

Adopting Digital Green Bonds

Benefits, Barriers, and Solutions

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Colophon



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Abstract

This research addresses the barriers in adopting Digital Green Bonds (DGBs), which are financial instruments that integrate Distributed Ledger Technology (DLT) into traditional green bond processes. DGBs aim to enhance transparency, liquidity, and efficiency, which can potentially reduce transaction costs and improve sustainability outcomes. Despite these theoretical benefits, practical adoption remains limited, leading to an in-depth exploration through a stakeholder-based case study focusing on the landmark ABN AMRO-Vesteda DGB issuance in the Netherlands. Identified barriers in traditional green bond processes include regulatory fragmentation, market inaccessibility, high transaction costs, gaps in technical expertise, and risks of greenwashing. DLT and DGBs show promise in addressing these issues by facilitating real-time compliance monitoring, fractionalization, 24/7 trading, automation, faster settlement processes, and improved transparency and reporting. However, significant obstacles persist, particularly outdated regulations, liquidity constraints, high initial investments, infrastructural and technical fragmentation, and limited market familiarity with DLT applications. Through empirical findings from semi-structured interviews with key stakeholders—including financial institutions, regulatory bodies, and technology providers—this research outlines actionable strategies to overcome these barriers. Recommended measures include developing clear and adaptive regulations, investing in interoperable and standardized infrastructures, conducting pilot projects to demonstrate feasibility, and raising market awareness through education and successful case studies. Ultimately, this research contributes to the growing body of knowledge on sustainable finance innovation by identifying practical strategies to accelerate DGB adoption and supporting the broader objective of closing the green financing gap.

Key words: green finance, DLT, digital green bonds, digital bonds, DLT bonds, blockchain, green bonds, adoption barriers

1 Introduction

We are currently experiencing a global environmental crisis (IPCC, 2018). The past nine years have been the hottest on record worldwide (NASA Earth Observatory, 2023), sea levels continue to rise (Fleck, 2022), and natural disasters are increasingly frequent around the globe (MunichRe, 2020). As a result of this crisis, governments have set ambitious climate goals, ranging from the global Paris Agreement to the European Union's Green Deal. These agreements highlight the importance of aligning financial flows with 'green projects' that have a positive environmental impact (UNFCCC, 2015; UNFCCC, 2020).

Although financing for climate change mitigation has been increasing worldwide, significant financing gaps still need to be addressed to meet the mentioned goals and agendas. For example, to achieve the Paris Agreement goals, yearly financing needs to be bridged of \$4 trillion in 2022, rising to \$ 6.4 trillion by 2030 if trends continue (OECD, 2025). Moreover, the EU equires annual investments of approximately €350 billion in energy systems (excluding transport), along with an additional €130 billion for other environmental objectives to meet its 2030 climate and energy targets (Ramos Muñoz & Smoleńska, 2023, Chapter 2.2).

Finding innovative solutions to bridge these green financing gaps is crucial for achieving the set sustainable goals and agendas (Hafner et al., 2020). As a result, innovative instruments, such as green bonds, have gained momentum to direct financing to environmental-positive initiatives and green projects (Berrou, 2019; GBP, 2018), growing from a 0.6% to 8.9% 'green' bond market share between 2014 and 2023 (European Environment Agency, 2023). Nevertheless, despite the recent growth of the green bond market, it still represents only a small segment of the broader fixed-income landscape, accounting for just 3% of total bond issuance within the European Union (Ramos Muñoz & Smoleńska, 2023, Chapter 2.2) due to different policy, market, financial, capacity and awareness challenges, such as high transaction costs and debt costs, limited eligible projects, regulatory fragmentation, process complexity and greenwashing risks (Banga, 2019; Bhutta et al., 2022; Maltais & Nykvist, 2020; Nguyen et al., 2024; Park, 2018; Saari et al., 2022; Sartzetakis, 2021).

Considering these challenges, recent developments in financial technology, particularly Distributed Ledger Technology (DLT), can provide solutions and make green bonds more attractive to issue and invest in (Dorfleiter & Braun, 2019). By implementing DLT into traditional green bond processes, and therefore creating a '[digital green bond](#)', some of the key barriers restraining the traditional green bond market can be overcome by potentially enhancing transparency, liquidity, process efficiency and lowering transaction costs, amongst others (Benedetti & Rodríguez-Garnica, 2023, p. 111; Chen et al., 2022; Heines et al., 2021; Ma & Steininger, 2025; Ojukwu et al., 2024; Pavlidis, 2022).

However, the problem with Digital Green Bonds (DGBs) is that despite the theoretical advantages found in the literature, their adoption remains limited. After the first DGB issuance in 2019 by Spanish bank BBVA for MAPFRE and some issuances in Asia (especially Hong Kong), the global Digital Green Bond issuance only totaled €483 million in 2024, growing from € 260 million the year before. This low adoption rate limits the potential of the financial instrument and, consequently, its impact on making the issuance and investment in green bonds more attractive, thereby hindering the acceleration of the green finance market. Additionally, due to the novelty of the financial instrument, there is only a limited amount of

academic literature available on Digital Green Bonds (DGBs). As mentioned in Walker et al.'s (2023, Chapter 2) book, the topic is relatively new, and therefore, the literature suffers from a lack of comprehensive studies that examine the interplay of fintech and sustainability. Thus, [this research aims to address the gap in the literature by identifying potential adoption barriers faced by Digital Green Bond stakeholders in practice and presenting strategies for facilitating its adoption](#), thereby accelerating the growth of the green finance market and contributing to the closure of the green financing gap by making investments in green securities more attractive.

To achieve this research goal, first, the barriers identified by stakeholders in traditional green bond processes are examined. Second, it is investigated how DLT and the subsequent creation of Digital Green Bonds can overcome these barriers. Third, several barriers are identified that limit the adoption of Digital Green Bonds. Lastly, strategies to overcome these adoption barriers are presented, which are all tested against the available academic literature. Therefore, this research will answer the following research question, structured around four sub-questions:

1.1 Research questions

RQ: How can the adoption of Digital Green Bonds be accelerated to help close the green finance gap?

- **SQ1:** What barriers do stakeholders identify in the issuance and management of traditional green bonds?
- **SQ2:** How can Distributed Ledger Technology (DLT) and the development of Digital Green Bonds potentially address the barriers found in traditional green bond processes?
- **SQ3:** Which barriers currently hinder the broader adoption of Digital Green Bonds in the financial market?
- **SQ4:** How can these barriers be addressed to facilitate the broader adoption of Digital Green Bonds?

1.2 Research context

These questions will be answered through a stakeholder-based case study within the Dutch regulatory and financial context. This context is interesting due to the limited uptake and implementation of 'digital green bonds' in a mature green debt market, which has established itself as an international leader in traditional green bond issuances, ranking fifth worldwide and third among European countries in terms of the cumulative value of green bonds issued (Climate Bonds Initiative, 2024). This situation, in which the green finance market is as vast as it is, combined with the relatively low adoption of digital green bonds, presents great opportunities to explore the barriers perceived by traditional green bond stakeholders in adopting digital green bonds. It also offers insights that can be applied to other EU member states facing similar adoption challenges.

2 Literature review

The literature review is structured to systematically address and clarify the current state of knowledge relevant to the research objectives. Firstly, this literature review examines existing literature on the barriers encountered in traditional green bond processes. Secondly, it examines how Distributed Ledger Technology (DLT) can address these barriers by exploring the theoretical potential of Digital Green Bonds. Subsequently, it explicitly highlights the absence of literature specifically addressing barriers in Digital Green Bond adoption, thereby defining the research gap this thesis intends to fill.

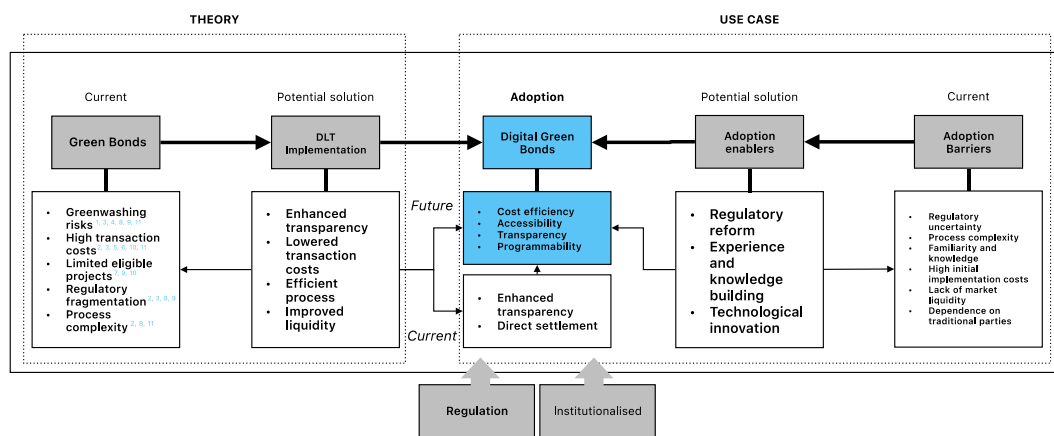


Figure 1: (Alamgir & Cheng, 2023 ¹; Banga, 2019 ²; Bužinskė & Stankevičienė, 2023 ³; Christodoulou, 2023 ⁴; Climate Ledger Initiative, 2018 ⁵; Malamas et al., 2024 ⁶; Maltais & Nykvist, 2020 ⁷; Nguyen et al., 2024 ⁸; Saari et al., 2022 ⁹; Sartzetakis, 2021 ¹⁰; Schletz et al., 2020 ¹¹)

2.1 Green bonds: Barriers

Green bonds are bond instruments where the proceeds are exclusively applied to finance or refinance, in part or in full, new and /or existing eligible green projects, according to the leading Green Bond Principles framework (ICMA, 2022b). The promotion and success of green bonds are essential for achieving the goal of sustainable development, as the United Nations calls for maintaining the temperature through the Paris Agreement by redirecting financing to environmentally friendly projects (Bhutta et al., 2022). Green bond markets could prove essential for bridging the green financing gaps noted earlier in the introduction.

Green bonds, which emerged for the first time in 2007 with the first “Climate Awareness Bond” issuance by the European Investment Bank (EIB), have evolved from niche products to mainstream financial instruments (Mutua, 2025). Green bonds are part of the sustainable market encompassing green, social, sustainability, sustainability-linked and transition bonds. This market totals to \$6.2 trillion of sustainability-labelled outstanding debt in 2024, responsible for only around 4.4% of the total outstanding debt worldwide (The World Bank, 2025). Annually, the market has reached \$1.1 trillion in issuances in 2024, where green bonds accounted for 57%, or \$571 billion, topping 2021’s \$563,5 billion, as seen in figure 15 (Gardiner & Freke, 2024; Mutua, 2025; The World Bank, 2025).

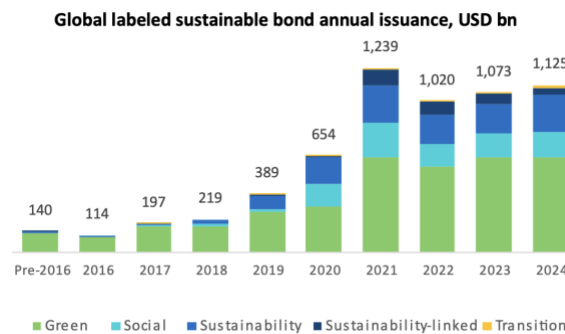


Figure 2: Global labeled sustainable bond annual issuance in USD Bn (The World Bank, 2025).

Of this global green bond market, Europe leads in green bond issuance, benefitting from proactive governments pushing sustainable finance agenda and policies (Mecu et al., 2024; Statista, 2024). Europe accounts for \$310 billion in total green bond issuances in 2023, and therefore, approximately 52.7% of the total global green bond issuance (Statista, 2024). Of all European countries, Germany and France are among the leading global issuers in terms of outstanding debt, followed by the Dutch market, which accounted for €172.9 billion in green bonds by January 2025 and has the biggest proportion of green bonds of all European countries (Climate Bonds Initiative, 2024; DNB, 2023, 2025; Statista, 2024).

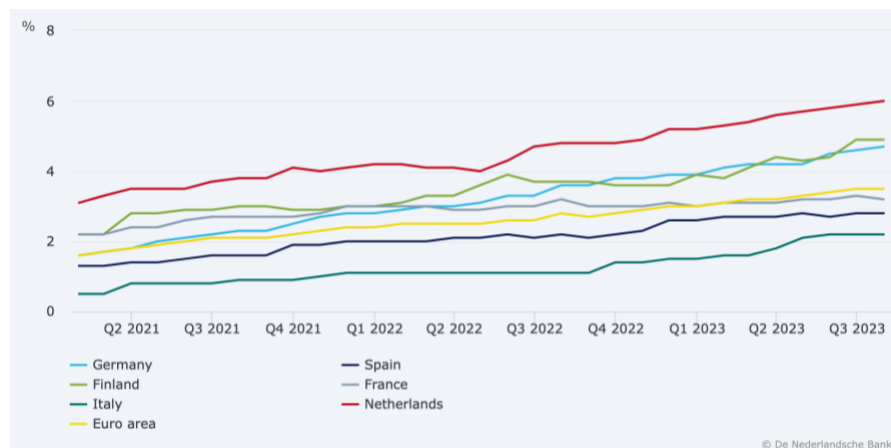


Figure 3: Green Bonds as a percentage of total outstanding debt of companies and governments (DNB, 2023)

However, despite the recent growth of the green bond market, it still represents only a small segment of the broader fixed-income landscape, accounting for just 3% of total bond issuance within the European Union (Ramos Muñoz & Smoleńska, 2023, Chapter 2.2). This limited market penetration highlights the ongoing green financing gap.

To meet its 2030 climate and energy targets, the EU requires annual investments of approximately €350 billion in energy systems (excluding transport), along with an additional €130 billion for other environmental objectives. Under the 2021–2027 Multiannual Financial Framework (MFF) and the temporary recovery instrument Next Generation EU (NGEU), the EU has committed €605 billion to climate-related initiatives and €100 billion to biodiversity. Importantly, 30% of the NGEU package must be funded through green bonds, an amount that corresponds to the total global green bond issuance

in 2020, highlighting the EU's commitment to leverage sustainable finance to achieve its climate goals (Ramos Muñoz & Smoleńska, 2023, Chapter 2.2).

Nevertheless, despite this institutional commitment and strong investor demand, the supply of green bonds remains low. Investor demand continues to exceed the supply of green bonds, highlighting the need to address structural and market barriers to scale issuance and close the ongoing green finance gap (Ramos Muñoz & Smoleńska, 2023, Chapter 2.2).

This chapter synthesizes the academic literature to identify and categorize the key barriers that continue to hinder the development of the green bond market. For categorizing the found Green Bond barriers, the categorization by Nguyen et al. (2024) will be used. In this research, barriers identified by green finance experts are classified in the following themes: Policy, Market, Financial, Capacity, and Awareness Barriers. A short description of each of the categories is placed in Table 1:

Table 1: Green Bond Challenge Categorization (Nguyen et al., 2024)

Barrier Type	Summary Description
Policy Barriers	Inadequate or fragmented regulations, weak legal frameworks, and misalignment with international standards. These raise uncertainty, compliance costs, and reduce investor confidence.
Market Barriers	Structural market issues such as limited project pipelines, poor data access, and undeveloped pricing mechanisms. These reduce market attractiveness and investor participation.
Financial Barriers	Economic impediments such as high transaction costs, lack of credit enhancements, liquidity issues, and risk perception. These undermine the financial viability of green bonds.
Capacity Barriers	Lack of institutional knowledge, human capital, coordination, and technical tools, especially in smaller issuers or public agencies. These constrain effective bond issuance and management.
Awareness Barriers	Limited understanding and trust among investors, issuers, and regulators regarding green bonds. Concerns include greenwashing, reputational risks, and unclear environmental benefits.

While the categorization by Nguyen et al. (2024) offers a helpful structure for grouping green bond barriers, the importance or ranking of these barriers in their study is based on expert opinions from Vietnam. Since Vietnam is a developing country with different market and regulatory conditions, these rankings may not apply to other contexts, such as the European green bond market. Therefore, only the categorization will be used, and not the specific rankings and weights.

Table 2: Literature review results

Barrier Type	Barrier	Due to	Source
Policy Barriers	Regulatory enforcement	Voluntary frameworks	(Pyka, 2023; Wang et al., 2022)
	Regulatory fragmentation	Lack of standardization	(Hyun et al., 2023; Park, 2018; Pyka, 2023)
Market Barriers	Lack of eligible projects	Lack of supply	(Maltais & Nykvist, 2020)
	Market inaccessibility	Investment thresholds	(Banga, 2019; Cisar et al., 2025a)
	Currency risks	No standardized currency	(Banga, 2019; Hale et al., 2020)
Financial Barriers	High issuance costs	Process complexity and intermediation	(Ackassi, 2020; Banga, 2019; Walker, 2023)
	Slow settlement	Lack of automation, complex process, intermediation	(Ackassi, 2020; Deschryver & De Mariz, 2020)
	Yield uncertainty	Uncertain 'greenium'	(Doran & Tanner, 2019; Flammer, 2021; Hachenberg & Schiereck, 2018; Pietsch & Salakhova, 2022; Teti et al., 2022)
Capacity Barriers	Lack of technical skills	Process complexity	(G20 Green Finance Study Group, 2015)
	Limited track record	Lack of available performance data	(Zhang et al., 2018)
Awareness Barriers	Lack of familiarity	Unawareness of the concept	(Sangiorgi & Schopohl, 2023; Zhang et al., 2018)
	Risk of greenwashing	Lack of regulatory enforcement or ability to present performance reports	(Alamgir & Cheng, 2023; Christodoulou, 2023; De Freitas Netto et al., 2020; Flammer, 2021; Hawn & Ioannou, 2016; Hyun et al., 2023; Shi et al., 2023; Talbot, 2017)

2.1.1 Policy barriers

Regulatory enforcement

Defining what makes a bond 'green' has been a recurrent problem for green finance stakeholders, and therefore for the acceleration of the green bond market. Since uncertainty about its definition can harm the credibility of the green finance market, it can create a substantial problem for its development and usage (Migliorelli & Dessertine, 2019). Therefore, several initiatives have established robust frameworks that guide green bond issuance, such as the EU's European Green Bond Standard (EUGBS) (Malamas et al., 2024b), described earlier in the theoretical framework.

The problem is that these frameworks are voluntary: Pyka (2023) argues, the EUGBS does not solve the main issue, there are no clear legal consequences if issuers fail to meet their green promises. Although the EUGBS aims to set a high-quality standard, it doesn't provide investors with stronger legal protection than existing private frameworks. This resonates with the statement in Wang et al.'s (2022) research, which states that although guidelines exist, their impact is limited without strict enforcement or consistent interpretation across regions.

Regulatory fragmentation

Pyka (2023) also argues that because the EUGBS coexist alongside other voluntary standards, they may create more confusion in the market, rather than providing a clear definition of what a green bond should be, thereby contributing to regulatory fragmentation.

