A Pricing Model Proposal for Evaluating Green Bonds Premiums

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Abstract

Market participants dedicate significant time to analysing the green bond premium, often referred to as "greenium." While much attention has been given to measuring greeniums, few studies have addressed their fair value. This paper aims to fill that gap by exploring the question: "Where should green bonds be priced?" Accurately pricing greeniums is crucial for investors who seek to balance environmental objectives with their fiduciary duties. A well-priced green bond market fosters investor confidence, whereas a loss of trust in the green label could lead to widespread repricing and negatively impact returns.

To address this challenge, this paper proposes a novel pricing model for greeniums based on avoided emissions, treating these emissions as a financial asset. By incorporating avoided emissions into the pricing mechanism, the model provides a more robust reflection of green bonds' environmental impact. Adopting this approach may encourage greater ambition within the green bond market and lead to more rigorous evaluation of the bonds' true environmental contributions.

Key Takeaways

- Considerable efforts are being made to measure greeniums through observed market prices. However, investors should focus more on determining the appropriate pricing for green bonds and assessing whether the observed prices align with their expectations.
- Green bond pricing requires the use of well-defined models. This paper proposes an approach that links green bond prices to the monetization of avoided emissions. According to this model, a higher level of avoided emissions should be associated with a proportionally higher greenium.
- This approach suggests that greater scrutiny of a green bond's impact reports is necessary, as the reported environmental outcomes could directly influence the bond's pricing based on the level of impact achieved.
- There is a need for the market to standardize avoided emissions calculations and increase transparency.
- To scale up the green bond market, issuers should be remunerated appropriately for their climate impact.

JEL Classification: G12, G32, Q54, Q56

Keywords: Green bonds, risk premium, Yield spread, cost of capital, carbon emissions, environmental accounting, climate, pricing.

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1 Introduction

Since its debut in 2007 with a €600 million transaction from the European Investment Bank (2021), the green bond market has grown exponentially, developing into a distinct sub-asset class within the wider world of fixed income investing. About £575 billion worth of green bonds was issued in 2023 alone, and while the market has been historically dominated by public and quasi-public institutions to finance massive green investment plans, corporates have become an important part of the market (Environmental Finance, 2024).

In 2014, the International Capital Market Association (ICMA) introduced the Green Bond Principles (GBP), a set of voluntary guidelines aimed at ensuring transparency and integrity in the issuance of green bonds. These principles, along with Climate Bonds Initiative's (CBI) certification standards, have been instrumental in the global growth of green bonds. Investor confidence in the potential of these instruments to support climate transition has been a major factor in their growth.

Despite safeguards to maintain the market's credibility, green bonds have faced significant criticism. A major concern for investors is the risk of greenwashing, where issuers label bonds as "green" while funding projects with minimal environmental benefit. For example, projects focused on marginal efficiency improvements rather than transformative changes (Bounds, 2023). Additionally, some issuers of green bonds may have unambitious transition plans, even though they are investing in certain green assets. [1]

As part of their fiduciary duties, investors have actively been exploring how green bond pricing compares to conventional bonds. Traditionally, green bonds have been priced at a premium due to their relatively smaller market size (Erlandsson, 2020). However, in recent years, growing demand for sustainable investment products has led to green bonds being priced at a discount, a market phenomenon now referred to as the "greenium."

The concept of greenium, which refers to the lower yield bond investors are willing to accept for holding a green security, has been widely discussed in the market. While there is general agreement that a greenium can be observed on average, its underlying drivers remain somewhat unclear. Some studies have suggested a correlation between greenium and the bond's green credentials credibility,(Pietsch and Salakhova, 2022). while others have pointed to the issuer's environmental, social, and governance (ESG) profile (Ben Slimane et al. ,2020). However, there appears to be no consistent predictability regarding the greenium that issuers may achieve.

A central question is whether the ambition of a green bond is reflected in its market price. Uncertainties in green bond pricing can present challenges for both investors and issuers. Investors may be hesitant to pay a premium if the environmental benefits do not align with their expectations, while issuers may refrain from issuing green bonds if they are unable to achieve a better cost of capital, especially given the higher issuance costs compared to standard bonds.

Both market participants and the academic community have invested considerable effort in developing models to measure the "greenium." However, the market has largely overlooked researching what should be the theoretical (or fair value) of green bonds. Such considerations around the pricing of labelled-debt instruments have been explored in the context of sustainability-linked bonds (Mielnik & Erlandsson, 2022). However, so far, no widely accepted models for calculating the fair value of greeniums has been developed. The absence of such models for the green bond market may limit its efficiency, as it makes it challenging for participants to determine whether green bonds are accurately priced. This could potentially reduce confidence in the market and lead to massive market repricing over time.

This paper introduces a novel approach to pricing the fair value of greeniums based on the avoided emissions reported by green bonds following allocation of proceeds. The model's rationale is that if an issuer was able to monetize avoided emissions, investors could expect an improvement in the issuer's financial position – which would be reflected in the bond's credit risk and, in turn, its spread. While issuers are not currently monetizing avoided emissions, the growing incorporation of carbon pricing into financial planning and the expansion of the carbon credit market suggest that green bonds may naturally evolve in this direction.

[1] See K. Leung (2024) as an example.

The application of such pricing model could encourage greater ambition within the green bond market. If two bonds, assuming all other factors are equal, report different levels of avoided emissions, the bond with the higher emissions reduction would likely benefit from more favourable pricing due to its larger positive environmental impact. This could help to improve the quality of projects funded by green bonds and further support efforts towards climate transition.

An additional advantage of this model is the potential to enhance the focus on green bond impact reports. According to the ICMA's Green Bond Principles (GBP), green bond issuers are required to publish annual reports outlining the environmental outcomes of the projects they finance. While there has been progress in improving the quality of these reports, as reported by Environmental Finance (2023), there are still calls for further harmonization and increased transparency in reporting, as highlighted by Climate Bonds Initiative (2021) and Nordic Public Sector Issuers (2024).

