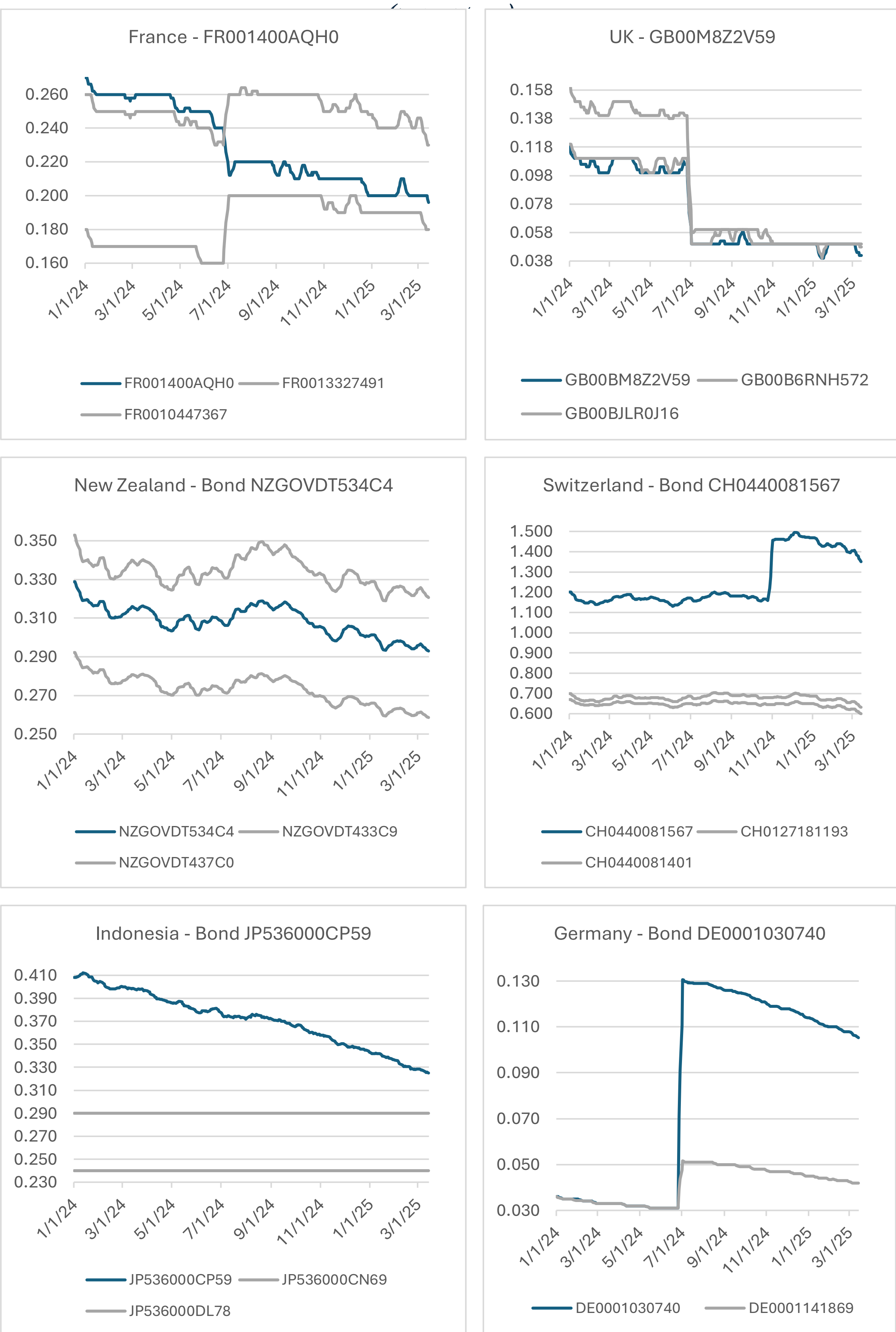

Figure 87: DZS density distribution