Consequently, Park (2018) states that the absence of a standardized definition of what constitutes a green bond can undermine investor trust and, consequently, impede the growth of the green bond market. As a result, investors function as quasi-regulators, and private governance regimes prevail, such as the voluntarily accepted ICMA Green Bond Principles and the European Green Bond frameworks described earlier in this document.

Additionally, regulatory arbitrage can also make green bonds more expensive than traditional bonds, due to the lack of oversight and higher greenwashing risks by strategic misinterpretation of the regulation, as stated in Cao et al.'s (2021) research in the Chinese market, which suffers from high regulatory arbitrage. This suggests that in jurisdictions with weak regulatory alignment, green bonds may incur higher costs, further slowing the growth of the green bond market. Information enhancers such as green labels, certifications, and external reviewers help reduce information asymmetry, thereby lowering bond yields (Hyun et al., 2023)

2.1.2 Market barriers

Lack of eligible projects

Respondents in the analysis by Maltais & Nykvist (2020) argue that there is a lack of good green projects/assets appropriate for green bond financing, also citing that there is a need to improve the pipeline of bankable green projects in order to grow the market for green bonds. This is highly likely to be true across Europe, as they argue that most of the results with respect to issuer and investor incentives look like they could easily be generalized to similar financial markets, especially in Europe. This research therefore states that there is enough demand for green bonds from the buy side, but not as much demand from the sell side.

Market inaccessibility

In Banga's (2019) research, the researcher states that for big institutional investors, the size, tenure, and liquidity of green bonds are key elements that need to be considered before lending their money. It is also mentioned that regarding the issuance of green bonds, there is no regulated minimum investment size. However, the international bond markets generally prefer a large minimum issue size (from EUR 300 to 500 million) (European Commission, 2019, p. 18). Also, rating agencies (CRAs) have a minimum size constraint, starting at USD 100 million face value for firms such as Moody's (Moody's Analytics, 2019). Banga (2019) also states that this minimum size restricts the private capital market, smaller investors, and developing countries from investing in green bonds, as the observed cost of the

individual projects is well below the minimum size that institutional investors require for green bond transactions. Cisar et al. (2025) mentions that market barriers remain, some of which are impossible or difficult for smaller organizations to overcome, leaving them below the market access threshold.

Currency risks

Hale et al. (2020) argue that there is a mismatch in the issuance of green bonds, between the currency in which issuers would prefer to sell green bonds and the currency demanded by many international investors. To mitigate this currency mismatch and the encompassing risk, international bond placements are increasingly placed in the issuer's home currencies, especially in advanced economies with low inflation. However, as most bonds are settled using dominant currencies such as the YEN, US Dollar and the Euro, developing countries must issue their green bond in these international currencies to be able to participate in the international markets and be able to raise large amounts of capital, forcing them to convert their currencies, suggesting that the implementation of local currency-based green bond issuance could be beneficial for developing countries (Banga, 2019).

2.1.3 Financial barriers

High issuance costs

Walker et al., 2023 (Chapter 2) note that green bond processes are often highly manual, paper-based, process with a high number of intermediaries. As mentioned by Park (2018), some of these added intermediaries are second party opinion (SPO) providers, external reviewers, and dedicated sustainable finance structuring teams, collectively forming an informal governance network that supplements the role of traditional underwriters, validating the environmental integrity of the bond, thereby mitigating greenwashing risks and reducing information asymmetries, touching upon the awareness barriers (Bachelet et al., 2019).

However, this involvement of additional external actors due to the green label involves extra costs. For example, the costs of an SPO or third-party assurance can range from USD 10 to 100 thousand dollars, as mentioned by the G20 Green Finance Study Group (2015). While the cost appears low considering the full issuance costs, it can still serve as a deterrent for small issuers, as noted in the same G20 study, where 41% of respondents cited "an extra cost associated with a green issuance" as a deterrent.

Banga (2019) also states that due to this added complexity of the process, the green label of the bond and its required intermediaries, the costs of a green bond transaction are higher than those of a plain-vanilla bond. Akassî's (2020) research highlights the additional costs and obligations associated with issuing green bonds, due to the increased process complexity as a result from the additional obligations of the green label:

"For issuers one of the reasons not to issue a green bond, is around [...] not so much the financial cost but the time cost, that comes along in issuing or rather setting up a green bond. So, before they issue their first green bond, issuers often have to set up a green bond framework, they have to set up reporting processes, management structures. They also have to get an external review on the green bond which costs some money and it is also the screening on an ongoing basis. Most investors want to see at least an annual reporting on how their money is being spent and what sort of environmental benefits are being achieved by the projects. So that costs time and some money as well and you need someone to

do that reporting and tracking, so that are the implemental costs for the issuer” – Ackassi (2020), interviewee C.

Slow settlement

Due to this complex process, lack of process automation, and lengthy upstream processes, the traditional primary bond issuance and settlement process has a typical settlement cycle of up to T + 4 days for a single bond issue (Walker et al., 2023, Chapter 2).

Yield uncertainty

Apart from the procedural costs, it is often unclear what the financial benefits are of issuing green bonds. The lack of a clear pricing benefit acts as a barrier for issuers who are considering green bond issuance but are daunted by the new process (Doran & Tanner, 2019).

Some studies suggest that green bonds are priced differently from conventional bonds. Specifically, as stated by Hachenberg & Schiereck (2018), green bonds rated between AA and BBB tend to trade at tighter spreads than plain-vanilla bonds issued by the same issuer, indicating a slight pricing advantage, or ‘Greenium’. Moreover, the research by Pietsch & Salakhova (2022) for the European Central Bank suggests that green bonds generally have slightly lower interest rates, ranging from +4 bps (basis points), +5.3 bps for externally reviewed green bonds, to +22.2 bps for externally reviewed green bonds issued by a company recognized for its green practices. Regarding externally reviewed green bonds, Hyun, Park, and Tian (2020) note that the review enhances investor confidence and often results in a yield discount, making green bonds more attractive to the market. The research by Fatica et al. (2019) highlights that there is a ‘greenium’ for supranationals and companies that repeatedly issue green bonds; however, financial institutions do not enjoy the same advantage and are not benefiting from lower costs of debt. Moreover, Teti et al. (2022) also state that green bonds are issued and traded at lower spreads (35 to 40 bps lower) compared to plain-vanilla bonds for especially corporate issuers, and not for financial institutions.

However, the research by Flammer (2021) finds no pricing difference between corporate green bonds and plain-vanilla bonds by the same issuer, showing that the issuance of green bonds does not result in a lower cost of capital. It is therefore uncertain whether issuing green bonds can lower borrowing costs, given the inconsistencies in the literature on whether there is a clear financial incentive to issue green bonds.

2.1.4 Capacity barriers

Lack of technical skills

Banga (2019), illustrates the complexity of the green bond process by highlighting the issuing institutions’ lack of essential technical skills needed to ensure that projects are implemented according to a selected framework, such as the GBPs. This barrier, primarily evident in developing countries, results in a reported 74% of respondents indicating a lack of knowledge about green bond practices in a survey by the G20 Green Finance Study Group (Green Finance Study Group, 2016).

As stated by Flammer (2021) and (Hyun et al., 2023), this lack of knowledge and skills, also results in an increased process cost compared to traditional plain-vanilla bonds, due to the need to build capacity in identifying green projects, managing a separate account, regularly reporting and tracking the green bond’s proceeds usage, and engaging a third-party intermediary to review or certify their green bonds

that involve added administrative and compliance costs. This perception of green bonds having a costly process works as a deterrent in the long run, as issuing a green bond requires additional efforts in terms of monitoring, disclosure, and impact reporting to align with the GBP (Deschryver & De Mariz, 2020).

Limited track record

In addition to skill-related barriers, the lack of historical data and performance metrics for green bond projects presents a significant obstacle for investors. As (Zhang et al., 2018) state: "Green bond investors are still facing challenges in assessing the effectiveness of green bond projects. If investors lack the historic data and credit ratings of the newly issued green bonds, in the long run, they might tend to invest more on traditional bonds." This underscores the market's current incapacity to provide reliable benchmarks or performance evidence, further exacerbating investor hesitancy and contributing to the limited scalability of the green bond segment.

2.1.5 Awareness barriers

Lack of familiarity

A barrier to green bond issuance, along with similar capacity constraints, is the lack of familiarity and awareness about what green bonds involve. This issue arises not from a lack of technical expertise or institutional capacity, but rather from limited understanding and familiarity with the concept, objectives, and process of green bond issuance. Sangiorgi & Schopohl (2023) highlight that insufficient awareness was a key factor preventing issuers from entering the green bond market sooner. Their survey results indicate that many potential issuers were unaware of the requirements, benefits, and frameworks associated with green bonds, which discouraged their participation in the market. Therefore, Sangiorgi and Schopohl (2023) also emphasize the importance of engaging and educating stakeholders on the benefits of issuing green bonds, such as the treasurers of the issuing party and their boards.

Moreover, Zhang et al. (2018) also mention in their research that one of the key barriers for businesses to invest in green projects or adopt green standards lies in their awareness. When environmental risks are not considered in investment decision-making processes, or the carbon price is not included in modeling operational costs, businesses will have neither incentives nor tools to green their operations.

Risk of greenwashing

Information asymmetry related to environmental impacts and greenwashing-related reputational risks poses a key challenge for green bond market development (Hyun et al., 2023). Greenwashing is known as the phenomenon where a firm, or in this case, an issuing party, communicates positively about its environmental performance, but the actual environmental performance is poor (De Freitas Netto et al., 2020).

Christodoulou (2023) distinguishes two kinds of greenwashing: active and passive greenwashing. Active greenwashing involves false claims regarding the environment friendly attributes of a product, in the case of bonds, falsely labelling a bond 'green' when its use of proceeds does not contribute sustainably. Passive greenwashing differs to active greenwashing, as it entails selectively disclosing positive information whilst withholding the negative information concerning environmental issues.

Greenwashing affects the green bond market negatively, as green skepticism is growing, further obstructing real green claims due to investors having a harder time differentiating greenwashing practices from true green claims (De Freitas Netto et al., 2020). Green bonds, which essentially

communicate a positive environmental outcome to its investors, are potentially exposed to a risk of greenwashing when it is issued with an ambiguous or unsubstantiated framework, and subsequently, a vague use-of-proceeds without external verification (Alamgir & Cheng, 2023; Hawn & Ioannou, 2016).

Currently, various frameworks such as the previously described ICMA Green Bond Principles and the European Union's EUGBs, are in place to safeguard the transparency of the reporting of the green bond proceeds, further limiting the risk of greenwashing (Hyun et al., 2023; Talbot, 2017). However, due to this increasingly strict and thorough information disclosure, greenwashing can occur in other forms.

According to the research by Shi et al. (2023), green bonds are used by heavily polluting sectors for creating an image of being environmentally conscious by superficially increasing the number of green patent applications, without actually making substantial improvements to their green innovation capabilities. Essentially, green bonds are utilized strategically to signal environmentally positive actions, albeit with limited tangible outcomes. This is a more concealed form of greenwashing, where issuers manipulate innovation outputs rather than just reports. Therefore, a further increase in transparency is demanded to further grow the market by ensuring that said greenwashing risks are overcome (Alamgir & Cheng, 2023; Talbot, 2017).

However, Flammer (2021) discusses that green bonds are not merely a tool of greenwashing. If that were the case, no improvements in environmental performance following the issuance of green bonds should be observed, as studies find that green bond financing is positively related to energy efficiency (Anh Tu & Rasoulinezhad, 2022).

In conclusion, the literature identifies several barriers within green bond processes, structured around the following themes: Policy, Market, Financial, Capacity and Awareness Barriers. Policy barriers include regulatory uncertainty and fragmentation, affecting investor confidence. Market barriers highlight a shortage of eligible projects and accessibility constraints, while financial barriers point to high issuance costs due to increased complexity and unclear yield benefits. Capacity issues reflect institutional and technical constraints among smaller issuers, and Awareness barriers emphasize limited stakeholder understanding and concerns over greenwashing. However, as Bhutta et al. (2022) stated in their research, findings from the literature suggest that issuer-specific factors affect the performance of green bonds, and results from different studies contradict each other. Therefore, the identified barriers are often case- and context-specific.

2.2 Digital Green Bonds: Potential

Alongside the emergence of Green Bonds, bonds utilizing Distributed Ledger Technology (DLT) have gained significant traction. These DLT-based bonds, more commonly known as Digital Bonds, are debt instruments whose register of ownership is stored using distributed ledger technology (DLT) (ICMA, 2022a).

The first bond utilizing DLT throughout its lifecycle was the World Bank's \$110 million digital bond issuance in 2018. This bond was created, allocated, transferred, and managed throughout its life cycle using DLT. Following this transaction, the digital (DLT-based) fixed-income market has expanded rapidly, reaching over €3 billion globally by 2024, representing a 260% increase from 2023. Of this fixed-income market, €2.3 billion (76.7%), is attributed to Digital Bonds. Europe contributed significantly, with total digital bond issuances of €1.7 billion in 2024, mainly due to experiments and trials conducted by central banks such as the ECB. Among all digital (DLT-based) fixed income issuances, Germany leads with a total of €765 million, followed by Switzerland with €557 million in 2024 (AFME, 2024). Regarding the Dutch market, only two digital bond issuances have taken place under Dutch law, both of which were underwritten by ABN AMRO. First in January 2023 for APOC, and later in the year for Vesteda, the latter being a Digital Green Bond, which converges Digital and Green Bonds (ABN AMRO, 2023a, 2023b, 2025).

Recent studies have reviewed this convergence of DLT (Digital Bonds) and traditional Green Bond processes, ultimately leading to the creation of these Digital Green Bonds (DGBs), which are essentially Digital Bonds with a green label or “a blockchain-based financial instrument designed to raise funds for environmentally sustainable projects” (Walker et al., 2023, Chapter 2).

According to several studies, DLT-based Digital Green Bonds have the potential to address some of the previously identified Green Bond barriers (Benedetti & Rodríguez-Garnica, 2023, p. 111; Chen et al., 2022; Heines et al., 2021; Ma & Steininger, 2025; Ojukwu et al., 2024; Pavlidis, 2022). Pavlidis (2022) emphasizes this potential, noting:

“The next big challenge will be creating a new breed of fully digitalized green bonds, using blockchain from its issuance until the reporting phase, which in the case of green bonds covers both the use of proceeds and the proof of impact. Combining digitalization with international standardization will further allow the scaling of green bond markets to meet the growing demand.” – Pavlidis (2022).

This subchapter examines the existing academic literature on the potential application of DLT to conventional green bonds, culminating in the concept of Digital Green Bonds. The analysis is structured around the five categories identified by Nguyen et al. (2024), linking the identified barriers with the DLT's potential to mitigate these.

Table 3: Literature review results

Barrier Type	DLT Potential	DLT characteristic	Source
Policy Barriers	Regulatory compliance	Immutability	(Zhang et al., 2018)
	Standardization	Immutability	(Zhang et al., 2018)
Market Barriers	Fractionalization	Tokenization	(Heines et al., 2021)
	24/7 Market Access	Disintermediation	(Maleki, 2023; Nassiry, 2018)
Financial Barriers	Lower issuance costs	Disintermediation, automatization	(Cisar et al., 2025b; Heines et al., 2021; HSBC, 2019; Malamas et al., 2024a; Migliorelli & Dessertine, 2019, Chapter 9; Parra-Moyano & Ross, 2017; Zhang et al., 2018)
	Lower transaction costs	Disintermediation, automatization	(Ojukwu et al., 2024; Santo et al., 2016; Saramago, 2023; Schloesser & Schulz, 2022; Sirikanchana, 2020)
	Faster settlement	Disintermediation, automatization	(Arcodia et al., 2025; Axelsen et al., 2023; Pinna & Ruttenberg, 2016; Zhang et al., 2018)
	Pricing differences	Transparency, risk reduction	(Chen et al., 2022; Cui et al., 2023; Jiang et al., 2024)
Capacity Barriers	None	Complexity	-
Awareness Barriers	Transparency	Immutability, auditability	(Antal et al., 2021; Flourentzou, 2025; Malamas et al., 2024b; Ojukwu et al., 2024; Pavlidis, 2022; Schloesser & Schulz, 2022)
	Performance reporting	Immutability, auditability, automatization	(Flourentzou, 2025; Ojukwu et al., 2024; Pavlidis, 2022)

2.2.1 Policy impact

Regulatory compliance

According to [Zhang et al. \(2018\)](#), DLT has the potential to ensure the regulatory compliance of green bonds through several mechanisms related to awareness barriers. It enables real-time monitoring of funds to verify compliance with green finance regulations, provides immutable records for regulators to verify compliance, enhances transparency by making all transactions visible, and facilitates data analytics that help identify potential compliance issues early, enabling proactive measures to address them.

Standardization

Also according to [Zhang et al. \(2018\)](#), DLT can facilitate standardized reporting mechanisms for environmental, social, and governance (ESG) indicators. By providing a unified platform for green bond issuance and reporting, blockchain can help align local and international regulations, reducing fragmentation and enhancing investor confidence.

2.2.2 Market impact

According to Migliorelli & Dessertine (2019, Ch. 9), DLT in green bond processes allows for anyone to access the ledger via a unique public or private key, opening the market for a more diverse and broader share of investors, independent of geography or time.

Fractionalization

DLT offers the possibility of fractionalizing assets such as green bonds into smaller investment sizes through tokenization, allowing smaller investors to invest in partial ownership, opening investment possibilities that were deemed out of scope (Heines et al., 2021). This can potentially lead to improved liquidity, as markets with higher divisibility and lower prices per unit tend to be more liquid than markets that trade only in large batches (Benedetti & Rodríguez-Garnica, 2023).

24/7 Market Access

Both Maleki's (2023) and Nassiry's (2018) studies state that DLT enables 24/7 trading and settlement, allowing investors to trade on news and developments over the weekend, potentially leading to increased liquidity and making it easier for investors to sell these assets.

2.2.3 Financial impact

As stated in Cisar et al. (2025), DLT allows for disintermediation in theory, potentially streamlining the bond issuance and trading processes, creating a transparent and automated framework (Cisar et al., 2025a).

Lower issuance costs (Primary Market)

Efficiency gains resulting from DLT implementation in Green Bond processes are estimated to more than 10X of that of a traditional green bond by HSBC (2019). Cisar et al. (2025) proposes a framework for issuing digital bonds in a "Digital Native" form, as the prototype aims to reduce transaction costs (TAC) and improve the efficiency of bond markets by utilizing smart contracts and a decentralized ledger system. This research highlights how Digital Bonds can reduce transaction costs (TAC) by facilitating higher transaction frequencies, allowing for peer-to-peer transactions by eliminating manual processes and replacing intermediaries in traditional methods. This comprises two potential impacts for green bond processes: disintermediation and automation.

The research by Malamas et al (2024) and its proposed "Digital Native" digital issuance framework also back this statement, as it is stated that DLT reduces intermediary costs by automating processes and enhancing transparency, minimizing the need for third-party verification, and lowering administrative expenses. Moreover, Heines et al. (2021) also DLT's potential to reduce the need for trusted intermediaries, potentially lowering transaction costs in financial markets by eliminating intermediary parties such as banks and reviewers through smart contracts. Zhang et al. (2018) add that not only can the efficiency of the process be increased, but the accuracy can also be improved by reducing human errors in documentation.