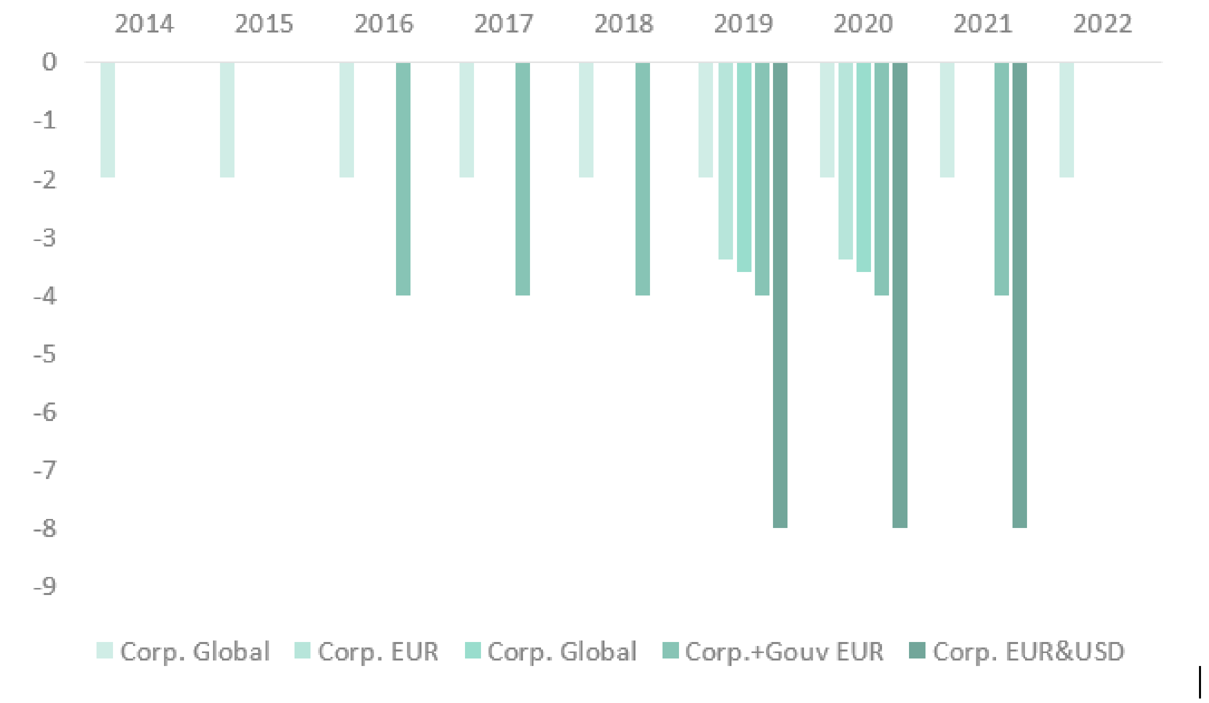
2 Understanding the Dynamics of Greeniums

2.1 The Elusive Greenium

The "greenium" of a green bond refers to the premium investors are willing to pay compared to conventional bonds, typically seen in the form of a lower yield for green bonds relative to similar non-green bonds. This premium is generally attributed to investors accepting a slightly lower return in exchange for the environmental benefits and sustainability features green bonds offer.

While it seems generally accepted by the academic world that a greenium can be observed in recent years, there is variability in the level observed and over time. Figure **??** presents these results, which suggest that the greenium observed for corporate issuers ranged from -2bps to -8bps between 2019 and 2022. This is a very wide interval, especially if applied to Investment Grade bonds. Additionally, these results mostly apply to larger issuers, which have already issued a certain number of liquid bonds, and therefore, the results may not apply to issuers with only a few liquid bonds, especially in the sub-investment grade part of the bond market. Additionally, not all green bonds exhibit a greenium, and in some cases, a negative greenium occurs, although the reasons for this are not always clear.

Figure 1: Review of a sample of academic studies on greeniums over time



Adapted from: *Facts and Fantasies About the Green Bond Premium (p. 33), by M. Ben Slimane, D. da Fonseca, and V. Mahtani, 2020, Amundi Asset Management (https://research-center.amundi.com/article/facts-and-fantasies-about-green-bond-premium); Pricing of Green Bonds: Drivers and Dynamics of the Greenium (Working Paper No. 2728, p. 18), by A. Pietsch and D. Salakhova, 2022, European Central Bank (https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2728~7baba8097e.en.pdf); The Green Corporate Bond Issuance Premium (International Finance Discussion Paper No. 1346, p. 13), by J. Caramichael and A. Rapp, 2022, Board of Governors of the Federal Reserve System (https://www.federalreserve.gov/econres/ifdp/files/ifdp1346.pdf); Greenium Fluctuations and Climate Awareness in the Corporate Bond Market (p. 4), by M. Dragotto, A. Dufour, and S. Varotto, 2023, SSRN (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4511974&download=yes).*

Regarding the drivers of positive greeniums, Pietsch & Salakhova, (2022) suggest that credible issuers with a high level of transparency tend to exhibit greeniums. Green bonds premiums also seems to vary over time – as highlighted by Ben Slimane et al. (2020) and, more recently, Pietsch and Salakhova (2022). Some studies and market observation also suggest that there is simply no greenium. Flammer (2021) founds no evidence of greenium in corporate green bonds while Larcker and Watts (2020) reported similar findings in the US municipal bond market. Moreover, there are instances of issuers coming to the market without any realized greenium at issuance (Hay Gong, 2024; Kounis et al., 2023).

In summary, there is no clear market consensus on the drivers of greenium, and its occurrence does not appear to follow a deterministic process. The presence of a greenium seems unpredictable and does not indicate a strong correlation with observable factors beyond supply and demand for "green" labelled securities.

This uncertainty presents some challenges for investors. First, the unpredictability of greeniums can reduce confidence in valuation models, as fluctuations over time may undermine the reliability of traditional fixed income valuation models and introduce additional volatility to green bond portfolios. In the context of a global multiasset portfolio with volatility limits, this might lead investors to reduce their exposure to the asset class.

Second, although higher-quality green bonds tend to show higher greeniums, there is no guarantee that the ambition of a green bond will be properly rewarded. Consequently, investors conducting thorough due diligence on the quality of green bonds may not experience financial advantages over those investing in lower-quality portfolios. The lack of clear financial differentiation between high- and low-quality green bonds may hinder the incentive to finance projects with higher green standards or more detailed disclosures and reporting.

2.2 The rationale for the occurrence of greeniums

From a basic financial analysis perspective, investors might question whether there is any justification for green bonds to be priced at a discount. In most cases, there is no significant contractual difference between green and traditional bonds, as both share the same credit risk and seniority. Additionally, green bonds do not come with contractual obligations to ensure that proceeds are invested according to the green finance framework. They are not project-specific financing instruments, and the funds raised may not be ring-fenced, meaning the money can be used for purposes other than green initiatives.

For instance, an issuer allocating 50% of its proceeds to coal-related assets may face reputational damage but would neither default nor violate any regulations. Given these factors, one could argue that fiduciary duty should discourage investors from accepting a “greenium.” Investors who are willing to pay a premium for a green bond are essentially paying for the assurance that the company is using an equivalent amount of funds for green projects. However, while green bonds are not primarily designed as project-based funding instruments, issuers are still required to allocate the proceeds to specific selected projects. Additionally, they must provide metrics for investors to assess the bond’s environmental impact, such as avoided carbon emissions, renewable energy production, or energy savings. This contrasts with standard bonds, as green bond investors can directly associate their investments with tangible, real-world environmental outcomes.

Figure 2: An example of green bond’s impact report

5 Impact reporting

Output indicators and CO2 emissions avoided by project

Eligible Project Category	Output indicator		Impact indicator *Estimated CO2 emissions avoided*, when operating at nominal load*
Biogas	Annual production of biogas	592,100 MWh	118,420 tCO2eq/y
	Annual amount of landfill gas produced	346,900 MWh	55,538 tCO2eq/y
Energy efficiencies	Annual reduction of energy consumption	17,520 MWh	7,008 tCO2eq/y
Hydrogen	Annual hydrogen production	4,352 tH2	47,572 tCO2eq/y
	Number of HRS (Hydrogen Refuelling Station) installed	51 HRS	67,109 tCO2eq/y
Air gases	Energy saving of the ASU	25,000 MWh	9,200 tCO2eq/y
Green buildings	Surface area	23,000m2	983 tCO2eq/y

Source: Green Bond Allocation Impact Reporting 2023 (p. 13), by Air Liquide, 2023 (https://www.airliquide.com/sites/airliquide.com/files/2023-06/green-bond-allocation-impact-reporting-2023-.pdf).

Amongst the different impact metrics that can be reported, avoided emissions are particularly interesting as a measure of direct climate impact. Avoided emissions represent emissions prevented or reduced as a result of projects financed by green bonds. They are calculated by comparing the GHG emissions that would have occurred under a business-as-usual scenario (e.g. continuing to use fossil fuels) with the emissions that result from the green bond's projects. For example, if a green bond funds the construction of a wind farm, the avoided emissions would be the amount of CO2 that would have been emitted if the same amount of energy had been produced consistently with the local energy mix.

As outlined in International Capital Market Association's Harmonized Framework for Impact Reporting (2022), green bond issuers are expected to report impact metrics, such as avoided emissions, at least once a year in their green bond impact reports. This reporting typically continues until all proceeds have been allocated or, as is common market practice, until the bond reaches maturity. To summarize, while green bonds are quite similar to standard bonds in terms of structure, they offer investors the added benefit of account for positive environmental impacts of their investments. Therefore, investors who financially value impact may be willing to pay a premium for green bonds.

3 Assessing greeniums by monetizing green bonds' avoided emissions

3.1 Financially accounting for avoided emissions

Currently, avoided emissions are mostly used as a reporting metric, helping investors evaluate the effectiveness of projects funded by green bonds. However, if investors start recognizing financial value in avoided emissions, it could shift their perspective. In a scenario where green bond issuers can monetize their avoided emissions, it would offer significant incentive for investors to price green bonds more competitively, potentially leading to discounted cost of capital for issuers achieving ambitious climate targets.

Although current accounting standards do not permit including the financial value of avoided emissions in financial statements, this concept is not far from becoming reality. The growing efforts of accounting bodies to integrate carbon accounting into standard financial reports suggest that a company's carbon footprint could eventually become a standard part of financial analysis, much like other financial metrics (Lee, 2024).

Emissions are also becoming increasingly integrated into companies' financial planning. Some businesses are deducting carbon-related costs from their financial forecasts to encourage a reduction in their carbon footprint.[2] A growing number of organizations are implementing internal carbon pricing (ICP) programmes to better manage their transition risks and align their strategies with the shift towards a low-carbon economy (Golovcsenko et al., 2023).

Initiatives to assign financial value to sustainable impacts are also gaining traction in the fixed income sector. For example, the Bank for International Settlements' Project Genesis 2.0 (Nolens et al., 2022) has demonstrated the potential for connecting green bonds with carbon markets, highlighting the possibility of linking financial instruments to sustainability-driven initiatives. The project specifically focuses on attaching to green bonds' mitigation outcome interests, which are essentially carbon credits tied to environmental projects. This should help issuers obtain cheaper financing for green projects and make it easier for investors to verify the environmental impact of their investments.

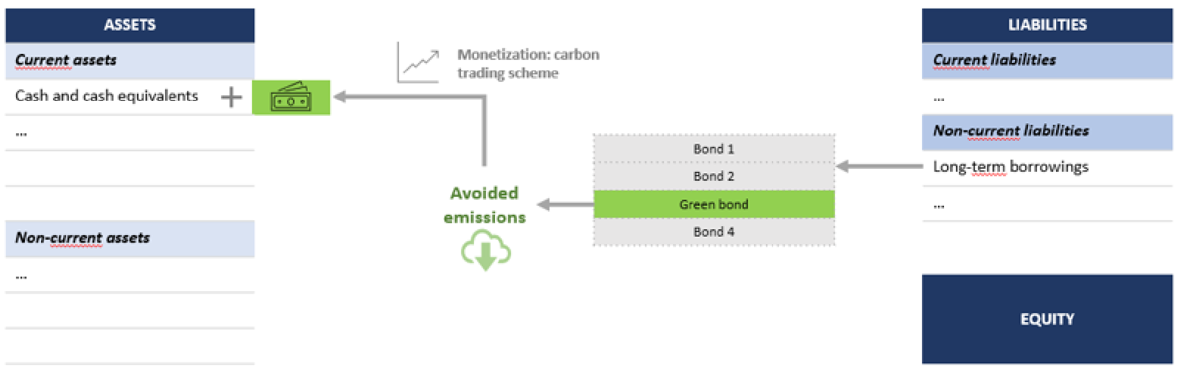
While there is currently no direct connection between a company's financial performance and avoided emissions from green bonds, it is not unreasonable to consider attributing some financial value to these avoided emissions. Although issuers can only monetize avoided emissions under certain strict considerations, this does not prevent investors from factoring them into their pricing considerations.

Assuming that avoided emissions can be monetized, one could argue that green bonds should be priced more favourably than traditional bonds. By considering avoiding emissions as a source of financial gain for a company, this means that green bonds could generate additional cash flows compared to traditional bonds. If this additional financial flow is significant, it could enhance the company's financial stability. An improved cash position may lead to decreased financial leverage, which could subsequently lower the likelihood of the issuer defaulting on its debt. Consequently, this enhancement in the issuer's ability to

[2]See, for example, Getlink (2023). The company introduced its decarbonized margin reporting in 2023, allowing investors to evaluate how emissions affect its profitability.

meet its debt obligations is likely to be reflected in a reduced risk perception among investors and, in turn, more favourable credit spreads.

Figure 3: Illustrating financial flows under the assumption of green bonds' avoided emissions being monetized.



Source: *Nerthus Research.*

Under this assumption, an improvement in credit spreads based on the idea that the green bond's avoided emissions strengthen the company's financial position could serve as a basis for determining how greeniums should be priced. Such approach would provide a clear and objective method for assessing green bonds' value relative to conventional bonds.

In practice, investors have several methods for estimating the financial value of avoided emissions. The most reliable approach is to use the issuer's ICP, if available, as it provides the clearest reflection of what carbon emissions cost the company (Golovcsenko et al., 2023). If ICP data is unavailable, investors can reference prices from carbon markets. There are two primary types of carbon markets: voluntary and compliance markets, such as national or regional emissions trading systems (ETSs).[3] Based on a green bond's objectives and the projects funded, investors can select the most appropriate carbon price. This research used the EU ETS 2023 average price (European Securities and Markets Authority [ESMA], 2024), as it offers transparency and comparability across the bonds under consideration.