Regarding the issuance phase, Parra-Moyano & Ross (2017) mention that onboarding can be automated, streamlining KYC and AML processes, consequently reducing costs, improving the customer experience and increasing transparency of the onboarding process. This automated KYC

authentication makes transactions more reliable, efficient, and easier to process at a lower cost (Migliorelli & Dessertine, 2019, p. 220).

Lower transaction costs (Secondary market)

Regarding the trading phase, Ojukwu et al. (2024) highlight the potential of DLT and the establishment of digital trading platforms to facilitate more efficient transactions, lower costs, and increase trade speed, ultimately improving the liquidity of the green bond market. Moreover, the research by Sirikanchana (2020) mentions that to buy or sell securities on the securities exchange, transactions must generally be conducted by or through intermediaries. This is something that by implementing DLT, the decentralization of databases enables direct connectivity among nodes or ledger holders. Furthermore, since all nodes verify the record of transactions, all data related to executed transactions can be referenced or serve as evidence for all nodes considered participants. Therefore, considering this context, the need for intermediaries seems to be reduced.

However, Santo et al. (2016) does state that disintermediation might not be realistic even if technical issues were resolved, as they also play the role of law enforcement and dispute resolution which cannot be removed. The paper by Saramago (2023) also backs this statement as, it mentions that intermediation offers several advantages: Firstly, it simplifies transfers by allowing the trading of bonds without the involvement of the issuers. Secondly, pooling accounts enable netting and settlement efficiencies by combining transactions. Lastly, it broadens the market by facilitating interactions with ICSD-based intermediated structures for central bank collateral and international central security depositories. Therefore, Saramago (2023) states that a better way to improve the position of final investors in bond markets is to explore how DLTs may enhance the benefits already created by intermediation, rather than relying on these technologies to eliminate intermediation in a direct holding structure. The paper suggests that DLTs could introduce efficiencies in the management of the bonds, the performance of obligations by issuers, the settlement process, the performance of securities financing transactions, and the provision of services by these intermediaries.

Regarding post-trade processes, Santo et al. (2016) note cost reduction as a key advantage of using distributed ledger technology (DLT) in capital markets. Traditional clearing and settlement face burdens due to manual operations and data reconciliation, leading to a global cost of around \$40 billion annually. Integrating DLT into the post-trade process could reduce these inefficiencies through automation, real-time data synchronization, and shared ledgers, ultimately decreasing duplicative processes among intermediaries and lowering transaction costs. Schloesser & Schulz (2022) also mention that smart contracts can create a decentralized system where a specific action enables a smart contract to trigger buy or sell orders once certain thresholds are reached. This facilitates fast and automated payments, as well as predetermined actions that can be triggered when a specific event occurs, allowing for the automation of workflows and the streamlining of related processes, thereby further enhancing efficiency.

Faster settlement

Arcodia et al. (2025) mention that traditional settlement cycles in financial markets can take up to several days (e.g., T+2 or T+3), while DLT-based systems can enable simultaneous settlement. Pinna & Ruttenberg (2016) mention that DLT has the potential to enable the trading and settlement of securities to occur almost simultaneously, not only on the same day (within the T+0 cycle), but potentially even with instantaneous settlement. However, this is only possible for buyers and sellers utilizing the same DLT ledger in relation to a Digital Native bond, where cash is settled on the ledger. Axelsen et al. (2023) adds that this instant settlement (T+0 rather than T+2), potentially reduces trade

costs and diminishes counterparty credit risks, ultimately reducing the cost of capital. [Zhang et al. \(2018\)](#) also add that this settlement in milliseconds frees up cash deposits and collateral and simplifies ownership recording and coupon payment processing.

Pricing differences

Currently, there are no explicit empirical studies examining the yield spreads or cost of capital associated specifically with Digital Green Bonds (DGBs). However, insights from related research on digital and blockchain-based bonds suggest that digitalization may have a positive impact on these financial metrics.

[Cui et al. \(2023\)](#) find that bond issuing firms with higher levels of digital transformation can help reduce credit risk, leading to a lower credit spread. [Jiang et al., \(2024\)](#) also find evidence that digital transformation reduces credit spreads by reducing the information asymmetry between firms and investors with enhanced information transformation mechanisms and lowering corporate default risk by strengthening operating efficiency. While these studies primarily explore broader corporate digitalization rather than blockchain-specific bond issuances, their findings highlight potential indirect benefits applicable to digital securities.

More directly related to blockchain-enabled issuances, [Chen et al. \(2022\)](#) study asset-backed securities (ABS) issued via blockchain technology in China. They observe a statistically significant reduction of 31.4 basis points in the yield spread, translating to a relative reduction of approximately 13%, when compared to traditional ABS issuances. This reduction suggests that blockchain technology may effectively lower the perceived risk premium by increasing transparency, improving operational efficiency, and reducing settlement times.

Nonetheless, despite these promising implications, a significant research gap remains regarding the cost of capital specific to Digital Green Bonds. To date, no empirical analyses directly address whether the benefits observed in general blockchain-based bonds explicitly translate to this environmentally labeled subset. Thus, it can be cautiously suggested that Digital Green Bonds have the potential to reduce transaction and issuance costs through digital infrastructure; however, robust empirical validation is still needed for definitive conclusions.

2.2.4 Capacity impact

As stated earlier, Digital Green Bonds can automate specific, complex, and time-consuming processes, such as Know Your Customer (KYC)/Anti-Money Laundering (AML) verification, issuance, and trading, using smart contracts, also allowing for the replacement of intermediaries. However, [as Petrov et al. \(2021\)](#) emphasize, despite automation, Digital (Green) Bond issuance remains a highly technical process, especially when adapting to new digital frameworks. Expertise is still required to design, implement, and oversee digital bond systems, particularly in navigating regulatory requirements and developing smart contracts. Moreover, transitioning to digital bonds necessitates an initial investment in technology and training, and organizations may still encounter a learning curve.

2.2.5 Awareness impact

Transparency

Pavlidis (2022) states that digitalization and standardization of the green bond markets can significantly increase the credibility and transparency throughout the bond lifecycle, from issuance to reporting. In both the issuance and in the secondary market, the implementation of blockchain in green bond processes can ensure an auditable and immutable transaction record, strengthening data integrity and investor confidence. Additionally, Axelsen et al. (2023); Flourentzou (2025), Malamas et al. (2024b), and Schletz et al. (2020) highlight that by creating an end-to-end audit trail of all transactions, blockchain offers full traceability of the execution of all agreements, further enhancing accountability.

For investors seeking to align their portfolios with ESG values, the blockchain's immutable ledger increases the transparency of the investment, allowing for the thorough tracking and verification of the use of green bond proceeds, ultimately enhancing trust in green finance instruments such as green bonds (Antal et al., 2021; Ojukwu et al., 2024).

Performance reporting

Malamas et al. (2024) mention that DLT and blockchain technology can especially be used as an instrument for establishing trust in impact reporting processes for Green Bonds. The proposed framework in this research enables green bond issuance that safeguards investors' confidence in the use of proceeds for a 'green project', while protecting the issuer from accusations of greenwashing. Flourentzou (2025) also states that DLT enables real-time, verifiable reporting of sustainability metrics, such as carbon footprints, tracking of carbon credits, renewable energy certificates, and sustainable supply chains, thereby addressing widespread concerns of greenwashing and fragmented data. In the research by Pavlidis (2022) is also mentioned that DLT allows data to be collected through sensors and the internet of things (IoT) translated onto the blockchain and delivered to the markets with minimum cost, significantly improving ESG reporting and compliance (Ojukwu et al., 2024).

This performance reporting potential and awareness benefit can be linked to the enforceability (Policy barriers) of current green bond frameworks, as DLT can ensure the transparency of the green bond proceedings being invested in qualified environmentally friendly projects by tracing the movement of every dollar along the value chain and, in turn, publicizing the authentic environmental impact of the green bond for investors. Thus, DLT could redefine the green bond certification process (Zhang et al., 2018).

2.3 Digital Green Bond Barriers: Research Gap

The problem with Digital Green Bonds (DGBs) is that despite the theoretical advantages found in the literature, their adoption remains limited. After the first DGB issuance in 2019 by Spanish bank BBVA for MAPFRE and some issuances in Asia (especially Hong Kong), the global Digital Green Bond issuance only totaled €483 million in 2024, growing from €260 million the year before. Additionally, the European market experienced limited activity, with only €101 million issued through digital green bonds in 2023 and none in 2024. The Dutch digital green bond market is even more limited, only comprising of one €5 million proof-of-concept issuance by ABN AMRO for the real estate fund Vesteda in 2023 (AFME, 2024).

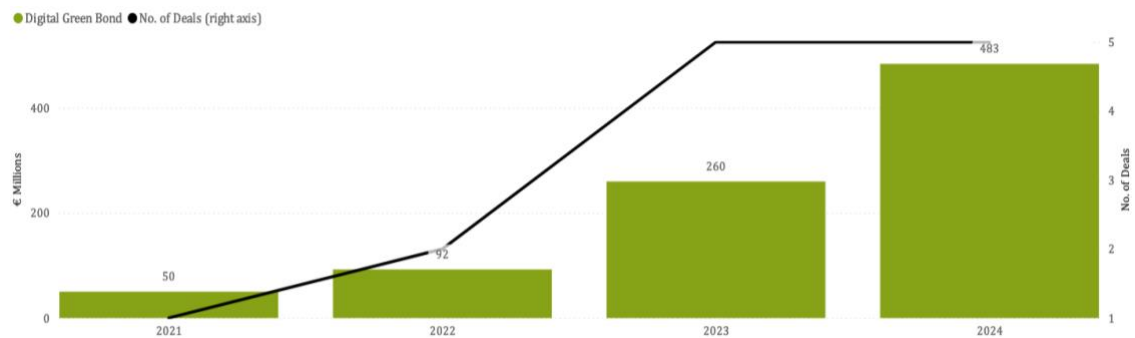


Figure 4: Global DLT issuance of Digital Green Bonds (AFME, 2024)

This low adoption rate limits the potential of the financial instrument and, consequently, its impact on making the issuance and investment in green bonds more attractive, thereby hindering the acceleration of the green bond market. Additionally, due to the novelty of the financial instrument, there is only a limited amount of academic literature available on Digital Green Bonds (DGBs). As mentioned in Walker et al.'s (2023, Chapter 2) book, the topic is relatively new, and therefore, the literature suffers from a lack of comprehensive studies that examine the interplay of fintech and sustainability. Thus, [this research aims to address the gap in the literature by identifying potential adoption barriers faced by Green Bond stakeholders in practice and presenting strategies for facilitating its adoption.](#)

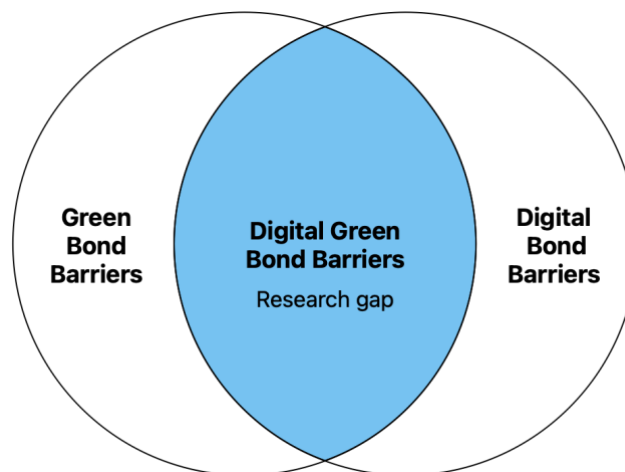


Figure 5: Literature research gap

Despite the limited literature, some studies have highlighted potential barriers that the implementation of DLT in financial processes may face, combining obstacles related to the 'green' sustainability aspect with those concerning the 'digital' DLT aspect. Although a complete list of all the potential barriers posed by DLT implementation in financial processes such as bonds is out of scope for this thesis, this section discusses a few major ones to illustrate that several barriers for adoption have to be overcome to fully utilize the DLT-enabled Digital Green bonds. These barriers are, again, categorized according to the five-part framework suggested by Nguyen et al. (2024): Policy, Market, Financial, Capacity, and Awareness Barriers.

Table 4: Literature review results

Barrier Type	Barrier	Source
Policy Barriers	Regulatory uncertainty	(Migliorelli & Dessertine, 2019; Priem, 2020)
	Regulatory compliance	(Migliorelli & Dessertine, 2019, Chapter 9; Priem, 2020; Thanasi Boçe & Hoxha, 2024)
Market Barriers	Investor privacy	(Eloul et al., 2025; Pinna & Ruttenberg, 2016; Santo et al., 2016)
	Liquidity constraints	(Arcodia et al., 2025; Santo et al., 2016)
Financial Barriers	High initial investment	(Benos et al., 2019)
	Internalized cost reductions	(Benos et al., 2019)
	Dependence on intermediaries	(Pinna & Ruttenberg, 2016)
Capacity Barriers	Infrastructure interoperability	(Migliorelli & Dessertine, 2019, Chapter 9)
	Infrastructure fragmentation	(Pinna & Ruttenberg, 2016)
	Technological scalability	(Migliorelli & Dessertine, 2019, Chapter 9; Thanasi Boçe & Hoxha, 2024)
	Security	(Aponte-Novoa et al., 2021; Sirikanchana, 2020; Thanasi Boçe & Hoxha, 2024)
Awareness Barriers	Lack of familiarity	(Migliorelli & Dessertine, 2019; Thanasi Boçe & Hoxha, 2024; Zhang et al., 2018)
	High energy consumption	(Migliorelli & Dessertine, 2019, Chapter 9; Thanasi Boçe & Hoxha, 2024)

2.3.1 Policy barriers

Regulatory uncertainty

Migliorelli & Dessertine (2019, Chapter 9) emphasize that the emergence of innovative technologies always generates an “environment of uncertainty,” which requires the adaptation of existing legal and regulatory frameworks or the implementation of new ones. For blockchain technology and its applications, legal and regulatory frameworks must be established, where the challenge lies in finding the balance between no regulation and overregulation. Since innovative technologies usually move and evolve rapidly, regulations must be adaptable.

Literature emphasizes that most barriers resulting from regulatory impediments are identified in post-trade clearing and settlement processes. As Priem (2020) mentions, if not addressed, legal challenges regarding DLT applications in clearing and settlement processes could be a barrier to adoption. The following regulations act as a barrier to the DGB’s potential, and therefore, adoption by the market, as stated by Priem (2020):

First, the EMIR (EU Regulation 648/2012) mandates that standardized OTC derivatives, including securities such as green bonds and digital green bonds, must be centrally cleared through a Central Counterparty (CCP), effectively granting CCPs a quasi-monopoly within this market segment. Therefore, if a DLT-based system were to operate without a CCP for these types of derivatives, it would be in direct breach of EMIR. Second, the Central Securities Depositories Regulation (CSDR, EU Regulation 909/2014) stipulates that securities traded on EU trading venues must be issued and settled through a licensed central securities depository (CSD). This implies that a DLT system without an issuer CSD would not be a lawful option for issuers, thus excluding such infrastructures from participating in regulated issuance and settlement activities. In the Dutch context, the Dutch Securities Giro Act (WGE) complements the European CSDR and establishes requirements for central securities depositories. It mandates Euroclear Netherlands to safeguard and administer securities, as well as facilitate Giro-based transfers, which are supervised by the Dutch Authority for the Financial Markets (AFM). This law encompasses all bonds traded through the Giro system, including tradable green bonds, and does not accommodate DLT-based clearing or settlement. Lastly, the Settlement Finality Directive (SFD) is built on legacy legal constructs such as “transfer orders” and “accounts,” typically defined in the context of double-entry bookkeeping. Since these concepts may not directly apply to the structure of native DLT systems, a DLT solution lacking double-entry accounts would likely not be recognized as a valid securities settlement system under existing law.

Regulatory fragmentation

Apart from regulatory uncertainty, Priem (2020) also highlights that the creation of a separate national regulation regarding DLT usage in securities would create regulatory fragmentation and may lead to inconsistent interpretations across member states, fragmenting regulatory approval. Thanasi Boçe & Hoxha (2024) add that the decentralized nature of DLT creates regulatory challenges, making it difficult to comply with varying international regulations and currencies. Migliorelli & Dessertine (2019, Chapter 9) also add that DLT is a borderless technology, operating across jurisdictions without regard for national boundaries. This characteristic, while central to its efficiency and global reach, introduces significant regulatory challenges. Because the technology is borderless, it necessitates the development of mutually compatible and non-conflicting legal and regulatory frameworks across jurisdictions. In the absence of such harmonization, regulatory fragmentation becomes a significant

barrier to adoption, creating uncertainty and complexity for cross-border transactions conducted via DLT.

2.3.2 Market barriers

Investor privacy

Eloul et al. (2025) mention that a key challenge is the creation of a privacy-preserving DLT that meets regulatory requirements is complex, as it must balance transparency with confidentiality. As Pinna & Ruttenberg (2016) also note, regulators in DLT systems must access the details of a transaction to verify its legitimacy. However, this requirement conflicts with the commercial interests of market participants, who are generally reluctant to expose sensitive trading strategies. This creates a fundamental barrier to implementation, particularly in competitive institutional environments where information asymmetry can offer strategic advantages. Eloul et al. (2025) note that public blockchain ledgers originally use anonymous accounts, yet values, transaction graphs, balances, and assets remain public. From a trading view, a small transaction history can reveal strategies or positions; however, auditing requires maintaining traceability. Santo et al. (2016) add that this information disclosure would not be accepted by existing market players.

Liquidity constraints

Arcodia et al. (2025) mention that because of the ability of DLT to provide atomic settlement, it removes the risk that one party fails to pay or deliver. However, this also means that it could introduce liquidity constraints, as institutions must always have enough money and assets ready to support these real-time settlements, therefore, traditional systems allow a few days between trade and settlement such as delayed T+2 settlements. Furthermore, Santo et al. (2016) adds that helpful tools like netting (combining multiple trades into one to reduce cash needed) and queuing (delaying some settlements to save liquidity) have still not proven to be useful DLT processes. Therefore, further research should be done to balance this speed benefit with the liquidity constraints.

2.3.3 Financial barriers

High initial investment

One of the most predominant barriers is financial, which are the high initial investment costs needed to implement DLT in securities. According to the research by Benos et al. (2019) which studies the economics of DLT for Securities, these high transitional costs are a key barrier for institutions to adopt digital securities such as DGBs:

First, research and development (R&D) is needed to gain technical skills and knowledge to establish said DLT-based issuance or settlement platforms. This involves additional, transitional costs, including designing ledger architectures, consensus mechanisms, permissioning frameworks, and smart contract modules. According to Benos et al. (2019): *“those firms or entities engaged in the development of DLT-based solutions for settlement purposes are likely to face high costs associated with the relevant R&D expenses”* (p. 32).

Second, legacy systems must be replaced or integrated with the DLT infrastructure, thereby reconfiguring their existing business processes. These transition costs are not only technical, but also organisational, as training and changing business models is also needed.

Third, fixed infrastructure costs stem from core operational components in permissioned DLT environments, including configuring validating nodes, notary services, and implementing governance and cybersecurity protocols. As noted, “there would likely be some fixed costs associated with a DL-based securities settlement system” (p. 33).

Lastly, it is the question if these initial investment costs are even carried out, as internal bank decisions often require short payback periods, not focusing on the long term. The authors observe that “banks only invest in new technologies if the initial investment is recouped by the resulting cost savings within 3 years” (p. 33). This narrow time horizon discourages investment in transformational technologies with longer-term efficiency gains.

Internalized cost reductions

Benos et al. (2019) critically note that the anticipated cost savings from DLT implementation may not necessarily benefit market participants in the short term. They argue that incumbent institutions—such as existing central securities depositories (CSDs) and other intermediaries—are more likely to adopt distributed ledgers to optimize internal operations without fundamentally changing their business models. In such scenarios, any operational efficiencies or reductions in back-office costs could be internalized rather than passed on to end-users. Consequently, settlement costs for market participants may remain largely unchanged, with the financial gains from DLT adoption accruing primarily to the existing market infrastructure providers

Dependence on intermediaries

Moreover, despite the ability of DLT to disintermediate, Pinna & Ruttenberg (2016) deem a fully peer-to-peer issuance or settlement between issuer and investor on a DLT unrealistic, as the involvement of regulated entities is generally required, irrespective of the technology adopted. Also, Pinna & Ruttenberg (2016) mention that the usage of DLT for securities would not necessarily eliminate the need for CSDs “under current (EU) regulations” due to their governance and legal roles. However, it could be said that a regulatory change could make it a possibility.

2.3.4 Capacity barriers

Infrastructure interoperability

Many financial institutions lack the necessary infrastructure to support DLT, leading to concerns about scalability and performance (Manning, 2016).

Migliorelli & Dessertine (2019, Chapter 9) also mention that the integration of blockchain and DLT presents a barrier to adoption, as linking existing systems with DLT may be challenging.

Infrastructure fragmentation

Pinna & Ruttenberg (2016) identify a lack of harmonization and standardization as a significant barrier to the adoption of distributed ledger technology (DLT) in financial markets. While institutions invest in proprietary DLT solutions, this fragmented development reduces interoperability across systems. Without common technical standards and standardized processes, DLT’s full efficiency cannot be realized market-wide. Although some financial institutions benefit from tailored technologies, broader systemic efficiency requires seamless communication across different DLT platforms. Therefore, harmonization is essential for the adoption of the technology

Technological scalability

Thanasi Boçe & Hoxha (2024) mention that scalability is a critical technical challenge for blockchain, as increased transaction volumes can reduce system performance and efficiency. Also Migliorelli & Dessertine (2019, Chapter 9) mention that due to complex verification processes transaction speed is rather low and makes blockchains more resource consuming, which is also confirmed by Santo et al., (2016), which states that “the throughput capacity we have gained through proofs-of-concept limits applicable field of businesses and does not reach a level sufficient to handle a high traffic volume market stably”.

Security

Arcodia et al. (2025) states that although the decentralized nature of the chain makes DLTs less exposed to single points of failure, Proof of Work (PoW) and Proof of Stake (PoS) mechanisms are potentially vulnerable to cyber-attacks. According to Thanasi Boçe & Hoxha (2024) cybersecurity is a concern that potentially lowers trust in DLT-based securities such as DGBs. Despite inherent protections, blockchain is susceptible to cyber threats like the 51% attack, and new vulnerabilities may emerge as the technology evolves (Aponte-Novoa et al., 2021). Moreover, Sirikanchana (2020) also mentions cybersecurity as a potential barrier for adoption. The study emphasizes the security risks posed not by the blockchain itself, but by the platforms and interfaces built upon it, such as digital wallets, exchanges, and third-party services. The research concludes by stating that no system is perfect; however, it is important to understand the risks associated with the system so that these risks can be mitigated.

2.3.5 Awareness barriers

Lack of familiarity

According to Thanasi Boçe & Hoxha (2024), resistance to adopting new technologies like blockchain is common, often due to limited understanding or concerns about potential impacts. Integrating blockchain into existing systems can be complex and costly, posing significant barriers for organizations, especially smaller ones with limited resources. Moreover, Migliorelli & Dessertine (2019, Chapter 9) also state that a certain level of knowledge and experience is needed to encourage widespread adoption, as this familiarity with the concept builds the basis of trust and usability of an innovative technology. Zhang et al. (2018) add to this barrier that governments need to increase their awareness of how blockchain and DLT work to align innovative technological solutions with the broader sustainable finance agenda.

High energy consumption

According to Migliorelli & Dessertine (2019, Chapter 9) and Thanasi Boçe & Hoxha (2024), blockchain networks, especially those using proof-of-work (PoW) mechanisms, require significant computational resources, leading to high energy consumption. This poses environmental concerns, particularly regarding sustainability objectives aimed at reducing carbon emissions, such as green bonds.

3 Methodology

3.1 Research design

As mentioned earlier in the introduction, this research will [identify potential adoption barriers faced by Digital Green Bond stakeholders in practice](#) and [present strategies for facilitating its adoption](#), thereby accelerating the growth of the green finance market and contributing to the closure of the green financing gap by making investments in green securities more attractive. Consequently, the main research question will be answered through four sub-questions:

RQ: How can the adoption of Digital Green Bonds be accelerated to help close the green finance gap?

- **SQ1:** What barriers do stakeholders identify in the issuance and management of traditional green bonds?
- **SQ2:** How can Distributed Ledger Technology (DLT) and the development of Digital Green Bonds potentially address the barriers found in traditional green bond processes?
- **SQ3:** Which barriers currently hinder the broader adoption of Digital Green Bonds in the financial market?
- **SQ4:** How can these barriers be addressed to facilitate the broader adoption of Digital Green Bonds?

The posed research questions will be answered through an explorative case study of a relevant Digital Green Bond transaction, as an explorative case study is well-suited for exploring contemporary phenomena in depth and within their real-world context (Barlett & Vavrus, 2017; Yin, 2014), supplementing the minimal academic literature around Digital Green Bonds with practical insights. Moreover, the research will also propose workable strategies for DGB stakeholders to adopt these DGBs, thereby accelerating the green finance market and helping to close the green financing gaps.

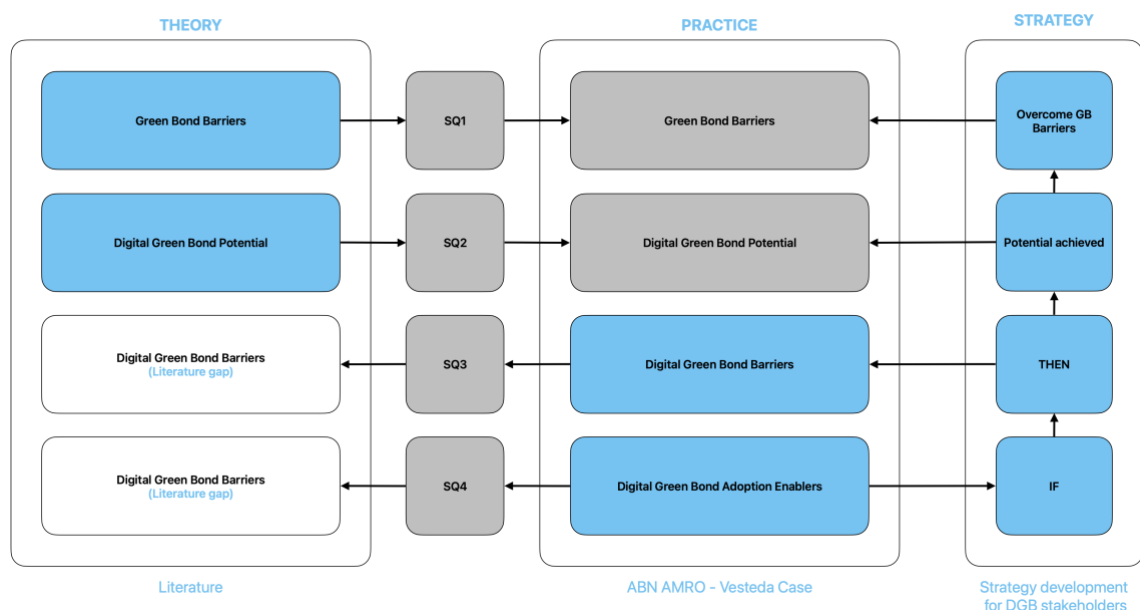


Figure 6: Research design

3.2 Case study: ABN AMRO-Vesteda DGB

3.2.1 Case information

In September 2023, Vesteda Finance B.V., a leading Dutch institutional residential real estate investor, successfully issued a €5,000,000 digital green bond under Dutch law, marking a landmark transaction in the convergence of green finance and DLT (Digital Green Bond). The bond, structured as a Floating Rate Note (FRN) maturing on September 12, 2024, was privately placed with DekaBank Deutsche Girozentrale. This issuance represents the first and only digital green bond on a public blockchain (Polygon) for a large institutional client in the Netherlands and was executed in close collaboration with ABN AMRO, which took on multiple roles, including Sole Arranger, Tokenization Agent, Registrar, Wallet Provider, and Digital Custody Provider.

The bond was organized following Vesteda's Green Finance Framework, compliant with EU Taxonomy, ICMA's Green Bond Principles, and Dutch regulations. The Notes feature a quarterly floating coupon of 3-month EURIBOR plus 40 basis points and are digitally represented as tokens on the Polygon Proof-of-Stake blockchain, with legal ownership confirmed by public address entries in the distributed ledger register held by ABN AMRO.

Notably, there was no physical certificate or entry in a central securities depository (CSD). The complete lifecycle of the bond, covering issuance, settlement, registration, and redemption, was managed through tokenization technology offered by Tokeny and Fireblocks, while ABN AMRO took care of wallet creation, transaction signing, and the secure storage of digital assets.

Legally, the bond issuance was executed under a Private Placement Memorandum, which is not subject to the EU Prospectus Regulation and therefore not registered with any supervisory authority. ABN AMRO, leveraging its established digital assets infrastructure, managed all technological and operational aspects, allowing Vesteda to participate without needing in-house blockchain expertise or technical systems. Legal documentation, including the Tokenisation Agency Agreement and wallet arrangements, was prepared in collaboration with Allen & Overy (for Vesteda) and Clifford Chance (for ABN AMRO). The tokens were minted, transferred, and will be destroyed at maturity entirely under ABN AMRO's supervision, ensuring legal certainty and compliance with existing Dutch financial regulations.

This case shows the viability of tokenized debt instruments for institutional real estate financing. By leveraging public blockchain infrastructure, it illustrates that DLT can meet the regulatory, operational, and risk standards required for institutional capital markets, particularly in ESG-focused funding. As noted by ABN AMRO, this project also contributes to a broader strategy of transforming capital markets infrastructure by integrating digital asset custody, instant settlement, and smart contract-driven servicing into mainstream banking operations. With the development of growing regulatory frameworks such as the EU DLT Pilot Regime, such innovations are expected to scale in complexity and volume, potentially redefining how private placements and green bonds are structured, traded, and settled in the future.

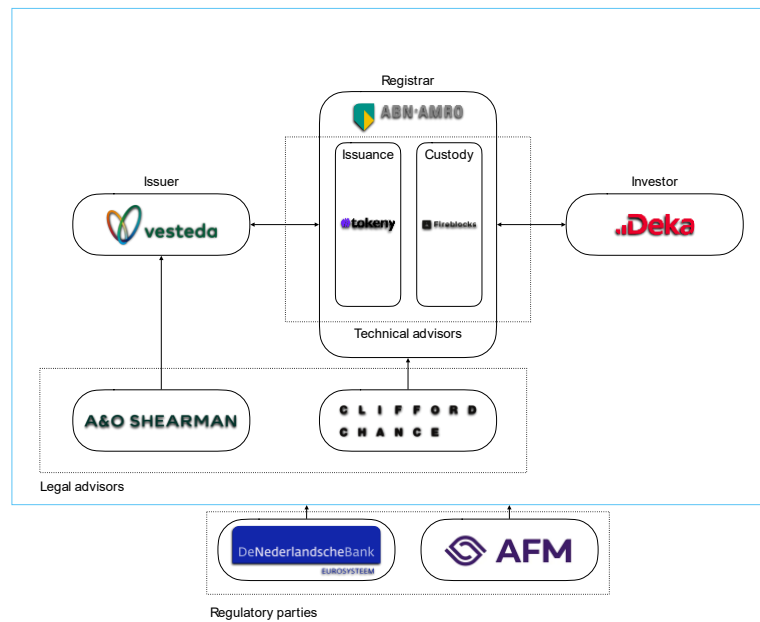


Figure 7: Vesteda-ABN AMRO Digital Green Bond Issuance Stakeholders (own work)

3.2.2 Case selection

This case offers valuable transferable insights, partly due to its context: the Dutch regulatory and financial context. This context is interesting due to the limited uptake and implementation of 'digital green bonds' in a mature green debt market, which has established itself as an international leader in traditional green bond issuances, ranking fifth worldwide and third among European countries in terms of the cumulative value of green bonds issued (Climate Bonds Initiative, 2024). This situation, in which the green finance market is as vast as it is, combined with the relatively low adoption of digital green bonds, presents great opportunities to explore the barriers perceived by traditional green bond stakeholders in adopting digital green bonds. It also offers insights that can be applied to other EU member states facing similar obstacles in adoption.

3.2.3 Interview approach

In this study, 10 experts from the banking, fintech, legal advisory, market regulatory, and real estate domains were interviewed. These interviews covered the complete capital-markets value chain, from underwriting and issuance through custody, technology provision, investment, and supervisory oversight. The focus was on assessing the barriers identified in green bond processes, the role of DLT, and the creation of Digital Green Bonds (DGBs) to overcome these barriers, as well as how the adoption of these DGBs can be facilitated to advance the broader green finance market further.

Table 5: Interviewed experts, roles, expertise, and locations.

#	Company	Role	Expertise	Location
1	ABN AMRO 1	Issuer	Digital Assets ('DLT')	The Netherlands
2	ABN AMRO 2	Issuer	Sustainable Markets ('Green')	The Netherlands
3	ABN AMRO Clearing Bank*	Custody*	Clearing, Custody & Settlement Expert (Innovation)	The Netherlands
4	Vesteda	Client	Real Estate (Treasury)	The Netherlands
5	DekaBank	Investor	Digital Assets	Germany
6	Tokeny	DLT Provider	DLT (Fintech)	Luxembourg
7	A&O Shearman	Client's legal advisor	Policy (Capital Markets)	The Netherlands
8	Clifford Chance**	Issuer's legal advisor	Policy (Capital Markets)	The Netherlands
9	Autoriteit Financiële Markten (AFM)	Market regulator	Policy	The Netherlands
10	De Nederlandsche Bank (DNB)	Market regulator	Policy (Digital Assets)	The Netherlands

* The wallet provider (FireBlocks) involved in the custody did not participate in the study. Therefore, a clearing, custody, and settlement expert is interviewed to acquire information for these phases in the Digital Green Bond.

** Clifford Chance's interview was not recorded, but notes have been taken.

The qualitative data is gathered through [semi-structured interviews](#) with the stakeholders in the ABN AMRO-Vesteda issuance, conducted either via Microsoft Teams (online) from February 2025 to June 2025 or physically at the interviewees' offices, lasting 45 minutes to 60 minutes. Given the exploratory nature of this research, [non-probability sampling methods](#) are employed for the case study. Due to the hard-to-reach population, the [snowball sampling method](#) is utilized. Initially, the researcher selects the first participants, who are then referred to additional interesting candidates for interviews. As illustrated in Figure 36, the researcher opts for a sample instead of random selection, as the organizations involved in the selected cases are the only available options. The contacted organization subsequently chooses the eligible interviewee based on their expertise.

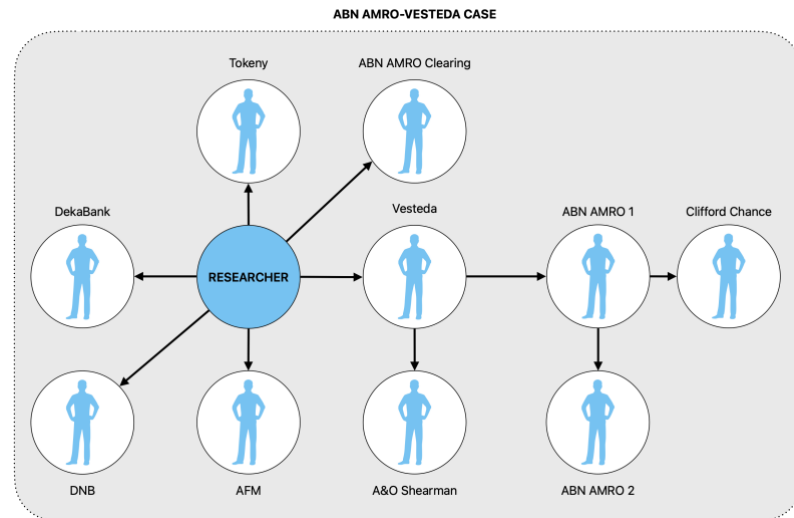


Figure 8: Snowball method for this case study (own work).

The chosen sampling technique enables access to difficult-to-reach populations involved in the process, avoids ethical risks by allowing participants to participate or decline, and saves money and time since current subjects are used to locate other participants (Simkus, 2023). Drawbacks attributed to this method is that it is difficult to determine a sampling error as it is a non-probability sampling method, a researcher bias is possible, as the initial participants will strongly impact the rest of the sample, and it will not always be representative of the greater population (Chegg Writing, 2021).

For the Vesteda case, all stakeholders were contacted simultaneously to elicit a response from one party. This approach creates opportunities for referrals and facilitates snowball sampling, as most parties are difficult to reach without such referrals. The first responder was Vesteda, the issuer of the bond, who referred most of the other interviewees, leading to the underwriter, ABN AMRO, the central organizational party, having the most contacts within the transaction. Other parties were contacted through purposive sampling when snowball sampling was ineffective. Deka, DNB, AFM, and Tokeny were contacted through purposive sampling.

3.2.4 Interview structure

The semi-structured interviews are designed according to Bearman's (2019) practical approach to writing semi-structured interview schedules. Here, the author presents the following three steps:

First, the interview development process begins with creating open-ended questions centered on a core event that represents the phenomenon of interest: the act of issuing, investing in, or otherwise participating in a Digital Green Bond (DGB) transaction. These questions are designed to explore four key themes, organized into four interview sections: (A) the perceived barriers in GB processes that should be overcome, (B) the perceived value or motivation for choosing DGBs over traditional GBs, (C) the barriers encountered or perceived during the DGB adoption process, and (D) potential solutions to address these DGB barriers. Open-ended questions are crucial to encourage detailed, experience-based responses rather than simple yes-or-no answers.

Second, an intuitive conversational structure has been developed to guide the flow of the interview. This begins with introductory questions to build rapport and clarify the participant's role in the DGB

transaction, followed by a deeper exploration of their experiences and perceptions related to the core themes. The interview concludes with reflective or abstract questions that allow for broader insights or closing thoughts, such as *“What would you do differently if you were to engage in this process again?”* or *“Is there anything else you would like to add about your experience with DGBs?”*

Third, the interview schedule is refined through piloting with similar participants. Feedback on question clarity, logical flow, and data richness is collected, and the schedule is adjusted iteratively to ensure it supports the gathering of meaningful and relevant empirical data that aligns with the study’s research objectives.