3.2 Incorporating avoided emissions monetization in default probabilities

If avoided emissions can be assigned a financial value (even a hypothetical one) and influence a company's financial performance, they could also impact its probability of default. The key question is how to quantify this impact. While only a few mathematical approaches currently exist to link default probabilities with financial metrics, Merton's model and its adaptations offer a useful framework for establishing this connection (Merton, 1974)

The (virtual) financial flow generated by a green bond's avoided emissions will ultimately end up in the company's asset, so the level of assets somehow depends on the dynamics of carbon prices. There might be questions regarding when the company can cash out its avoided emissions, as it may influence how avoided emissions are being accounted. To simplify the problem, all avoided emissions are assumed to be cashed out at maturity of the bond. Thus, avoided emissions can be reported as an intangible asset while the bond has not yet matured.

The total monetary value of avoided emissions (MVAE) over the bond's lifetime is calculated by summing the annual avoided emissions, multiplied by the carbon price at the bond's maturity, as shown

[3] For further details on the difference between voluntary and compliance carbon markets, please see the United Nations Environment Programme's (n.d.) web page on carbon markets.

in Formula (1). The MVAE as a function of carbon prices for the bond sample in this case study is presented in Figure 6.

$$\text{MVAE}_T = \text{CarbonPrice}_T \times \sum_{i=1}^{T} \text{AnnualAvoidedEmissions}_i \tag{1}$$

We also assume that avoided emissions are disclosed annually and remain constant throughout the life of the bond.[4] Therefore, the value of assets A_t at time $t \leq T$ can be expressed as follows:

$$A_t = A_0 + DF_{(T-t)} \times \text{MVAE}_T \tag{2}$$

where:

- A_0 is the initial value of the standard bond's assets,
- $DF_{(T-t)}$ is the discount factor.

s suggested by the above equation, if avoided emissions remain constant—namely, at the latest level available in the latest impact report—then assets only depend on interest rates (discount factor) and the price of carbon at bond maturity. According to Merton (1974), it is considered that a default may occur at a certain date when a company's assets fall below the face value of its debt. By estimating the probability of default at inception of the bond, the face value of the debt is equal to the last reported value $\text{D}_T.Therefore, theprobabilityofdefaultatmaturityTcanbeexpressedasfollows:$

$$PD = \Pr(A_T < D_T) \tag{3}$$

If the company has issued a green bond (whose notional is consequently included in D_T) and under the assumption of monetized avoided emissions, applying Formula (2) produces the following:

$$PD = \Pr(A_0 + DF_{(T-t)} \times \text{MVAE}_T < D_T) \tag{4}$$

Therefore, the following formula can be derived:

$$PD = \Pr(A_0 < D_T - \text{MVAE}_T) \tag{5}$$

This formula implies that the threshold at which assets must decline to trigger default can be reduced by the financial value of avoided emissions. Consequently, investors generating such avoided emissions by issuing a green bond could experience a lower probability of default. Additionally, issuers with ambitious emissions reduction projects tied to their green bonds could further decrease their default risk. Since issuers choose which projects to allocate to green bonds from among all company projects, it may encourage them to select only the most ambitious projects tend to be financed through green bonds, leaving other projects to be funded through traditional means. This creates a mechanism to drive greater ambition within the green bond market. Another implication of this formula is that the probability of default is influenced not only by the dynamics of assets and liabilities but also by changes in carbon prices. Consequently, it can be connected to investors' expectations regarding the level of carbon prices at the bond's maturity. Research has suggested that ambitious decarbonization plans tend to be associated with higher carbon prices (Kaufman, 2020; Organisation for Economic Co-operation and Development, 2021). Linking the financial value of debt to carbon prices establishes a direct relationship between rising carbon prices and economic benefits for the issuer, as well as for the sustainable investment community more broadly.[5] Assuming the issuer's asset value A_t follows a geometric Brownian motion, the equation can be expressed as:

$$dA_t = rA_t dt + \sigma_A A_t dW \tag{6}$$

[4] This is a strong assumption, as projects financed by the green bond may be sold and replaced by other projects by the issuer or production levels may change over the asset's lifetime.

[5] In option pricing terms, buying green bonds can be considered purchasing an option on carbon prices with the expectation that higher carbon prices will result in the option being "in the money," potentially leading to increased returns for the buyer.

Using Itô's formula, the value of the company's assets at maturity T can be determined by the following equation:

$$A_T = A_0 \times \exp\left((r - \frac{\sigma_A^2}{2}) \times T + \sigma_A W_T\right) \tag{7}$$

Therefore, the Probability of Default (PD) can be written as:

$$PD = \Phi\left(\frac{\log(\varphi_T/A_0) - (\sigma_A^2/2) \times T}{\sigma_A\sqrt{T}}\right) \tag{8}$$

where:

- $\varphi_T = D_T - N \times \text{AvoidedEmissions} \times CP_T$,
- D_T is the value of the debt at time T,
- CP_T is the price of carbon at time T,
- σ_A is the asset volatility.

This is a closed-form expression that links a company's default probability to avoided emissions levels and carbon prices at the bond's maturity. While default probabilities can be influenced by various factors, this methodology provides investors with an easy way to assess how a company's efforts to reduce emissions may impact its default risk.

3.3 Case study: EDF1.00%29NOV33 green bond

Electricité de France (EDF) is a well-rounded green bond issuer, having issued its first green bond in 2013 to fund its environmental initiatives. The **EDF1.00%29NOV33** bond was issued in November 2021, primarily to finance renewable energy projects. As a result, the company has included the associated avoided emissions in its most recent green bond reports. Details of the bond are presented in Table 1.

Table 1: EDF1.00%29NOV33 Bond Description

Bond Name	**ISIN**	**Tenor (Years)**	**Issue Date**	**Amount Issued (Bn EUR)**	**Avoided Emissions ($MtCO_2$-eq/year)**	**Company Assets (Bn EUR)**	**Liabilities (Bn EUR)**
	FR0014006UO0	12	29.11.2021	2.1	1.11	364.8	300

Adapted from Bloomberg; EDF 2023 Consolidated Financial Statements (p. 4), by EDF, 2024 (https://www.edf.fr/sites/groupe/files/2024-02/annual-results-2023-consolidated-financial-statements-2024-02-16.pdf). Accessed 4 February 2025.

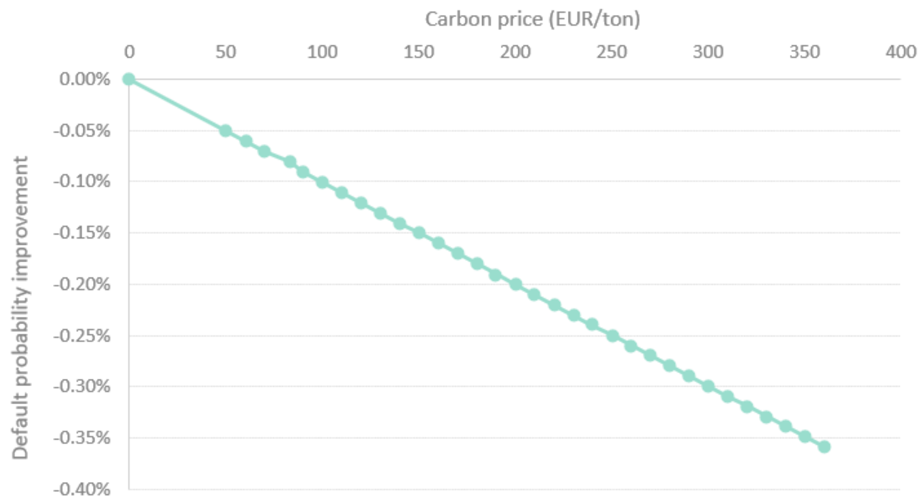
Formula (8) can be used to evaluate how various parameters may influence the default probability of the bond. First, asset volatility, which can be difficult to determine directly due to limited data, can be estimated using Merton's formula based on observed bond prices. The detailed calculation, found in Annex I, produced a result of 17%.

On the other hand, carbon prices under the EU ETS are available daily, but due to their volatility, this paper used the 2023 average price of €83/tCO_2, as reported by ESMA (2024) in its latest market report. This approach helped smooth out short-term market fluctuations. Consequently, the "virtual" financial value of these emissions was estimated at €1.1 billion—a significant amount, especially considering it represents half of the bond's face value.

Using these values, EDF's bond default probability at maturity was estimated to be 19.5% without monetizing avoided emissions and 19.4% when including the financial value of the emissions. **This suggests that assigning a value to avoided emissions, based on a carbon price of €83, results in a modest improvement of 0.10% in the default probability**. This is a small improvement, considering the bond's long duration and other factors that may influence EDF's default risk.

If investors anticipate stricter carbon policies and higher carbon prices, they might place greater value on avoided emissions. For example, with an assumed carbon price increase to €300, the default probability would improve further, decreasing by 0.30%. A sensitivity analysis of the probability of default to carbon prices is presented in Figure 4.

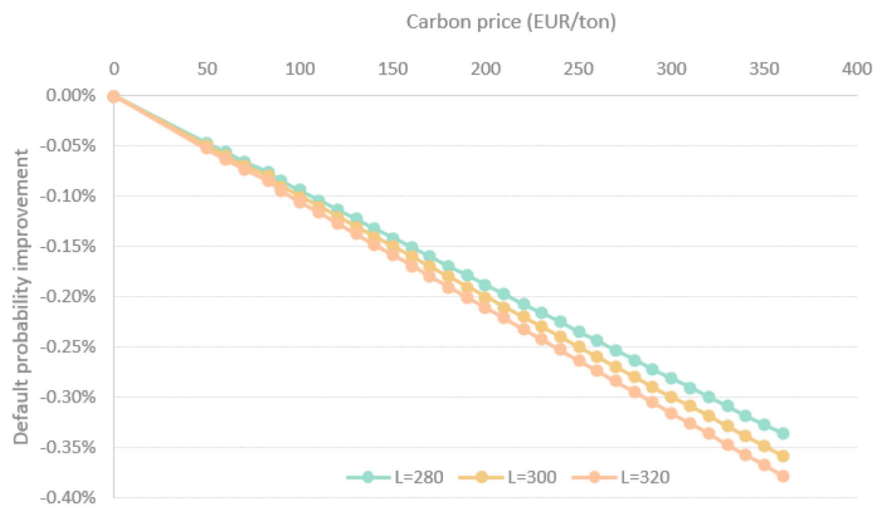
Figure 4: Default probability improvement of EDF1.00%29NOV33 as a function of carbon prices



Source: *Nerthus Research.*

Hence, how monetizing avoided emissions from a green bond might differ for issuers with varying levels of leverage can be explored. To assess this, carbon prices across three different liability level scenarios were evaluated. The results are presented in Figure 5.

Figure 5: Default probability improvement of EDF1.00%29NOV33 as a function of carbon prices and liability level



Source: *Nerthus Research.*

The graph shows an interesting trend: Companies with higher leverage tend to see greater improvements in their default probability as carbon prices (or avoided emissions) increase. This suggests that, under such conditions, lower-rated companies in the bond market may have added financial motivation to fund more ambitious projects through green bond issuances.
In conclusion, when avoided emissions are monetized, a company's probability of default tends to decrease relative to the level of avoided emissions and expectations of future carbon prices. This indicates that higher carbon market prices could encourage companies to further reduce their emissions. Additionally, companies with higher leverage may benefit more from the value of monetized avoided emissions, potentially leading investors to offer a greater greenium to such companies.

4 A pricing model for evaluating green bonds' fair value

4.1 A closed formula for evaluating greeniums

In the previous section, we looked at how avoided emissions might affect issuers' default probabilities. If avoided emissions are monetized, green bond issuers could benefit from a lower default probability, which may lead to an improvement in their bond spread. In this section, we provide a methodology to estimate the potential level of this spread improvement.

The model is based on the idea that investors should financially reward companies for their climate efforts. So, when comparing two green bonds with all else being equal, the bond with higher avoided emissions should receive a larger greenium. As a result, the greenium should directly correlate with the level of avoided emissions.

Building on the formulas from the previous section, we suggest using a formula derived from Hull et al. (2004). We can then adjust this formula to estimate credit spreads for green bonds, factoring in the financial value of avoided emissions. The difference between the two credit spreads will indicate the "greenium" that can be reflected in a green bond's pricing. We define s as the spread of a standard bond. Applying Merton's formula produces the following equation:

$$\begin{cases} s = y - r = -\ln\left[\frac{N(d_2)+N(-d_1)}{L}\right]/T \\ \begin{cases} d_1 = \frac{\ln(A_0 e^{rt}/D)}{\sigma_A\sqrt{T}} + 0.5 \times \sigma_A\sqrt{T} \\ d_2 = d_1 - \sigma_A\sqrt{T} \end{cases} \end{cases} \tag{9}$$

where:

- $L = D/A_0$, the company's leverage ratio
- σ_A is the assets' volatility
- A_0 is the initial value of the standard bond's assets
- T is the time to maturity.

Under the hypothesis of monetized avoided emissions, the following formula can be derived:

$$A'_t = A_0 + N \times DF_{(T-t)} \times \text{AnnualAvoidedEmissions}_T \times CP_T \tag{10}$$

where A'_t is the value of the green bond's assets at time t.
Therefore, the initial value of the green bond's assets can be written as:

$$A'_0 = A_0 + N \times DF_T \times \text{AnnualAvoidedEmissions}_T \times CP_T \tag{11}$$

We define s_{GB} as the green bond's spread. Applying Merton's formula with an updated value for initial assets results in the following equation:

$$\begin{cases} s_{GB} = -\ln\left[\frac{N(d_2)+N(-d_1)}{L}\right]/T \\ \begin{cases} d_1 = \frac{\ln(A_0 e^{rt}/D)}{\sigma_A\sqrt{T}} + 0.5 \times \sigma_A\sqrt{T} \\ d_2 = d_1 - \sigma_A\sqrt{T} \end{cases} \end{cases} \tag{12}$$

with $\sigma_{A'}$ representing the green bond's asset volatility under the assumption of monetizing avoided emissions.
Therefore, the "true intrinsic value" of the greenium can be expressed as:

$$\text{Greenium} = s - s_{GB} \tag{13}$$

This formula offers several advantages. First, it enables investors to assess the theoretical value of greeniums using a closed-form equation with a limited set of parameters. As a result, it can be easily applied to a wide range of bonds across different sectors, making it a versatile tool. This facilitates investment decisions and arbitrage opportunities, ultimately contributing to market efficiency. The two

more challenging parameters to assess are the asset's volatility, which is not directly observable, and the value of avoided emissions. However, asset volatility can be implied from the market prices of existing bonds or estimated using proxies, while the value of avoided emissions can typically be found in a bond's impact reports or assessed at the time of issuance. An additional implication of this model

is its relevance to mark-to-market. The model suggests that as carbon prices change over time, greeniums should adjust accordingly and be reflected in the market prices of green bonds. This indicates that the dynamics of greeniums are influenced by the volatility of carbon prices. The next section presents applying this formula to a selected sample of green bonds for further illustration.