3.3 Data analysis

The qualitative data from the semi-structured interviews is analyzed using a [thematic stakeholder analysis](#). This proposed method combines the six-step thematic analysis method by Braun and Clarke (2006) with a stakeholder analysis approach by Varvasovszky and Brugha (2000). Due to this unconventional analysis type, thematic analysis enables the identification, analysis, and reporting of patterns (themes) within the data, while stakeholder analysis provides insight into the roles, perceptions, needs, and tensions among stakeholders. Therefore, a structured stakeholder exploration is possible while maintaining analytical depth. Furthermore, the analysis will be conducted using [constructivist and interpretative epistemologies](#), wherein meaning is created between the researcher and the participants. The researcher is not a neutral observer but actively interprets the data they have gathered (Swain, 2008).

In short, four a priori themes are created, arising from the four sub-questions, as seen in Table 5. These themes divide the research into four parts: benefits, process impacts, adoption barriers, and adoption solutions for digital green bond adoption. Then, deductive codes are developed based on the literature, which are later combined with inductive codes throughout the coding process of the interview transcripts. Simultaneously, the codes are further categorized by stakeholder, allowing for stakeholder-oriented analysis. A more step-by-step description of the data analysis is described below, which is based on the six steps by Braun & Clarke (2006) modified by allowing stakeholder analysis by Varvasovszky & Brugha (2000).

Table 6: Analysis ste-by-step, adapted from (Braun & Clarke, 2006; Varvasovszky, 2000).

Step	Description
1. Familiarize with Data	Listen to audio recordings, transcribe interviews, and thoroughly read the transcripts to immerse yourself in the data.
2. Generating Initial Codes	a. Deductive coding (thematic): Derive codes from literature (e.g. benefits, process impacts, barriers, and solutions related to DGB adoption). b. Deductive coding (stakeholder-based): Generate codes based on known stakeholder categories from literature (e.g. issuer, investor, underwriter). c. Inductive coding: Identify additional relevant codes emerging from the data per sub-question theme.
3. Code and Tag per Stakeholder	Apply stakeholder labels to each code to allow analysis of responses per stakeholder group.
4. Searching for Themes	Organize and group related codes into initial themes, structured according to stakeholder groupings.
5. Compare Themes Across Stakeholders	Evaluate how themes hold across stakeholder-coded extracts and examine similarities, divergences, and tensions between groups.
6. Review Themes	Refine and clarify each theme's scope and relevance; identify stakeholder-specific subthemes where applicable.
7. Defining and Naming Themes	Develop clear definitions and concise labels for each theme and subtheme.
8. Map Stakeholder Positions	Interpret stakeholders' roles, interests, and interrelations using analytical tools such as matrices or visual diagrams.
9. Produce the Report	Present findings thematically per stakeholder group, incorporating illustrative quotes, visual maps, and linking back to the research questions.

Table 7: Thematic codes

Interview section	Folder	Sub question relation	Deductive Themes (literature)	Deductive Codes (literature)
A	GB Barriers	SQ1	Policy, Market, Financial, Capacity, Awareness	Regulatory enforcement; regulatory fragmentation; lack of eligible projects; market inaccessibility; currency risks; high transaction costs; intermediation; yield uncertainty; lack of technical skills; limited track record and performance data of green projects; lack of awareness; reporting; risk of greenwashing.
B	DLT Impact	SQ2	Policy, Market, Financial, Capacity, Awareness	Regulatory compliance; standardization; 24/7 market access; fractionalization; disintermediation; automatization; lower cost of capital; none; transparency; performance reporting.
C	DGB Adoption Barriers	SQ3	Policy, Market, Financial, Capacity, Awareness	Research gap
D	DGB Adoption Enablers	SQ4	Policy, Market, Financial, Capacity, Awareness	Research gap

Table 8: Stakeholder codes

Stakeholder	Stakeholders code
Vesteda	Issuer; Underwriter
Buy side	Investor; Trader
Advisors	Legal advisor; technological provider
Regulator	Market regulator;
Market infrastructure providers	Clearinghouse; CSD; Custodian

3.4 Data management and ethics

3.4.1 Data management plan (DMP)

This research follows TU Delft's ethical research and data stewardship standards. A Data Management Plan (DMP) was developed using the DMPonline tool and is included in Appendix B. The DMP details the procedures for collecting, storing, managing, and protecting the project data. Primary data includes semi-structured interview recordings, pseudonymized transcripts, coded datasets from Atlas.ti, and limited administrative contact information. All data is securely stored on TU Delft OneDrive, accessible only to the researcher and supervisors. Audio recordings from personal devices are deleted within 24 hours and not synced to cloud services. Personally identifiable information (PII) is stored separately in encrypted form to minimize the risk of re-identification. Raw and coded data will be deleted no later than one month after project completion, except for anonymized excerpts in the publicly available MSc thesis in the TU Delft Education Repository.

3.4.2 Research ethics

To ensure ethical compliance, a Human Research Ethics Checklist (HREC) was completed and submitted (see Appendix C). The study involves expert stakeholders in digital green bonds. Informed consent was obtained through a formal process, informing participants about the study's purpose, data handling, and their rights, including withdrawal at any time. Consent forms were signed digitally and stored securely. Interview data were pseudonymized, and participants could review their transcripts before use. While personal names are omitted from public outputs, organizational affiliations may be referenced with participant approval. No sensitive personal data were collected, and the legal basis for data processing is informed consent. Due to the qualitative nature of the research, full anonymization was not applied to maintain analytical value, but steps were taken to mitigate re-identification risks. The research was considered low-risk and did not require a Data Protection Impact Assessment (DPIA) per GDPR guidelines.

4 Findings

This chapter provides a structured analysis of expert perspectives on Digital Green Bonds (DGBs) in the Dutch financial sector, using the ABN AMRO–Vesteda case study and addressing four research sub-questions. It analyzes the perceived barriers to issuing and managing traditional green bonds, as identified by the interviewees. It also explores how Distributed Ledger Technology (DLT) and DGB design can overcome these challenges, enhancing efficiency, transparency, and accessibility. Then, barriers obstructing DGB growth are analyzed, including regulatory, technical, and institutional issues. Finally, it outlines stakeholder strategies and enabling factors that could enable DGB adoption, such as regulatory alignment, market education, and technological standardization. Through thematic and stakeholder analysis, the chapter highlights the agreements and disagreements among key players and explains how DGBs could accelerate the progress in closing the green finance gap.

4.1 Traditional Green Bond Challenges

This section synthesizes the barriers identified by the interviewees that motivated them to engage with the Digital Green Bond market. The identified barriers mentioned by the interviewees will be categorized into the five deductive themes used by [Nguyen et al. \(2024\)](#): Policy, Market, Financial, Capacity, and Awareness Challenges. The identified barriers are coded, and illustrative quotes are shown in Table 9:

Table 9: Identified barriers in traditional Green Bond markets

Theme	Green Bond Challenge (Deductive + inductive codes)	Illustrative quote
Policy challenges	Regulatory enforcement	“...you can lose the green label. That’s unfortunate, but there aren’t many consequences attached to it yet.” – Vesteda interview (±04:32)
	Regulatory fragmentation	Not mentioned
Market Challenges	Lack of eligible projects	Not mentioned
	Market inaccessibility	“A minimum amount is required, right? That’s what they call the benchmark size. And that’s not so much for us, but investors generally want that. And that’s quite a large amount — it needs to be 300 or 500... 500 million is what you then call a benchmark.” ABN AMRO Clearing Bank interview
	Reliance on market hours	“If you build a big position over the weekend and a pipeline blows up, that has an effect—and we can’t receive or deliver additional collateral because the ECB is closed. We can’t move funds.” ABN AMRO Clearing interview (±22:27)
	Currency risks	Not mentioned

Financial Challenges	High issuance costs	“The auditor, the lawyer, all must be paid. An auditor is not cheap either. Banks also charge a fee. In our case, we pay 30 basis points, which amounts to about 1.5 million euros that we pay to the banks. That’s for the work they do. So, in total, you’re quickly looking at around 2 million in costs.” – Vesteda Interview (±17:48).
	Slow settlement (Inductive)	“Ultimately, what our client wants is to get the money to the right place as quickly as possible.” – ABN AMRO Interview (±36:00).
	Yield uncertainty	Not mentioned
Capacity Challenges	Lack of technical skills	“It’s just that no one had done it before, so I was the first to structure a green bond for ABN AMRO. Which basically also meant: how do I measure that? What definition do you use for it? What qualifies as green? What data do you need for that? And did we have that?” - ABN AMRO 2 Interview (±6:08)
	Limited track record and performance data of green projects	Not mentioned
Awareness Challenges	Reporting	“Everyone actually wants to see: hey, this is how the funds are used, this is what it delivers for that building, and this is the resulting saving.” – Vesteda interview (±25:29)
	Risk of greenwashing	Not mentioned
	Ownership transparency (Inductive)	“...our bond is traded on the stock exchange, and from that point on, we no longer know who the new investors are or to whom the bonds are resold...” - Vesteda interview (±20:12)

4.1.1 Policy Barriers

Regulatory enforcement

The transaction’s issuer still mentions that there is no binding regulation enforcing measures to reduce the risk of greenwashing. Nonetheless, according to them, there are no severe consequences attached to any misinformation or greenwashing concerns, so trust in green bonds will remain low because of this:

“Yes, that’s quite new. The first ones are now also being issued. Everyone was very cautious, because, well, this still has a fairly non-binding character. So if you don’t fully comply — for example, if you issue a bond and can’t demonstrate that you meet the conditions — you can lose the green label. That’s unfortunate, but there aren’t many consequences attached to it yet.” – Vesteda interview (±04:32).

4.1.2 Market Barriers

Market inaccessibility

Traditionally, bond issuances require large minimum investment sizes, effectively excluding smaller issuers and non-institutional investors from the (green) bond market. According to Vesteda, small businesses in the Netherlands lack access to capital markets and remain largely dependent on bank

financing. Even when access is theoretically possible, the required issuance volumes are prohibitively high, typically starting at €500 million for public placements or €50 to €100 million for private placements (Vesteda interview, ± 18:57).

From the investor's perspective, these high thresholds are also driven by regulatory and portfolio diversification constraints. As explained by the Sustainability Expert, institutional investors generally require transactions of at least €300 to €500 million to meet internal investment criteria. Issuances below that benchmark are often unattractive, as investors are restricted from holding more than a certain percentage of any single transaction (Hessels interview, ±17:38).

These findings highlight a fundamental barrier within the traditional market structure: the scale required for bond issuance effectively excludes smaller participants on both the supply and demand sides, thereby limiting broader accessibility and inclusivity in the green bond market.

Reliance on market hours

Institutional investors trade traditional green bonds on 9-to-5 markets on business days. Stakeholders mention that this limited accessibility restricts flexibility in risk management, liquidity, and collateral provision, particularly outside business hours and during weekends. As one stakeholder from ABN AMRO Clearing notes, this inflexibility becomes problematic when unexpected events occur:

"If you build a big position over the weekend and a pipeline blows up, that has an effect—and we can't receive or deliver additional collateral because the ECB is closed. We can't move funds." (±22:27)

4.1.3 Financial Challenges

High issuance costs (Inefficiency, process complexity and intermediation)

Stakeholders have identified the traditional green bond issuance process to be inefficient, as it is deemed slow and dependent on numerous intermediary parties, thereby increasing issuance costs. This is highlighted by the issuer during their interview, showing their innovative drive:

"[...] we recognize the inefficiency in the current issuance of debt and believe it can be improved. At Vesteda, we are very open to innovations across all areas in which we operate. So, when something new shows potential to work effectively, we are keen to explore it. This also applies to our financing strategies. We are therefore interested in examining whether this could offer an alternative solution to the conventional methods of debt issuance." – Issuer interview (±10:03).

The issuer indicates that the green bond issuance process is lengthy and outdated, still depending on manual steps, such as phone calls to investors. Along with the requirement for long regulatory approvals, second-party opinions, credit ratings, and coordination with various intermediaries, this procedural complexity restricts issuance flexibility and responsiveness. Consequently, market opportunities may be missed, and issuance and transaction costs rise, lowering the overall efficiency and attractiveness of green bonds for both issuers and investors. (Vesteda interview, ±18:44; ±52:49) Stakeholders indicate that issuing a traditional green bond involves significant costs, primarily due to the participation of various intermediary parties such as auditors, legal advisors, and banks. According to the issuer, total issuance costs can reach approximately €2 million. This includes fees for auditors and lawyers, as well as underwriting fees charged by banks, reported to be around 30 basis points, translating to roughly €1.5 million (Vesteda interview, ±17:48).

Slow Settlement

From the interviews, stakeholders raised concerns about the time it takes for traditional green bonds to be delivered and settled. Settlement periods ranged from T+5 to T+2, as the Clearing and Settlement Expert explained: “The formal settlement only takes place two days after the trade date [...] If you trade today, settlement occurs tomorrow morning at 8 o'clock” - ABN AMRO Clearing Interview (±10:46).

4.1.4 Capacity barriers

Lack of technical skills

The sustainability expert from ABN AMRO emphasizes that one of the main challenges in structuring their first green bond was the absence of established internal guidance and technical knowledge for issuing that green bond. As the first within the organization to structure such an instrument, they confronted several fundamental uncertainties. These included determining how to define and measure the “green” aspect of the bond, what standards or criteria should apply, which types of projects or expenditures would qualify, and what data would be required to substantiate the green classification. This highlights the broader barrier of definitional ambiguity and data availability that issuers face in the early stages of green bond structuring (ABN AMRO 2 interview, ±6:08)

4.1.5 Awareness barriers

Reporting

Green Bond stakeholders emphasize the need for greater transparency regarding allocation and reporting of Green Bond proceeds. The transaction’s issuer particularly underscored the burden of post-issuance verification processes, as confirming the allocation of funds toward those eligible green projects, such as in the Vesteda case, sustainable housing, remains a resource-intensive task (Issuer interview, ±05:09). The interviewee also stated that there is a lack of real-time access to impact data enabling investors and other stakeholders to track outcomes without needing to manually track and evaluate data across dispersed and inconsistent reporting formats throughout their multiple investments. The sustainability expert from ABN AMRO stated the following about this burden:

“And then you don’t have to keep searching every day, hoping that someone has published a report at some point, and then you still have to check: okay, what was the impact? How many deals are outstanding, how much did I eventually have? And then you can calculate what your impact is. That’s a lot of work.” – ABN AMRO 2 interview, (±11:09).

Ownership transparency

Green bonds lack in post-trade transparency and are difficult to keep track of its ownership. Issuers can lose sight of the bond’s ownership after its issuance, due to the custodial process. The issuer explains this challenge as follows:

“When we issue the bond, we know which investors have placed orders and what allocation each received [...]. But after that, our bond is traded on the exchange. From then on, we no longer know who the new investors are, who the bonds are being resold to. There is a custodian involved who keeps track of everything and ensures that the flows are processed correctly. But that process is not transparent — at least, not for us.” – Vesteda interview (± 20:12)

4.2 Digital Green Bond Potential

This chapter synthesizes the potential of digital green bonds powered by Distributed Ledger Technology (DLT). The results provide insights into why stakeholders are increasingly exploring digital solutions and what specific inefficiencies they aim to resolve in the traditional Green Bond market.

The identified potentials mentioned by the interviewees will be categorized into the five themes used by [Nguyen et al. \(2024\)](#): Policy, Market, Financial, Capacity and Awareness Challenges. The codes and their illustrative quotes are shown in Table 10:

Table 10: Themes and Codes concerning identified Green Bond barriers and the potential perceived benefits of adopting Digital Green Bonds.

Theme	Digital Green Bond Potential (Deductive + inductive codes)	Illustrative quote
Policy potential	Regulatory compliance	Not mentioned
	Standardization	Not mentioned
Market potential	Fractionalization	“(Traditionally) the costs are too high to do it in small chunks. What Siemens says is: with this technology, I can do small transactions.” – ABN AMRO Interview (±36:00)
	24/7 Market Access	“The added value for us is really the 24/7 availability. [...] the fact that you can make assets, like tokenized cash or bonds, transferable anytime, even when central infrastructures are closed.” - ABN AMRO Clearing Interview (±24:12)
Financial potential	Lower issuance costs (Disintermediation)	“That’s something I would like to change with this system — either to reduce those costs, so you need the banks less, and essentially make such a loan cheaper.” – Vesteda interview
	Faster settlement (inductive)	“... where we currently have a settlement period of 5 days, the settlement (of digital green bonds) takes place on the same day.” – Vesteda.
Capacity potential	None	Not mentioned
Awareness potential	Performance reporting	“We can also supercharge the token with data concerning ESG data or anything else.” “Putting more data directly on chain for more transparency... like carbon credits could be tokenized.” - Tokeny interview (±11:47)
	Traceability	“Blockchain in this case effectively serves as legal proof of the transfer. Yes. So in that sense, you do have evidence showing the movement from A to B. That is documented.” – A&O Shearman Interview (±20:20)

4.2.1 Market potential

Fractionalization

Stakeholders argue that enabling DLT in green bond processes could facilitate the fractionalization of large investment sizes, thereby allowing for the issuance of digital green bonds. Fractionalization of bond investments enables the entry of medium-sized investors into the large-scale green bond market, providing more individuals with access to capital markets that have traditionally been reserved for institutional investors. This could enhance the market's liquidity through increased participation from various market participants. During the interview, the underwriter noted this demand for fractionalization concerning traditional green bonds:

“We can also support smaller parties that are too small for the capital markets but too large for consumer markets, by providing them with financing from an external capital market (through digital green bonds).” – ABN AMRO 1.

24/7 market access

Stakeholders highlight that one of the main benefits of Digital Green Bonds is the possibility to trade the bonds at any time (24/7 market access), rather than just the 9-to-5 business days. This is especially of interest when these bonds are retail-oriented, as stated by the Clearing and Settlement expert (±22:04). Such continuous accessibility not only supports trading flexibility but also enables real-time settlement and collateral management. For instance, the ability to use tokenized instruments as collateral during off-hours reduces risk.

“The added value for us is really the 24/7 availability. Not necessarily the DLT itself, but the fact that you can make assets, like tokenized cash or bonds, transferable anytime, even when central infrastructures are closed.” (±24:12)

4.2.2 Financial potential

Lower issuance costs (disintermediation)

Consequently, the issuer of the Digital Green Bond transaction is motivated to issue a Digital Green Bond to ultimately reduce the number of necessary intermediaries and potentially lower issuance costs, resulting in decreased capital costs (Issuer interview, ±18:08). The transaction's underwriter also confirms the DLT's potential to act as an intermediary, highlighting the possibility of replacing current actors such as CSDs with automated blockchain processes. However, some stakeholders question whether this is truly a desired application of the technology. The investor points out that removing some parties from the transaction is technically feasible, but it underlines the importance of banks and underwriters in the issuance process, affirming their continued value in future DLT bond issuances.