4.2 Case study: Analysis of a green bond sample from the utilities sector

The model presented in the previous section can be a valuable tool for guiding investment decisions and accurately pricing green bonds. A practical application of the model is to analyse a sample of bonds with similar characteristics and compare the observed greeniums to the theoretical ones. This approach demonstrates how investors can use the model to make informed, objective investment decisions based on market prices.

This example presents four green bonds issued by European utilities companies. All are rated BBB, denominated in EUR, and have maturities ranging from 11 to 12 years (see Table 2). Given the similar characteristics of these bonds, it can be challenging for investors to compare them based on their potential environmental impact.

From a sustainability perspective, apart from Ørsted, recognized as a leader in ESG performance, the four issuers have broadly similar ESG ratings, as highlighted in Table 3. When considering their climate footprint, A2A and RWE have significantly higher carbon intensities. Consequently, it could be argued that these two issuers may have the most substantial environmental impact when issuing ambitious green bonds.

Table 2: Green Bond Sample from the Utilities Sector

Issuer Name	**Country**	**ISIN**	**Bond Description**	**Issue Date**	**Term (Y)**	**Amt Out (EUR Bn)**	**BBG Composite**
Ørsted	DK	XS2490472102	ORSTED 2.875%-33	14.06.2022	11	0.78	BBB
A2A S.p.A.	IT	XS2403533263	AEMSPA 1%-33	02.11.2021	12	0.58	BBB
RWE	DE	XS2412044641	RWE 1%-33	26.11.2021	12	0.68	BBB
EDF	FR	FR0014006UO0	EDF 1%-33	29.11.2021	12	2.08	BBB

Adapted from: *Bloomberg. Accessed 4 February 2025.*

Table 3: Issuers' ESG Profiles

Issuer Name	**MSCI ESG Score**	**CDP Score**	**Sustainalytics**	**Carbon Emissions ($MtCO_2$-eq)***	**Carbon Intensity (g CO_2e/kWh [Scope 1+2])**
Ørsted	AAA	A	15.6	7.2	38
A2A S.p.A.	BBB	B	20	15.1	310
RWE	A	A-	22.7	83.7	480
EDF	A	A-	20.7	92	30**

**Scopes 1, 2, and 3* ***Scope 1 only*

Adapted from: *MSCI; Sustainalytics; CDP; Ørsted Annual Report 2023 (p. 90), by Ørsted, 2024 (https://cdn.orsted.com/-/media/annual-report-2023/orsted-ar-2023.pdf?rev=526307f68e2047b3a1df8dd2cdf719echash=E6069E12C1792AD620FA12898587394C); A2A 2023 Integrated Financial Statements (p. 108), by A2A, 2024 (https://www.gruppoa2a.it/sites/default/files/2024-03/integrated-financial-statements-2023.pdf); RWE 2023 Sustainability Performance Report (p. 7), by RWE, 2024 (https://www.rwe.com/-/media/RWE/documents/09-verantwortung-nachhaltigkeit/cr-berichte/sustainability-performance-report-2023.pdf); EDF Group 2023 Carbon Footprint (p. 3), by EDF, 2024 (https://www.edf.fr/sites/groupe/files/2024-04/edf-urd-annual-financial-report-2023-en-updated-2024-04-11.pdfpage=569).*

To evaluate the theoretical greeniums of green bonds, the first step is to collect estimated avoided emissions for each bond, typically disclosed in the issuers' green bond impact reports. It is important to note that regulatory guidance on reporting avoided emissions remains limited. For instance, there is no universal standard for calculating emissions reductions across various technologies, and issuers may report either net or gross avoided emissions, considering the project's own emissions. These details are usually found in impact reports.

Furthermore, avoided emissions are estimates based on the anticipated output of projects, which can vary due to factors such as initial assumptions, weather conditions (particularly for renewable energy projects), and project ownership changes. Engaging directly with issuers can provide investors with valuable insights into the methodologies used to calculate these avoided emissions. (For further discussions on the topic, see Tuhkanen and Vulturius, 2020.) For the purposes of this case study, Table 4 presents the avoided emissions of the selected bonds, along with the types of projects financed.

Table 4: Green Bond Sample's Avoided Emissions

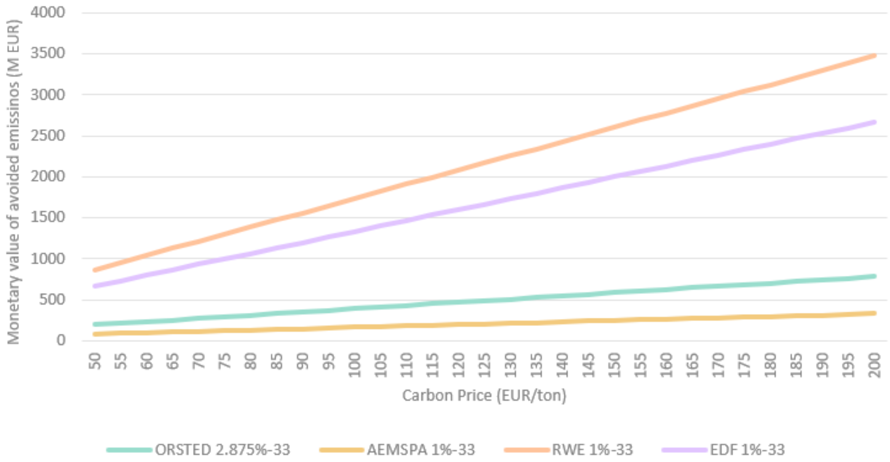
Bond Description	**Bond ISIN**	**Annual Avoided Emissions**	**Gross or Net**	**Fully Allocated**	**Projects Financed**
ORSTED 2.875%-33	XS2490472102	356 Kt/yr	Gross		Offshore wind, solar PV
AEMSPA 1%-33	XS2403533263	138 Kt/yr	Gross	Yes	Onshore wind, bioenergy, solar PV, Pollution Prevention and Control, Transmission and Distribution Networks, Energy Efficiency
RWE 1%-33	XS2412044641	1446 Kt/yr*	Assumed gross	Yes	Offshore wind, onshore wind, solar PV
EDF 1%-33	FR0014006UO0	1.11 Mt/yr		Yes	Solar PV, offshore/onshore wind, hydro, biodiversity