“People see banks as intermediaries and say, ‘If DLT comes, banks are out’. But I say no. You need investors. You need somebody who handles the issuers to find investors. You need somebody who does market making for the bonds, for liquidity [...]. In theory, you could take out the bank (from the transaction). But then, who starts to shape the market? That's the whole problem. You need those banks.” – Deka (±26:42)

While digital platforms could automate parts of the issuance process, full disintermediation remains unlikely. As the Sustainability Advisor notes, DLT may be suitable for simple sales, but large issuances

still require traditional parties to assess investor demand, structure the deal, and facilitate distribution. Banks play a crucial role by underwriting, providing market feedback, and ensuring transaction success, tasks difficult to replicate for issuers who access the market infrequently.

Faster settlement

In contrast, stakeholders highlight that Digital Green Bonds offer the potential for faster settlement times, allowing for instant settlement and Delivery versus Payment (DvP) settlement, particularly when a digital currency is used. Due to this enhanced transaction speed, Tokeny explains how this ease of fund transfer creates possibilities for a highly efficient secondary market, ultimately bringing more liquidity to the market, an essential driver for broader market adoption (±12:53).

However, the Clearing and Settlement Expert discusses whether the market desires this accelerated settlement. Parties involved in traditional green bond transactions often utilize the netting technique, which enables traders to buy and sell throughout the day without settling each trade individually, settling only the net result at the end of the day, as explained by the AFM (±25:00). While instant settlement is technically feasible, it is not necessarily advantageous for all market participants. Especially in institutional markets, current processes are highly optimized for liquidity, operational efficiency, and risk management through the use of netting. As the interviewee emphasized:

“For some companies or parties, T+0 would actually be inconvenient [...] you would have to make a payment transaction in the payment system for every single trade, and that too is not free.” – Clearing and Settlement Expert (±17:03–17:43)

Additionally, the interviewee from the AFM discusses a trade-off connected to the possibility of faster settlements. Deferred settlement (T+2) enables netting, which reduces operational friction and enhances liquidity. However, netting also involves counterparty risk, which Distributed Ledger Technology (DLT) could eliminate by allowing real-time settlement, thereby disrupting existing netting practices. The current infrastructure, dependent on end-of-day netting and collateral buffers, would become impractical in a real-time DLT environment with instant settlement (AFM interview, ±26:03).

This presents a key challenge for DLT in bond markets: while technology enhances transparency and reduces risk, it requires reengineering existing liquidity management. To maintain capital efficiency without netting, alternatives like programmable liquidity pools or on-ledger credit lines must be created. For high-frequency trading, intraday flexibility and capital efficiency are crucial. Instant settlement would require pre-funding trades in cash and securities, raising liquidity needs and diminishing market-making capacity. Thus, the desirability of T+0 depends on the specific use case and market structure.

4.2.3 Awareness Potential

Performance reporting

Digital green bonds could offer a solution to these performance reporting challenges, as highlighted by the interviewees. Stakeholders highlight the ability of DLT-based tokens of Digital Green Bonds (Digital Natives) to incorporate ESG and impact data. By incorporating this data into the token, investors can access real-time information about the environmental performance of their investments, which not only increases trust but also reduces risks of greenwashing by making the environmental value of the bond more transparent and verifiable. The underwriter’s sustainability advisor also describes the potential of this impact measurement:

“It’s a kind of [...] data warehouse where documentation is attached digitally [...] but the big, interesting [...] potential lies in adding impact data retrospectively to the smart contract. [...] Issuers can add impact per euro annually, and that information links to your wallet, so you immediately see your overall impact without constantly searching for reports or calculating it manually. [...]” – Sustainability Advisor Interview, (±10:33).

Additionally, the technology provider participating in the creation of digital green bonds confirms that these functionalities are already technically achievable (Tokeny interview, ±11:47). This includes the tokenization of ESG data and the incorporation of real-time environmental metrics, such as carbon emissions or energy generation via Internet-of-Things (IoT) devices. These advancements indicate a shift toward a more data-centric and automated green bond ecosystem, where transparency is embedded in the instrument itself rather than depending on periodic reports.

“So if you truly have a green bond fund, and you want to report on the impact of your portfolio, then I believe this (DGBs) could be a useful tool.” – Sustainability Advisor (±12:14).

The sustainability advisor mentions the need for wallets by both issuing and investing parties to track the performance of their investments, further linking to the need for system adaptation and the need for wallets on both sides of the market (Sustainability Advisor, ±15:32).

Ownership transparency

Digital green bonds offer traceable ownership through on-chain registration. By holding ownership on-chain, stakeholders increase the likelihood of having higher visibility on the bond after it has been issued and potentially traded from one investor to another. Stakeholders emphasize that when utilizing a public blockchain, such as in the Vesteda transaction, everyone can access the transaction on the blockchain, ownership is on-chain, and the central history of the token is also on-chain, as noted by Tokeny.

Additionally, due to the immutability of the blockchain, ownership cannot be altered incorrectly, potentially increasing trust in the issuing party. In this digital green bond issuance case, a smart contract is created where *“the ownership is consolidated at the moment the bond is issued and the proof of payment is recorded on the chain”*, as stated by the bond’s underwriter.

Therefore, stakeholders believe that digital green bonds can potentially increase the transparency of the bond process and lifecycle, further boosting stakeholders’ trust.

4.3 Digital Green Bond Adoption Barriers

This chapter presents the findings on the key barriers to the adoption of Digital Green Bonds (DGBs) supported by Distributed Ledger Technology (DLT). Based on expert interviews, this study explores why stakeholders remain hesitant to fully adopt DGBs and what challenges persist in comparison to traditional green bond processes.

The barriers mentioned by interviewees are categorized according to the framework by Nguyen et al. (2024), which groups challenges into five themes: Policy, Market, Financial, Capacity, and Awareness. Table 11 provides an overview of the codes used for analysis, accompanied by illustrative quotes from the interviews.

Table 11: Themes and Codes concerning identified Green Bond adoption barriers

Theme	Adoption barrier (Code)	Illustrative quote
Policy barriers	Regulatory uncertainty	"Sometimes, when there isn't a clear regulatory framework, people may attempt a small transaction just to engage with it. This happens because, in many cases, the framework is open to interpretation—and that's the problem." - DekaBank interview (±10:00)
	Regulatory compliance	Not mentioned
	Regulatory arbitrage	"...if a Dutch party contacts us... We first have to check it, as we have no experience with the Dutch law." – DekaBank interview (±09:40)
Market barriers	Investor privacy	"Some parties [...] they want privacy, and that is not what blockchain offers. The same goes, to some extent, for the larger institutional investors—they also demand privacy." – AFM interview (±18:33)
	Liquidity constraints	"I think the biggest barrier is the lack of demand-side liquidity from the market." – DNB Interview
	Lack of secondary market	"Currently there is no secondary market, and Digital (Green) Bonds cannot be traded" – Clifford Chance Interview For the moment, it's the regulation that limits the potential of this secondary market. – Tokeny interview (±20:33).
Financial barrier	High initial investment	"And look, this was a transaction of 5 million. And then you end up doing relatively a lot of work and incurring high costs for those 5 million." – Vesteda interview (±49:59)
	Internalized cost reduction	Not mentioned
	Dependence on intermediaries	They (traditional market parties) might not want to digitalize, as they already make lots of money (with the traditional process). Why would they change? – AFM Interview (±19:32).

	Yield uncertainty	"It is uncertain what the 'digital bond' product does to the price – is there a digital premium?" – Clifford Chance interview
Capacity barriers	Process complexity	"We have to reinvent everything, from documentation to terms. It all took longer." – Vesteda Interview
	Infrastructure interoperability	"Banks need to link their systems to the blockchain, and those systems are sometimes 30-40 years old." - De Nederlandsche Bank Interview
	Infrastructure fragmentation	Not mentioned
	Technological scalability	Not mentioned
	Security	Not mentioned
	Lack of technical expertise	"ABN AMRO hired Tokeny and Fireblocks so that we wouldn't need to have all the blockchain expertise in-house ourselves." "You can outsource knowledge and technology; you don't need to be a blockchain expert to do this." – Vesteda interview (±37:02; ±57:15)
	Lack of programmable money	"But to really get all the power of the blockchain technology, it's important that also the cash is on chain so that you can trigger it. The interesting part of tokenization is that the asset is now a piece of code s you can automate (it)."- Tokeny interview
	Lack of digital wallets	"... they (investors) will need to have a wallet and most of them don't have a wallet yet. Not very user friendly. It's important that the blockchain ecosystem provide more user-friendly tools." – Tokeny interview
	Limited track record	"Because it was a pilot transaction, we didn't yet have the benefits that you would expect to see in the future." – Vesteda interview (±48:59)
Awareness barriers	Lack of familiarity	"... that it simply isn't a well-known concept (digital green bonds), and as a result, few parties are getting involved." – DNB interview

4.3.1 Policy Barriers

Regulatory uncertainty

Stakeholders mostly agree that regulatory uncertainty significantly hinders the adoption of digital green bonds, impacting all phases of the green bond lifecycle. The investor, Deka, emphasizes that regulatory uncertainty can potentially generate unnecessary risks for investors, especially when regulations do not specify which type of technology can be used, leading to an ambiguous interpretation. By interpreting the regulation, the investor's legal advisors indicate that there is still a risk (DekaBank Interview, ±09:40)

Additionally, A&O Shearman emphasizes the need to clarify regulations for custody and ownership transfers of digital assets, particularly within the Dutch context, as they highlight the complexity and barriers that new initiatives encounter when navigating these regulations. The interviewee also

underscores the significance of legal recognition of digital ownership transfer, which brings greater clarity to the market (A&O Shearman Interview, ±21:45-22:07).

Yet, the market regulator partly disagrees on the need for regulatory clarification for digital securities such as digital green bonds. According to the market regulator, the issuance of digital securities is not prohibited; therefore, no new Dutch law is required. According to the interviewee, the Vesteda issuance was permitted under current Dutch regulations (AFM Interview, ±08:36). However, the AFM acknowledges that currently, the full digital implementation of DLT across all bond lifecycles (especially clearing) can be operationally challenging. As clearing documents still need to be printed for physical signing, it is not possible under Dutch regulations to effectively digitally transfer assets, thereby stopping the process at the Clearing phase (AFM Interview, ±38:37). The transaction's underwriter, ABN AMRO, also mentioned the need for physical documentation for the transfer of ownership:

“But we actually created a smart contract in which ownership is directly issued at the moment the bond is issued. However, there is still paper involved in the transaction. There are still legal documents.” – ABN AMRO interview (±17:35).

Moreover, when it comes to secondary market trading, the AFM states that all financial instruments may only be traded on an MTF, or a multilateral trading facility, with some exceptions under the European DLT Pilot Regulation (AFM Interview, ±12:54).

The challenge of moving beyond the issuance phase and digitalizing the clearing and settlement processes has proven to be a significant barrier. The issuer explains that the Digital Green Bond issuance occurred in a Private Placement form, allowing them to deviate from existing regulations and obtain approval from the AFM. However, in the end, the AFM made clear that *“if you were to create a fully on-chain asset, then it would indeed become a regulatory issue”*. Therefore, a lack of tailor-made regulation creates regulatory uncertainty and unnecessary risk for issuers and investors in the digital green bond market.

Regulatory arbitrage

Aside from the uncertainty surrounding current regulations, stakeholders emphasize that differences in local laws act as obstacles to broader adoption. Clifford Chance points out significant variations in local regulations; for instance, Luxembourg and Germany have specific digital security regulations, while the Netherlands does not, further underscoring the fragmented legal landscape in Europe.

This issue is further illustrated by DekaBank, the German investor, which notes that when approached by issuers from another country and its legislation, they must conduct extensive legal due diligence due to a lack of expertise in that country's regulations. Consequently, the transaction becomes more complex and delayed, as it requires assessing each case individually (DekaBank Interview, ±12:09).

4.3.2 Market barriers

Investor privacy

The market regulator states that investor, especially institutional ones, value privacy in their investment decisions, something that the blockchain's transparency, which is also seen as an advantage to blockchain, does not offer. This creates a paradigm, resulting in the AFM suggesting to move towards

an infrastructure that provides that privacy whilst it can be accessed by regulators such as the AFM, proposing a proprietary permissioned blockchain (AFM interview, ±18:33).

Liquidity constraints

A significant obstacle to adopting Digital Green Bonds, as noted in most interviews, is insufficient market liquidity. Currently, only a few market participants are willing and able to invest, resulting in an underdeveloped digital bond market. This lack of liquidity lowers investor confidence in the market, discourages involvement from traditional demand-side players, and restricts the product's scalability. The Dutch Central Bank also emphasizes this concern as the primary barrier to adoption, noting that the lack of demand-side liquidity is hindering market development (DNB interview).

From the issuer's perspective, the lack of market liquidity and potential investors is seen as a current barrier to issuing digital green bonds. Vesteda, the issuer of the Digital Green Bond, acknowledged that the lack of tradability of the transaction limited its appeal. As mentioned in the interview, it was particularly difficult to find an investor for the Digital Green Bond issuance:

"... initially, we spent a long time in discussions with a Dutch pension investor, and in the end, it turned out to be too complicated. That was the challenge with this transaction—it took a lot of time to find an investor." – Vesteda interview (±39:14)

From the investor's perspective, the transaction's investor confirmed that institutional investors often require a certain level of liquidity in their investments to manage portfolio risks. Therefore, investing in digital green bonds, which currently have a low tradability, is unattractive for investors, limiting the market to buy-and-hold investment strategies (DekaBank interview, ± 07:50). This buy-and-hold strategy impedes an active trading environment even further, with bond investors holding onto their investments until maturity. Investors need to be able to sell their bonds (ABN AMRO Interview, ±18:23). Additionally, this lack of tradability creates a negative feedback loop, as it reduces market liquidity, further hindering the market's development. Deka highlights this need for liquidity from the demand side:

"Funds need liquidity. If people take money out, they have to sell assets. Without buyers, it's a nightmare." – DekaBank (±30:08).

Lack of secondary market

A key barrier to the adoption of Digital Green Bonds is the absence of a functioning secondary market for DLT-based securities, which significantly undermines market liquidity and hinders their tradability. Multiple stakeholders view this lack of secondary infrastructure as a major adoption barrier, which could potentially be addressed in a way that positively impacts the previously mentioned liquidity barrier.

Clifford Chance confirms that the current market infrastructure does not support secondary trading of this type of digital instrument. This structural absence is largely attributed to regulation that doesn't support the trading of these securities on a decentralized exchange. According to the AFM, securities must currently be traded on a Multilateral Trading Facility (MTF), which excludes most decentralized or non-traditional platforms (AFM Interview, ±12:54). As a result, bonds cannot be traded, liquidity remains low, and it is challenging to attract investors.

In response to these challenges, efforts are underway to establish a compliant secondary trading venue. ABN AMRO has conducted pilots and developed a Proof of Concept for 21X, a decentralized security token exchange operating under the EU's DLT Pilot Regime. This platform, which is still under development, could be the first step toward enabling secondary market functionality for tokenized securities (ABN AMRO interview, ±18:23–19:20).

4.3.3 Financial barriers

High implementation costs

Stakeholders mentioned the relatively higher issuance costs due to the additional expenses of enabling the issuance of a Digital Green Bond, in relation to the limited scale of the transaction, which was a mere €5 million, resulting in a significantly higher cost per euro (Vesteda Interview, ±49:59). However, the issuer notes that these costs will decrease in the future as the transition to this type of issuance occurs and the process becomes standardized, potentially making issuance costs lower than those of traditional green bonds. At the moment, however, the issuance costs are higher, partly because it is a Proof of Concept and involves elevated expenses due to being a new process.

Regarding these added costs, the Dutch Central Bank (DNB) also emphasized the importance of traditional market participants across all phases of a green bond issuance investing in the development and implementation of new technologies and systems to accommodate digital solutions. The interviewee stated that these transitional costs can be substantial and pose a significant barrier to adoption, particularly during the early stages of market development, but it is necessary to incur these costs to ultimately utilize the technology to its fullest potential.

Dependence on intermediaries

Since major financial institutions dominate the traditional Green Bond market, stakeholders mention that overcoming the previously named adoption barriers depends on the actions of traditional market players, who have the power to drive change in this area. As DekaBank points out, banks play a key role as liquidity providers and risk-takers. This makes their involvement essential for the success of these Digital Green Bonds (DekaBank interview, ±27:00).

However, the interviewees who are not part of financial institutions mention that these established players have little incentive to change their current processes, as the traditional bond processes work well for them. The AFM explains that while adopting digital green bonds is not impossible, it is simply not a priority now due to these practical barriers and high transitional costs (AFM Interview, ±19:32). Moreover, the Clearing and Settlement expert supports this belief, stating that they already handle 90 million transactions per day, which are all automated; therefore, DLT does not significantly impact traditional processes. The interviewee concludes with:

“DLT is a solution that is looking for a problem” – ABN AMRO Clearing interview (±40:11)

Also, Clifford Chance highlights another barrier: reputational risk. Large institutions are hesitant to invest in unproven technologies because if something goes wrong, it could harm their reputation. This hesitant approach slows innovation down. This creates a paradox: digital green bonds need support from traditional financial players to grow, but those same players are reluctant to take risks or disrupt their existing systems. As a result, progress remains slow despite its potential.

Apart from these large institutions on the sell-side, investors on the buy-side are also hesitant and often risk-averse and prefer to minimize regulatory and financial risks before investing in new and innovative technologies such as DLT, as stated by the ABN AMRO:

“By definition, an investor in a bond is inherently risk-averse, so everything is tightly secured. The contracts associated with a bond often span 200 pages and consist almost entirely of risk clauses. If there is any uncertainty for the investor—for example, regarding such a process—that becomes problematic.” – ABN AMRO interview (±31:15).

This creates a vicious circle: without participation, there is no market growth, and without market growth, there is no participation.

Yield uncertainty

Apart from these high issuance costs, stakeholders mention that there is uncertainty about the financial performance of digital counterparts of green bonds, as few studies on the yield of digital green bonds due to the newness of the concept exist. This could make investment in this type of financial instrument more uncertain, and therefore, investors choose to invest in the already known traditional green bond (DNB Interview; Clifford Chance interview). According to the DNB, the potential high initial costs in combination with an uncertain yield can be a great barrier for adoption for issuers and investors:

“You can invest all that effort [...] but at the end of the day, what does it actually yield?” – DNB Interview

Moreover, the Vesteda interviewee highlights a challenge in issuing (digital) green bonds regarding investor participation. They emphasize the importance of managing pricing carefully to prevent low yields. An unattractive price may lead to an undersubscribed order book, causing institutional investors to withdraw. This shows the balance between competitive terms and sufficient demand for successful placement (Vesteda Interview, ±15 : 41).