** Avoided emissions are not provided on a bond-by-bond basis for RWE bonds but for all of RWE's green bonds. This number is an estimate based on the proportion of the portfolio XS2412044641 represents.*

Adapted from: *Ørsted Green Bond Impact Report 2023* (p. 13), by Ørsted, 2024 (https://orstedcdn.azureedge.net/-/media/annual-report-2023/green-bond-impact-report-2023.pdf?rev=2e63e32b6f3f47508857a7253d5c0617hash=0E371B46EA35D3999E745056D503D1EF);
A2A 2023 Green Bond Report (p. 7), by A2A, 2024 (https://content.gruppoa2a.it/sites/default/files/2023-12/A2A-green-bond-report-issuance-2023.pdf);
RWE Green Bond Report 2023 (p. 16), by RWE, 2024 (https://www.rwe.com/-/media/RWE/documents/05-investor-relations/anleihen-und-rating/2023-10-30-rwe-green-bond-report-2023.pdf);
EDF Universal Registration Document 2023, by EDF, 2024 (https://www.edf.fr/sites/groupe/files/2024-04/edf-urd-annual-financial-report-2023-en-updated-2024-04-11.pdfpage=569).
Accessed 4 February 2025.

Using Formula (1), the MVAE was evaluated as a function of carbon prices for each bond of the case study sample. The results are presented in Figure 6.

Figure 6: Monetary value of avoided emissions



Source: *Nerthus Research.*

From this graph, it might seem that RWE could achieve the highest greenium among the four bonds in the sample, given its potential to generate significant financial value from avoided emissions. However, this perspective does not fully consider a few important aspects: first, the bond's issuance size. While larger issuances can support more projects, they do not necessarily reflect higher ambition. The second aspect is the company's corporate structure: For firms with strong balance sheets and low leverage, additional funding may have a smaller relative impact compared to more leveraged companies. The model introduced earlier helps address these nuances by factoring in each company's corporate structure.

After gathering data on avoided emissions, the next step was to collect pricing parameters for the four bonds. Debt levels and asset values can be sourced from the issuers' financial statements. Asset volatilities, however, are not directly observable and must be calculated. To ensure consistency with standard market prices, these volatilities were derived using Formula (9) based on observed market prices. Additional details on the calculations are available in Annex I.

Subsequently, the theoretical greeniums for each bond in the case study sample were calculated. The results are summarized in Table 5. For these calculations, this paper applied the 2023 average carbon price of 83 EUR/tCO2, as reported by ESMA (2024) in its most recent market report.

Table 5: Green Bond Sample's Pricing Parameters

Bond	**ORSTED 2.875%-33**	**AEMSPA 1%-33**	**RWE 1%-33**	**EDF 1%-33**
Total assets (EUR Bn)	37.67	18.8	63.80	364.8
Total liabilities (EUR Bn)	27.24	14.0	49.10	300.1
Asset volatility	35%	33%	30%	25%
Time to maturity (Years)	8.45	8.84	8.90	8.91
EUR risk-free rate	2.37%	2.39%	2.39%	2.39%
Observed market spread (bps)	114.2	114.9	112.3	112.7
MVAE (Mln EUR)	28	132	1,389	1,066
d1	1.02	1.01	1.00	0.92
d2	0.01	0.04	0.11	0.17
Theoretical greenium (bps)	0.09	0.86	2.88	0.42

Source: *Nerthus Research.*

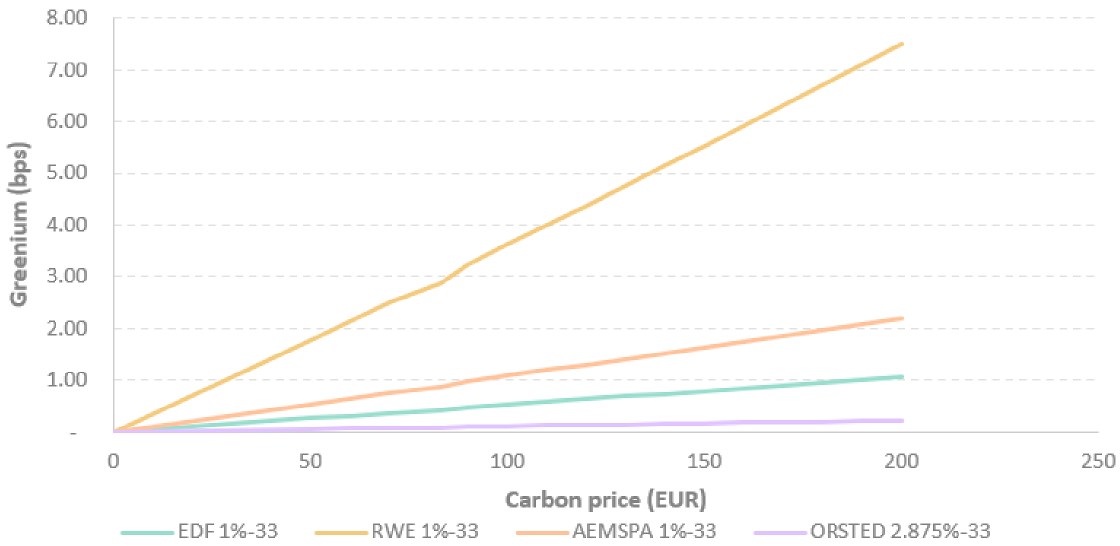
The analysis indicates that within the selected sample of bonds,RWE 1%-33 should be given the highest greenium, at nearly 3bps. On the other hand, ORSTED 2.875%-33 does not seem to warrant any greenium. This is particularly notable, given that RWE has the highest carbon intensity in the sample. It also suggests that the emissions reductions expected from the projects financed by RWE's bond are ambitious relative to the company's overall balance sheet.

Another notable observation is that although EDF and RWE have similar levels of avoided emissions, RWE seems to justify a higher greenium than EDF. This disparity can be attributed to the larger size of RWE's balance sheet. When RWE's assets and liabilities are scaled to align with EDF's levels, the RWE's greenium becomes comparable to EDF's. This suggests that RWE's green bond plays a more substantial role in decarbonizing its balance sheet relative to EDF's green bond.

4.3 Sensitivity to carbon prices

If investors anticipate a rise in carbon prices driven by policy changes, they may also incorporate their own carbon prices forecasts into their pricing decisions. Figure 7 illustrates how greeniums should be priced under varying carbon price scenarios.

Figure 7: Green bonds' greeniums as a function of carbon prices



Source: *Nerthus Research.*

As noted earlier, RWE appears to warrant the highest greenium among the four green bonds in the sample, regardless of carbon price levels. At a carbon price of €200, its greenium could reach up to 7.5bps. In contrast, Ørsted and EDF are unlikely to achieve more than a 1bp greenium, even with significantly higher carbon prices.

The second section of this paper indicated that greeniums for corporate issuers from 2019 typically ranged between -2bps and -8bps. RWE's theoretical greenium aligns with this range, while the theoretical greeniums for other issuers in the sample do not. This suggests that while a greenium may be observed on average, there is significant variability in how it should be priced, depending on the issuer and the ambition of the projects financed. This implies that investors might consider pricing greeniums differently based on the potential impact of the green bonds. If carbon prices increase in the future, the model presented in this paper predicts a corresponding rise in the average greenium.