4.3.4 Capacity barriers

Process complexity

Stakeholders involved in the digital green bond issuance process deem it more complex than a traditional green bond issuance. This is an adoption barrier, as a more complex process can involve greater risks, uncertainties, and costs: *“We have to reinvent everything, from documentation to terms. It all took longer.”* – Vesteda

Additionally, it is not just issuing parties that view the increasingly complex process as a barrier. Investors must also familiarize themselves with new technological requirements, such as secure key management and blockchain-based settlement procedures. According to DekaBank, recent transactions in Europe show the investor’s reluctance to engage in this technical onboarding. Institutional investors reportedly prefer to maintain their existing relationships with traditional custodians who already manage their conventional assets. Consequently, the expected efficiencies from decentralization are not fully realized, as investors often opt for familiar intermediaries like ABN AMRO to facilitate collective registration and asset custody (DekaBank, ±16:11-18:27). Also, issuers often outsource the technological and regulatory processes, just as in the Vesteda transaction:

“You don’t need to be a blockchain expert yourself to be able to do this.”, “No, also because — and this is actually one of the great aspects — you can simply outsource the necessary knowledge and technology.” – Vesteda Interview (±56:58).

This further contradicts the potential disintermediation mentioned earlier in the findings. However, it is essential to note that stakeholders expect that these barriers could be solved as the technology is increasingly adopted and understood. The process is deemed complex as it is one of the first digital green bond pilots done by the involved stakeholders, forcing parties to experiment and find the optimal processes.

Infrastructure interoperability

Due to the reliance on traditional market parties, stakeholders emphasize that the adoption of Digital Green Bonds depends on the adaptation of these parties’ financial systems. The Dutch Central Bank (DNB) noted that some of these systems can be over 40 years old, making it quite challenging to connect the systems to DLT ledgers.

Moreover, DekaBank states that Digital (Green) Bonds are currently not eligible as repo collateral with the European Central Bank; therefore, the Central Bank does not act as collateral, as the ECB does not recognize this security type. This compels the issuer to pay a pickup because it cannot be used as collateral, discouraging investment in these types of bonds due to the significant risk of lacking collateral (DekaBank Interview, ±21:17)

Infrastructure fragmentation

Apart from the outdated systems, the Sustainable Markets expert from ABN AMRO points to the lack of standardization across market participants. As stated:

“...what somewhat hampers the growth of the market—specifically the combination of digital and green bonds—is that it’s just not standardized. I’ve heard that quite often. If you want to structure such a process, well, there are different banks, different parties working with their own framework or their own approach, so to speak.” (ABN AMRO 2, ±16:13–17:09).

This observation highlights a fragmented development landscape, where each financial institution is constructing its own digital infrastructure in isolation. Such an approach results in inefficiencies and interoperability issues. While innovation advances within institutions, the absence of a shared technical foundation impedes the scaling of solutions across the financial ecosystem. This situation necessitates harmonized data standards and collaborative infrastructure development.

Lack of technical expertise

An interviewee from Vesteda highlights a key barrier to adopting digital green bonds: the lack of in-house blockchain expertise. ABN AMRO had to rely on external providers like Tokeny and Fireblocks for technical infrastructure, indicating that most issuing institutions lack these technological capabilities.

While one doesn’t need to be a blockchain expert for transactions, this reliance on external parties creates structural weaknesses in market development. It leads to operational dependencies on niche technology providers and introduces risks related to vendor reliability, integration, and compliance. Furthermore, the lack of internal expertise may limit issuers’ understanding of the technical implications of digital green bond issuance, reducing institutional confidence and delaying decisions. Thus,

restricted internal capacity hinders the growth of the digital bond market, especially for traditional or resource-constrained issuer institutions.

Lack of programmable money

The absence of stablecoins limits the possibilities of automating processes and creating programmable financial instruments, which are crucial for moving beyond the issuance phase and digitalizing the trading, clearing, settlement, and custody processes. Tokeny states in its interview that to truly utilize the DLT to its fullest potential, cash must be on-chain, enabling on-chain settlement and the automation of financial processes such as the distribution of funds (Tokeny Interview, ±12:53-13:56). Moreover, the ABN AMRO adds that by implementing stablecoins, wallet-to-wallet and true peer-to-peer financing is possible, eliminating geographical boundaries and enabling programmability (ABN AMRO Interview, ± 12:09).

For the Vesteda transaction, the settlement occurred off-chain in fiat currency while utilizing an on-chain Digital Green Bond token. Thus, Delivery vs Payment was not achieved, as the settlement was directed to an ABN AMRO cash account (Dekabank interview, ± 18:27). The issuer mentions that for the upcoming transaction, they want to do more than just provide proof of payment; they aim to enhance the tokens with data and payment automation.

“And maybe also expand by, for example, indeed including more data processed within the token itself. Yes, and perhaps expand further, because now, with the interest payments, they simply went from ABN AMRO to DekaBank every quarter.” – Vesteda interview, ±1:00:00

Lack of wallets

In addition to the banks, investors must also adjust their operations to adapt to the digital ledger technology (DLT) ecosystem (Sustainability Expert Interview, ±18:49). Investors will need to adapt primarily during the custody phase, as they require wallets to store their crypto keys and manage their investments, which most do not currently have. As the adoption of these wallets grows, investors can more easily invest in tokenized assets, such as Digital Green Bonds, further enhancing the market's liquidity (Tokeny Interview, ±15:35-16:58).

Moreover, to hold keys and serve as a digital custodian, a custodian license is required. However, the process of applying for such a license can be time-consuming, further discouraging the choice to adopt digital bonds and forcing parties to outsource the custody to an external party:

“When we made the trade, we didn't have the crypto custodian license [...] the regulators needed a long time to read our applications.” – Deka, 2025

Limited track record

A key capacity-related barrier identified in the Vesteda case is the limited track record and absence of proven performance data associated with digital green bonds. As a proof-of-concept transaction, the process required the issuer to develop most procedures from scratch, including structuring, documentation, and legal setup. This novelty resulted in inefficiencies and high relative costs, particularly given the small issuance size of €5 million. While some benefits were noted, such as same-day settlement and improved transparency, these remained limited and did not fully represent the broader potential. As the interviewee concludes, “because it was a pilot transaction, it didn't have the benefits you might expect to see in the future” (Vesteda interview, ±48:21). The absence of

demonstrable advantages reinforces hesitation among market participants and highlights how a limited operational track record constrains wider adoption.

4.3.5 Awareness barriers

Lack of familiarity

The interviewees highlight that a lack of familiarity with the underlying digital ledger technology (DLT) in Digital Green Bonds is a barrier to adoption for several stakeholders. One of the main problems is the association of blockchain technology and DLT with the cryptocurrency sector, which, in the early stages, was met with reputational concerns and a negative connotation. As stated in the interview with the AFM, market regulators were particularly cautious with regulating digital securities due to the perceived risks of crypto-related technologies, which are two totally different financial products:

Whenever ABN AMRO did anything involving wallets, the board would immediately be on high alert. I believe this has been a process in which the crypto world has matured, and I hope that the perception around it will gradually evolve as well. – AFM Interview (±42:45)

Investors are also discouraged from participating due to a lack of familiarity with Digital Green Bonds, as mentioned by the interviewees. The Dutch central bank (DNB) emphasized that this knowledge gap can lead to a broader lack of trust, resulting in low engagement levels from institutional investors, which in turn causes other parties to remain hesitant to engage in these Digital Green Bond issuances.

Vesteda adds that parties need to gain practical experience with the technology to build trust in its reliability. Only through exposure and successful implementation can investor confidence grow to a level where digital green bond issuances attract broader participation. The interviewee explains that initial perceptions were shaped by negative associations with cryptocurrency, which required extensive clarification: “There was mainly a lot of fear... everyone has heard of cryptocurrency—often in a negative context—so we had to explain in very simple terms what it is” (Vesteda interview, 27:46–28:07). This highlights the importance of demystifying the technology and demonstrating its legitimacy to overcome scepticism and encourage adoption.

This unfamiliarity has also resulted in misguided risk perceptions. For instance, stakeholders often cite concerns about cybersecurity and a perceived high energy consumption linked to blockchain technology. However, these concerns are not entirely accurate. The perceived cybersecurity risk arises from a negative perception of DLT due to concerns regarding the security of holding the wallet’s keys and the blockchain’s integrity, as there have been instances where wallets have been hacked and the investor’s keys have been stolen (A&O Shearman interview, ±21:16). Nevertheless, the ABN AMRO highlights that such concerns often stem from issues that are not related to the technology itself and are mistakenly perceived as breaches of the blockchain infrastructure, due to a lack of knowledge of the technology:

“And when you see something like the recent hack involving ByBit, people who don’t understand the technology say, ‘Look, the blockchain has been hacked again.’ Then they conclude that we shouldn’t issue bonds on a blockchain. But those are two completely different things.” – ABN AMRO interview (±32:03)

Regarding the perception of high energy consumption, some stakeholders also attribute it to a lack of knowledge. New blockchain technologies are consuming much less energy than before, mainly due to the development of the Proof of Stake consensus mechanism, which is significantly more energy-efficient than the older Proof of Work model (Tokeny interview, ±15:35).

4.4 Digital Green Bond Adoption Enablers

The following themes have emerged based on the inductive codes developed during the analysis process. Each theme has the potential to facilitate adoption and address the identified adoption barriers:

Table 12: Themes and Codes concerning identified Green Bond adoption enablers

Theme	Adoption enabler (Code)	Illustrative quote
Policy Enablers	Technology-neutral regulation	“In principle, regulation is always technology-neutral, but you cannot foresee what developments will emerge. [...] It remains difficult to fully align something that was written before such developments occurred.” – DNB interview
	Unambiguous Regulation	“There simply needs to be clarity about the route that must be followed if you want to issue something like [a digital bond]. There should be no room for interpretation.”- A&O Shearman interview (±41:03)
	Regulator-Stakeholder Collaboration	“We work with regulators to promote the adoption of standards that facilitate the use of blockchain in financial instruments” – Tokeny interview (±20:33)
	Regulatory harmonization	“I am strongly in favor of European regulation, a level playing field, and horizontal regulation across Europe.” – AFM (±34:52)
Capacity enablers	Programmable settlement	To get all the power of the blockchain technology, it's important that also the cash is on chain so that you can trigger it. The interest of tokenization is that the asset is now a piece of code, so you can automate lots of things. [...] So it's important that there is an adoption of stablecoin. – Tokeny interview (±13:56)
	Interconnected systems	“Of course, this only works if you stay in the computer environment, the same computer environment.” – Tokeny interview (13:56)
Awareness enablers	Proofs of concept	“As more parties become familiar with it and awareness grows, more participants will want to get involved, and that's what its success depends on.” – Vesteda interview (±52:50)

4.4.1 Policy enablers

Technology-neutral regulation

Market regulators emphasize the significance of regulations that promote innovation while not obstructing the adoption of new technologies in specific financial processes. According to the AFM, ideally, regulations should be technology-neutral, meaning they should neither favor nor disadvantage

any particular technology (AFM Interview, ±8:36). This approach ensures that rules remain relevant as new technologies emerge, reducing the need for frequent updates.

However, maintaining this neutrality has been difficult, especially with the rapid growth of decentralized finance (DeFi). While regulations are designed to be flexible, it is impossible to predict all future technological advancements. As a result, existing rules often struggle to fully accommodate innovations that were not anticipated when the regulations were first created. This misalignment presents barriers for both regulators and market participants as they strive to navigate an increasingly complex financial landscape.

Unambiguous Regulation

A key challenge with technology-neutral regulation is finding the right balance between encouraging innovation and ensuring rules are clear and easy to follow. While flexible regulations enable the development of new technologies, they can sometimes be perceived as too broad or vague, thereby creating uncertainty. Legal experts point out that when it comes to issuing digital bonds, for example, there should be absolute clarity on the required steps—no room for interpretation. Currently, the Netherlands lacks explicit, straightforward regulations specifically for digital bonds, which creates confusion (Clifford Chance interview; A&O Shearman interview, ±41:03).

This push for precise, detailed rules for digital (green) bonds, however, conflicts with the broader goal of technology-neutral regulation that is already in place. Regulators argue that laws should neither favor nor restrict any particular technology, thus allowing for future advancements. Occasionally, institutions assume that specific innovations aren't permitted simply because they aren't explicitly mentioned, an assumption that regulators dismiss as unfounded, as stated by the AFM:

“And when there are questions like: ‘How does this actually work?’ — sometimes institutions claim that certain things are not possible, because it’s not explicitly allowed. Well, sometimes that’s just nonsense. And then I help them understand, ideally, you want regulation to be technology-agnostic or technology-neutral.”- AFM Interview (±8:36)

Regulator-Stakeholder Collaboration

Stakeholders indicate that to enhance the issuance of digital green bonds, promoting collaboration between market regulators and active market participants is essential. This collaboration and ongoing discussion with the authorities can help clarify rules and develop standards that support DLT-based financial instruments such as Digital Green Bonds. Currently, stakeholders are seeking clearer digital bond regulations, like those of Germany, Luxembourg and the UK, which would enable the full utilization of technology beyond just issuance into secondary trading, clearing, and settlement (ABN AMRO interview, ±01:50-03:25; Clifford Chance interview).

Of the jurisdictions mentioned, Clifford Chance and ABN AMRO specifically highlight Germany's 2021 legislation. Unlike the Dutch jurisdiction, which relies on conventional systems despite digital alternatives not being technically prohibited, it permits blockchain to replace traditional CSDs such as Euroclear or Clearstream. These clarifications enable digital green bonds to be utilized to their fullest potential, extending beyond the issuance phase into the secondary market phase, and also modifying the clearing, settlement, and custody processes.

However, the AFM warns against overregulation (AFM Interview, ±32:25). The interviewee notes that existing EU and Dutch regulations already address digital securities to some extent. The challenge lies in balancing the need for regulatory clarity with maintaining regulatory flexibility, providing enough certainty to foster innovation without establishing rigid rules that may quickly become outdated. The solution likely involves making selective adjustments based on real market experience rather than introducing entirely new frameworks.

Regulatory harmonization

Subsequently, market regulators prefer harmonizing security regulations, particularly at the European level, over pursuing national approaches. This perspective is also shared by market participants such as DekaBank, which identifies regulatory fragmentation as a major barrier and sees value in coordinated European rules for digital securities.

However, this harmonization presents challenges, which may lead to regulatory uncertainty. Premature national regulations may cause complications in the future if they are later overridden by EU-wide rules, which could make existing national frameworks obsolete.

“Luxembourg, Germany, Switzerland — and also the EU with its DLT Pilot Regime — each have their own frameworks. But these frameworks are not harmonized. [...]. If EU-wide harmonization were to come into force one day through a single law, countries that already have their own national laws in place could experience disaffection.” - DekaBank interview (±12:09-13:42)

This situation poses a dilemma: while immediate national solutions could meet current market needs, they risk creating future misalignment. The best approach seems to be pursuing European harmonization while allowing enough flexibility to avoid stifling innovation during the transition period. This strategy would balance short-term market development with long-term regulatory coherence.

4.4.2 Capacity enablers

Programmable settlement

Stakeholders highlight that the integration of stablecoins and programmable settlement currencies is the key to unlock the Digital Bond's full potential and benefits. As stated in the Digital Green Bond Potential chapter of the analysis, programmable currencies unlock the digital green bond's full potential by allowing faster settlement times, transparency, and programmability through smart contracts. Most stakeholders interviewed mention the integration of DLT in the settlement layer as a key component to automate the settlement phase. Stablecoin innovation should be fostered, allowing for a fully programmable currency, allowing to receive, hold, and spend stablecoins as part of normal business operations.

Interconnected ecosystems

However, stakeholders warn that the adoption of this programmable settlement is dependent on interconnected payment systems, reliant on traditional finance parties and their infrastructures. In the interview with the central Dutch bank (DNB), they mentioned the drive for innovating the settlement of these digital green bonds and digital securities in general:

“There are a number of experiments in which platforms where digital bonds and other instruments can be issued are being linked to our payment systems. This enables settlement in central bank money,

which we always prefer, as it is the most risk-free means of conducting transactions. To answer your question, I think we are quite actively working on this. We are looking at the technology and, in that sense, largely letting the market take the lead in demonstrating how they want to use it. At the same time, we try to facilitate this by, for example, creating an experimental connection with our own system.”
– DNB

4.4.3 Awareness enablers

Proofs of concept

Stakeholders mention that the perception of digital green bonds could evolve positively as parties start engaging with the technology and process through so-called ‘Proofs of concept’. According to the interviewees, the Vesteda case was also a Proof Of Concept transaction, testing Dutch law and its DLT infrastructure. The issuer explains the importance of doing proofs of concept:

“As more parties become familiar with it and awareness grows, more participants will want to get involved, and that’s what its success depends on. Stakeholders need to start working with it and see that it functions reliably. If it gains enough trust and visibility, then when, for example, you want to raise debt, you could suddenly attract ten investors at once.” – Vesteda interview (±52:50)

Additionally, the participation of major issuers, or ‘pioneers’, has a significant impact, offering regulators and potential investors concrete evidence that Digital Green Bonds are viable, thereby transforming perceptions from theoretical scepticism to practical acceptance. Pioneers are needed to explore the capabilities of adopting digital green bonds, even if they do not currently possess the benefits that could potentially emerge in a more advanced adoption scenario. Pioneers need to invest in the technology and its adoption, even if it is not as beneficial in comparison to traditional bonds.

“If you want to get large issuers involved, they need to go through the transaction process — even if the immediate benefits are limited. By doing so, they still complete the journey. This gives regulators a reason to engage, because they see a major market player stepping in. They’ll say: ‘Okay, I understand you have market influence. Help me understand why you think this isn’t scalable right now.’ In doing so, the key issues are surfaced, and regulators can begin to address them.” – DekaBank (±24:17)

By taking the lead, these institutions not only validate the market but also create a feedback loop with policymakers. Their participation signals to regulators that digital green bonds are more than just an experiment and that Digital Green Bonds are a promising innovation that needs regulatory changes to be scalable. As large-scale, pioneering transactions increase, the combination of heightened market demand and regulatory responsiveness may accelerate the transition to a fully digital green bond ecosystem.

So, while regulatory changes remain important, pioneering and leading market participants play an equal role in the adoption of digital green bonds. These pioneers should, despite initial inefficiencies and challenges, engage in proofs of concept, potentially accelerating broader adoption by demonstrating their feasibility and driving improvements in both technology and policy.

5 Discussion

This research examined the potential and barriers associated with Digital Green Bonds (DGBs) through a diverse set of stakeholder interviews. The findings are discussed in relation to the available literature in the review, illustrating how this research contributes to the overall academic literature.

5.1 Traditional Green Bond Barriers

The study revealed that stakeholders identify six main core barriers in traditional Green Bond Processes based off [Nguyen et al.'s \(2024\)](#) categorization (Policy, Market, Financial, Capacity and Awareness Barriers).

Table 13: Literature versus interviewees' opinions on Green Bond barriers

Theme	Green Bond Challenge Codes (Inductive + deductive)	Literature	Interviews
Policy barriers	Regulatory enforcement	X	X
	Regulatory fragmentation	X	
Market barriers	Lack of eligible projects	X	
	Market inaccessibility	X	X
	Currency risks	X	
	Reliance on market hours (Inductive)		X
Financial barriers	High issuance costs	X	X
	Slow settlement (Inductive)		X
	Yield uncertainty	X	
Capacity barriers	Lack of technical skills	X	X
	Limited track record	X	
	Risk of greenwashing	X	
	Ownership transparency (Inductive)		X

5.1.1 Policy

[First](#), regarding policy, the results show a persistent demand for regulatory enforcement, in line with the conclusions in the studies by Pyka (2023 and Wang et al. (2022). As noted by the issuer, an issuer not complying with the commitments related to green bonds may lose the green label; however, “not many consequences attached to it yet.” This reflects the broader critique in the literature that voluntary standards like the EUGBS lack legal enforceability, limiting their effectiveness. Apart from this, regulatory fragmentation, as mentioned in Park (2018) and Pyka (2023), was not mentioned by the interviewees.