However, one limitation of this model is that it does not account for whether a company has issued additional green bonds that collectively contribute to a larger volume of avoided emissions. Incorporating the entire bond structure into the model could offer a more comprehensive view of an issuer's overall decarbonization efforts. Further limitations of the model are discussed in the next section.

5 Approach's limitations and potential improvements

5.1 Evaluating avoided emissions

As noted earlier, assessing avoided emissions can be challenging due to differing methodologies and assumptions across companies, particularly in the absence of formal guidelines. Investors should verify whether avoided emissions are reported as gross or net and understand the timeline over which they are calculated. While most issuers provide annual avoided emissions, they often omit details about emissions avoided over the full lifetime of the projects funded by the green bond. This omission can create inconsistencies when monetizing avoided emissions, as these figures may depend heavily on the bond's tenor. Additionally, a company might sell or retire assets before the end of their operational life, potentially forfeiting the benefits of avoided emissions. Such challenges highlight the need for market participants to advocate for stricter guidelines and greater transparency in the evaluation of avoided emissions.

5.2 Financing projects without avoided emissions

Moreover, although large issuers such as EDF may be able to issue green bonds that finance a selected set of categories, smaller issuers might issue green bond financing a wide set of projects, not all of which may be directly linked to avoided emissions. Therefore, issuers may want to disclose the approximate proportion of project types that will be financed by the green bond so investors can assess the bond's impacts appropriately.

It is important to note that green bonds can fund a wide variety of projects, some of which may not directly result in avoided emissions. For instance, they might finance electricity network projects, which are critical for distributing renewable energy and thus contribute to decarbonization. However, their impact in terms of avoided emissions is not easily measurable, and a more suitable metric for such projects is the length of the network installed.

Green bonds may also support initiatives such as biodiversity conservation or circular economy projects. For these types of bonds, alternative approaches to evaluating the financial value of their impact may be needed.

Additionally, while large issuers such as EDF may issue green bonds focused on a specific set of project categories, smaller issuers might use green bonds to finance a broader range of projects, not all of which may be directly related to avoided emissions. To improve transparency, issuers should consider disclosing the approximate proportion of each project type financed by the green bond at the time the bond is being issued.[6] This would enable investors to better evaluate the bond's overall impact.

5.3 Timing of impact metrics communication

The model proposed in this paper assumes that avoided emissions are disclosed before the bond's issuance. However, issuers typically do not provide detailed information about how funds will be allocated at the time of issuance. Investors usually only have access to general details about the types of projects the issuer intends to finance, without insight into the proportions allocated to each. As previously mentioned, this lack of detail makes it challenging for investors to assess the bond's impact at issuance. As a result, applying the approach presented in this paper to estimate the theoretical greenium at the bond's inception may prove difficult.

That said, given the lengthy approval processes for most industrial projects and the ability of green bonds to allocate proceeds retroactively, it is likely that issuers have a clear sense of how funds will be allocated at issuance. This creates an opportunity for investors to engage with issuers beforehand to gain a more detailed understanding of the planned allocations for the green bond.

Such engagement would not only improve green bonds' impact assessment but also enhance the overall ambition of the green bond market. Fostering dialogue between issuers and investors would encourage greater transparency of the green bond market.

[6] For instance, such information could be disclosed in the bond's green financing framework or its second party opinion.

5.4 Sectoral considerations

Sustainability and transition goals can vary significantly between sectors. The emissions reductions needed to align with a 1.5°C trajectory differ across industries, meaning that what qualifies as ambitious in one sector might seem relatively modest in another. Consequently, when applying the approach presented in this paper, investors should take an intrasector approach (i.e. comparing bonds only within the same sector).

5.5 Accounting for issuers' full bond term structure

The proposed model evaluates bonds individually without considering the full scope of an issuer's bond issuances. However, following the principle outlined in this paper that green bonds provide issuers with "extra cash," the financial impact can vary significantly, depending on the proportion of green bonds in the issuer's overall bond portfolio.

A potential enhancement to the approach would involve incorporating the issuer's entire bond term structure to better understand how these bonds collectively influence theoretical greeniums. In a scenario with high carbon prices, such an analysis could substantially impact the company's financial leverage.

6 Conclusion

Green bonds are a relatively new tool in financial markets, offering significant potential to help investors align their portfolios with climate goals. However, their pricing does not always reflect the level of ambition they represent, as evidenced by the somewhat inconsistent premiums – or "greeniums" – relative to standard bonds. This paper introduces a practical method for market participants to evaluate these greeniums more objectively. By accurately assessing the sustainable impacts of green bonds and integrating these impacts into pricing, the market can encourage greater ambition and innovation. However, implementing such models globally could lead to notable repricing, potentially improving the efficiency of the green bond market.

Among the various impact metrics available, avoided emissions stand out as one of the few that can be reliably assigned a financial value. This makes them particularly suitable for estimating the financial value of impacts and, by extension, the greeniums of bonds with decarbonization goals. Linking such pricing impacts to companies' progress on decarbonization targets could further strengthen the market's alignment with climate goals.

The green bond market ecosystem has already made progress with labels, frameworks, and auditing requirements, but there is still room for more robust and precise practices. This paper identifies gaps in current reporting requirements – advocating for clearer guidelines, particularly in calculating and communicating bonds' impacts. Additionally, greater engagement with issuers before bond issuance could help assess potential impacts more effectively.

An ongoing challenge is the accessibility and comparability of impact data across green bonds. Investors often face the time-consuming task of manually reviewing individual reports to gather avoided emissions data. To address this, bond data providers should broaden their scope to include comprehensive impact metrics alongside financial data for green bonds. Improved transparency would enable more systematic evaluations and support better decision-making by investors.

Although the model proposed in this paper has its limitations, it is intended as a starting point for further research and innovation in green bond pricing. By addressing these challenges, the green bond market can continue to grow and play a more effective role in driving the transition to a low-carbon economy.

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Annex I – Evaluating Asset Volatilities

To evaluate green bond premiums, we need to determine the asset volatilities of the issuers. Several methods can be used, including deriving asset volatilities from historical data or using equity volatility for listed companies as a proxy.[7] For consistency and comparability with market prices, asset volatilities were estimated based on the market prices of existing bonds from the same issuer, choosing bonds with maturities as close as possible to those of the green bonds in the study sample. Next, asset volatilities were implied using Formula (9). The table below provides a summary of the parameters used and the results obtained.

Bond	**ORSTED**	**AEMSPA**	**RWE**	**EDF**
Total assets (EUR Bn)	37.67	18.8	63.80	364.8
Total debt (EUR Bn)	27.24	14	49.10	300.1
Time to maturity (years)	8.6	9	9	9
r (12Y IRS 29/07/2024)	2.71%	2.71%	2.71%	2.71%
Observed bond spread (bps)	87	111	98	106
Implied volatility (%)	18%	19%	18%	17%

[7] Correia et al. (2018).