5.1.2 Market

Second, the interviewees confirmed several market barriers, such as the difficulties described in the literature by [Banga \(2019\)](#) and [Cisar et al. \(2025\)](#)

for smaller investors to access the Green Bond market, which is reserved for big institutional investors. Interviewees from both the issuer and investor side confirm that high minimum issuance volumes, ranging from €50 to €500 million, create a substantial entry barrier, excluding smaller issuers and private investors from the green bond market. The case demonstrates that this threshold may potentially hinder broader market participation by limiting market inclusivity. Additionally, the reliance on traditional 9-to-5 market infrastructure was identified as a practical limitation, particularly in managing counterparty risk during off-market hours, an issue that remains underexplored in the current literature. No comments on currency risk or the lack of eligible green projects emerged during the interviews.

5.1.3 Financial

Third, the results confirm some of the financial barriers identified in earlier studies. The findings confirm that the traditional green bond issuance process is lengthy and highly manual, necessitating coordination among multiple parties, including auditors, legal advisors, and underwriters, which in turn increases transaction costs. These findings align with [Ackassi \(2020\)](#) and [Walker et al. \(2023\)](#), who state that green bond processes are typically slower and more complex than those for plain-vanilla bonds due to additional procedural steps, intermediaries and documentation requirements. Moreover, the issuer's reported total cost of approximately €2 million supports findings by Deschryver & De Mariz, 2020 and the G20 Green Finance Study Group (2015), which mention that intermediary involvement and external reviews such as SPOs introduce significant costs, especially for smaller issuers. Interviewees also pointed to slow settlement times ranging from T+2 to T+5, confirming the findings from [Walker et al. \(2023\)](#) who mention longer issuance and settlement times in traditional bond processes, regardless of the green label. In contrast, no 'greenium' or financial 'yield' advantage was mentioned in the findings.

5.1.4 Capacity

Fourth, the findings confirm that a lack technical skills has been a barrier encountered by parties wanting to engage with green bonds, such as the ABN AMRO Sustainable Markets representative noted that structuring their first green bond involved substantial uncertainty around definitions, eligibility, and required data (ABN AMRO 2 interview, ±6:08). This confirms [Banga's \(2019\)](#) point that many institutions lack the skills to implement green bond frameworks. This capacity gap increases internal costs, as issuers must build systems for project selection, tracking, and reporting (Deschryver & De Mariz, 2020; Flammer, 2021)

5.1.5 Awareness

At last, although the interviewees did not explicitly mention greenwashing, the findings reveal awareness barriers closely related to concerns tied to reporting burdens and regulatory enforceability, both of which are important in managing greenwashing risks. The issuer noted that confirming the allocation of proceeds is resource-intensive (Vesteda interview, ±05:09). The ABN AMRO expert emphasized the inefficiency of impact tracking due to fragmented reporting processes (ABN AMRO 2 interview, ±11:09). These findings support the literature by [Malamas et al. \(2024\)](#) and [Zhang et al. \(2018\)](#), which highlight the difficulty of assessing the green bond's effectiveness without standardized, real-time data. Additionally, the earlier mentioned enforceability gap (policy barriers) where non-compliance leads to few consequences (Vesteda interview, ±04:32), reflects the greenwashing risk

identified by Alamgir & Cheng (2023) and Hyun et al. (2023), as lack of enforcement and transparency can allow issuers to misrepresent performance.

5.2 DLT Implementation Potential

The study revealed that stakeholders identify three of the six main core potentials of DLT implementation in traditional Green Bond Processes based on Nguyen et al.'s (2024) categorization: Market, Financial, and Awareness Barriers.

The findings are discussed in relation to the available literature in the review, illustrating how this research contributes to the overall academic literature.

Table 14: Findings versus literature and impact of DLT on identified GB barriers

Theme	Green Bond Barrier (literature + findings)	DLT Potential Codes (deductive + inductive)	Literature	Findings	Impact in practice
Policy potential	Regulatory enforcement	Regulatory compliance	X	-	Not mentioned
	Regulatory fragmentation	Standardization	X	-	Not mentioned
Market potential	Lack of eligible projects	-	-	-	Not mentioned
	Market inaccessibility	Fractionalization	X	X	Medium
	Reliance on market hours	24/7 Market Access	X	X	Medium
	Currency risks	-	-	-	Not mentioned
Financial potential	High issuance costs	Lower issuance costs	X	X	Medium
		Lower transaction costs	X	X	Medium
	Slow settlement	Faster settlement		X	High
	Yield uncertainty	Pricing differences	X	-	Not mentioned
Capacity potential	Lack of technical skills	-	-	-	Not mentioned
	Limited track record	-	-	-	Not mentioned
Awareness potential	-	Ownership traceability	-	X	High
	Lack of familiarity	-	X	-	Not mentioned

	Greenwashing risk	Performance reporting	X	X	High
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5.2.1 Policy

First, policy-related benefits of DLT such as real-time regulatory compliance and standardized ESG reporting are noted in the literature (Zhang et al., 2018), but were not mentioned by interviewees in the findings. The findings of the literature by Zhang et al. (2018) might be overly optimistic, as DLT cannot improve regulatory outcomes unless existing regulations are adapted to accommodate its application.

5.2.2 Market

Second, findings suggest that various market barriers can be addressed through the potential of DLT, thereby mitigating limitations in the traditional green bond market. Interviewees emphasized that fractionalization, enabled by DLT, allows medium-sized investors previously excluded due to high entry thresholds to access capital markets. This makes the market accessible for a more inclusive investor base (ABN AMRO 1 interview). This finding confirms claims by Benedetti & Rodríguez-Garnica (2023) and Heines et al. (2021) that tokenization enhances fractionalization, possibly enhancing liquidity. However, this potential may be overstated, as institutional investors still require large ticket sizes, suggesting that fractionalization may have a limited impact in practice. Another financial benefit offered by the DLT in Digital Green Bonds is the 24/7 market access, particularly interesting for collateral management and trading flexibility outside standard market hours (ABN AMRO Clearing interview, ±24:12). This potential supports the findings of Maleki (2023) and Nassiry (2018), who argue that round-the-clock access can significantly improve responsiveness and reduce settlement and counterparty risk. Together, these features suggest that DGBs could overcome traditional market constraints by broadening participation and enhancing operational efficiency. In this case, the literature aligns with the identified potential, as the underwriter emphasized the potential and positive impact of trading around the clock.

5.2.3 Financial

Third, key financial barriers to green bond issuance can be addressed by implementing DLT (creating a DGB), which has the potential to disintermediate, automate, and settle transactions faster, according to the findings. The issuer aims to issue a DGB to reduce reliance on intermediaries and lower issuance costs (Issuer interview, ±18:08), supporting efficiency claims by Cisar et al. (2025), Heines et al. (2021), and Malamas et al. (2024) about smart contracts and decentralized infrastructure that streamline issuance and cut transaction costs. However, stakeholders noted that complete disintermediation is impractical and undesirable, as banks and underwriters play essential roles in structuring, investor engagement, and market making, as also mentioned in Saramago (2023). As emphasized by DekaBank, banks are crucial to shape the market and will not be easily intermediated (Deka interview, ±26:42). This suggests that the literature is overoptimistic in assuming disintermediation as a default benefit of DLT, as it overlooks the continued relevance of financial intermediaries in facilitating effective issuance and secondary market functioning.

Regarding faster settlement, stakeholders acknowledge significant advantages of instantaneous transaction finality, particularly when paired with digital currencies (Tokeny interview, ±12:53). Literature from Arcodia et al. (2025), Axelsen et al. (2023), and Pinna & Ruttenberg (2016) confirms this potential. Nonetheless, interviewees including AFM and ABN AMRO Clearing (±17:03; ±26:03) highlight significant practical challenges, such as increased liquidity demands and disruption of

established netting practices, indicating a careful balance must be maintained between speed benefits and existing financial infrastructure, which was also mentioned by these sources.

5.2.4 Capacity

Fourth, while DLT introduces efficiency gains, it also increases technical complexity, which could worsen existing capacity barriers. Interviewees noted that even traditional green bond issuance required significant effort to define green criteria and gather data (ABN AMRO 2 interview, ±6:08), reflecting the broader skills gap highlighted by [Banga \(2019\)](#) and [Flammer \(2021\)](#). With DGBs, issuers must also navigate blockchain infrastructure, smart contracts, and digital custody, raising the technical threshold. Additionally, the lack of performance data on green projects (Zhang et al., 2018) limits investor confidence, which becomes even more crucial in a digital context. Therefore, DGBs risk making the process more demanding for less experienced issuers. So, DLT only would make capacity challenges worse if not outsourced.

5.2.5 Awareness

Lastly, the findings show that DLT can help overcome awareness-related barriers in green bond markets by enhancing transparency and performance reporting, crucial for building trust. Stakeholders noted that transparency was a main benefit of DLT and Digital Green Bonds, as blockchain provides an immutable audit trail and end-to-end transaction traceability (Vesteda interview, ±20:12). This aligns with [Axelsen et al. \(2023\)](#), [Malamas et al. \(2024\)](#), and [Pavlidis \(2022\)](#), who highlight DLT's role in enhancing data integrity and investor confidence. Moreover, the issuer mentioned challenges with post-issuance verification, while the ABN AMRO sustainable markets expert pointed out the inefficiency of collecting dispersed impact data (ABN AMRO 2 interview, ±11:09). This is supported by the research by [Flourentzou \(2025\)](#) and [Zhang et al. \(2018\)](#), who identify fragmented data and limited reporting as key challenges. Moreover, when a green bond is issued in a digital-native form, the token itself can be “supercharged” with ESG attributes, allowing sustainability data to be directly integrated into the token architecture (Tokeny interview, ±13:56), as also stated in [Pavlidis' \(2022\)](#) research, where it is stated that DLT will allow us to harvest recognised metrics, codified as data tokens that communicate in real-time to investors and build a shared asset history on the ledger accessible to multiple stakeholders. In the case of ensuring transparency, the case study confirms the awareness potentials of DLT.

5.3 Digital Green Bond Barriers

The study revealed that stakeholders identify six main barriers of DLT implementation in Digital Green Bond Processes based on [Nguyen et al.'s \(2024\)](#) categorization: Policy, Market, Financial, Capacity and Awareness Barriers.

The findings are discussed in relation to the available literature in the review, illustrating how this research contributes to the overall academic literature.

Table 15: Findings versus literature of DLT-based DGB Barriers

Theme	Adoption barrier (Code)	Literature	Findings
Policy barriers	Regulatory uncertainty	X	X
	Regulatory compliance	X	-
	Regulatory arbitrage	-	X
Market barriers	Investor privacy	X	X
	Liquidity constraints	X	X
	Lack of secondary market	-	X
Financial barrier	High initial investment	X	X
	Internalized cost reduction	X	-
	Dependence on intermediaries	X	X
	Yield uncertainty	-	X
Capacity barriers	Process complexity	-	X
	Infrastructure interoperability	X	X
	Infrastructure fragmentation	X	-
	Technological scalability	X	-
	Security	X	-
	Lack of technical expertise	-	X
	Lack of programmable money	-	X
	Lack of digital wallets	-	X
	Limited track record	-	X
Awareness barriers	Lack of familiarity	X	X

5.3.1 Policy

First, findings reveal that one of the biggest barriers to DGB adoption is several policy obstacles, resulting in a gap between current EU legal frameworks and their technological potential. The analyzed literature states that DLT creates an “environment of uncertainty” that necessitates regulatory adaptation (Migliorelli & Dessertine, 2019), especially in post-trade infrastructure such as clearing and settlement (Priem, 2020). Current EU regulations (EMIR, CSDR, and the Settlement Finality Directive) require centralized clearing and licensed depositories, which conflict with decentralized DLT-native bond issuance. This situation is also true in the Netherlands, as the Securities Giro Act mandates Euroclear’s role in securities administration, excluding DLT-based settlement.

However, in practice, there is a fragmented regulatory view. Legal experts (A&O Shearman interview, ±21:45–22:07) and investors (DekaBank interview, ±09:40) highlight ongoing regulatory ambiguity regarding digital custody, ownership transfer, and enforceability, resulting in operational legal risks. On the other hand, the Dutch regulatory authority insists that issuing these digital assets is allowed under current laws. However, they also acknowledge that fully digital clearing isn’t practical due to outdated requirements, such as the need for physical signatures (AFM interview, ±38:37). The issuer and ABN AMRO confirmed legal documents remain necessary despite using a smart contract (ABN AMRO interview, ±17:35). These issues reveal that DLT’s potential is limited not by technology but by an unprepared legal system.

Additionally, the findings indicate that regulatory fragmentation among Member States worsens the regulatory uncertainty. While Germany and Luxembourg have adopted digital securities laws, the

Netherlands has not, which complicates cross-border issuance and delays transactions (Clifford Chance; DekaBank interview, ±12:09). This aligns with the arguments of Priem (2020) and Boçe & Hoxha (2024), who suggest that DLT's borderless nature conflicts with national legal frameworks. Therefore, the findings and practice evidence align with the written literature.

5.3.2 Market

Second, these findings show that market-related barriers slow the adoption of Digital Green Bonds (DGBs), despite the literature suggesting that distributed ledger technology (DLT) could improve efficiency and access. Eloul et al. (2025) and Pinna & Ruttenberg (2016) caution that the transparency offered by blockchain can clash with institutional investors' demand for privacy. This concern was echoed by the AFM, which indicated that full transparency is often not desirable for institutional players, proposing permissioned DLT systems as a potential middle ground (AFM interview, ±18:33). Additionally, liquidity constraints—brought up by Arcodia et al. (2025) as a result of real-time atomic settlement—were also mirrored in our findings. DekaBank noted that low liquidity makes DGBs less appealing for funds that must manage redemption demands (DekaBank interview, ±30:08), and Vesteda mentioned the challenges they face in attracting investors for their issuance (±39:14). The literature's apprehension regarding the lack of secondary markets (Santo et al., 2016) was reaffirmed in interviews with Clifford Chance and the AFM, both confirming that current regulations only allow trading on multilateral trading facilities (AFM interview, ±12:54). While ABN AMRO is piloting a compliant platform (21X), it is still under development (ABN AMRO interview, ±18:23–19:20). These findings reveal that although the literature points to DLT's significant market potential, real-world adoption is hampered by privacy issues, limited liquidity, and regulatory challenges—suggesting that academic enthusiasm may not fully capture the complexities faced by institutions.

5.3.3 Financial

Third, financial barriers are a significant obstacle to DGB adoption. High upfront costs deter institutions from adopting DLT-based issuance. Benos et al. (2019) note these costs stem from R&D, system integration, and infrastructure upgrades, with banks needing short payback periods. This discourages investment in technologies with longer-term benefits. The Vesteda case shows that issuance costs for a €5 million DGB are disproportionately high due to novelty and scale of the transaction (Vesteda interview, ±49:59). The Dutch Central Bank (DNB) states that transitional costs are necessary for long-term efficiency. While DLT is often seen as a disintermediation tool, Pinna & Ruttenberg (2016) and stakeholders argue that full removal of intermediaries is unlikely under current regulations. DekaBank (±27:00) emphasizes that banks are crucial as liquidity providers, and ABN AMRO Clearing views DLT as unnecessary for existing high-volume infrastructures (±40:11). This mirrors Benos et al.'s (2019) assertion that incumbents may internalize DLT benefits without sharing savings with end users. Additionally, reputational risks and regulatory uncertainty diminish the incentives for traditional players to lead the transition (Clifford Chance interview). Risk-averse buy-side investors hesitate to engage in an immature market with unclear returns, aligning with Pinna & Ruttenberg's (2016) concerns about legacy roles. ABN AMRO (±31:15) and DNB note that investor conservatism and yield uncertainty limit market participation. There is a paradox: DGB adoption requires backing from established actors, yet these actors are hesitant to disrupt profitable systems, creating a negative spiral that hinders market growth.

5.3.4 Capacity

Fourth, capacity-related barriers hinder the scalability and institutionalization of Digital Green Bonds, with literature identifying infrastructure fragmentation, low interoperability, and scalability limitations as

key challenges (Pinna & Ruttenberg, 2016; Migliorelli & Dessertine, 2019; Boçe & Hoxha, 2024). These barriers are strongly echoed in the empirical findings. While the literature tends to treat these issues as system-level limitations, interviews highlight how legacy IT systems within financial institutions—some over 40 years old (DNB interview)—pose immediate practical obstacles. The integration of DLT into these infrastructures remains costly and complex, especially in the absence of common technical standards. As ABN AMRO points out, each actor currently builds its own framework, leading to a fragmented market landscape (ABN AMRO 2, ±16:13–17:09). Similarly, the lack of wallet infrastructure and custodian licenses limits investor participation and demands additional compliance steps (Deka interview, 2025). Furthermore, despite DLT's potential to simplify processes, stakeholders find that it introduces procedural complexity rather than reducing it: “We had to reinvent everything,” Vesteda noted, referring to structuring and documentation (Vesteda interview). Literature also underlines that process speed and scalability remain theoretical (Santo et al., 2016), which aligns with findings that the Vesteda transaction did not yet deliver measurable benefits due to its pilot nature and small scale. Although outsourcing technical tasks can mitigate internal knowledge gaps (e.g. to Tokeny or Fireblocks), this reliance creates structural dependencies, limiting control and institutional learning. Most crucially, the lack of programmable money constrains automation and on-chain settlement; the Vesteda pilot still required off-chain fiat payment (DekaBank interview), confirming that full DLT integration is currently not feasible. While scholars often emphasize future potential, the findings show that current DGBs still face steep onboarding requirements, coordination gaps, and untested infrastructure, all of which limit short-term adoption.

5.3.5 Awareness

Lastly, awareness-related barriers play a crucial role in the limited adoption of Digital Green Bonds (DGBs), yet this aspect is often underexplored in academic literature, which tends to focus more broadly on DLT-based securities. While studies recognize a lack of technological familiarity as a barrier (Migliorelli & Dessertine, 2019; Thanasi Boçe & Hoxha, 2024), the findings highlight that this barrier is intensified in DGBs due to their dual connection with innovative financial technology and sustainability-related goals. Stakeholders consistently report that the negative reputation of blockchain—linked to cryptocurrencies—creates fear and misunderstanding, especially among institutional investors and regulators (Vesteda interview, ±27:46; AFM interview, ±42:45). This stigma has fostered risk-averse behavior and heightened concerns about cybersecurity and energy consumption. The findings show that such concerns are often based on misinformation, conflating third-party platform breaches with blockchain failures (ABN AMRO interview, ±32:03), and overlooking advancements like the adoption of energy-efficient Proof of Stake mechanisms (Tokeny interview, ±15:35). More significantly, unlike the literature, which views awareness as a general technical barrier, the findings identify a green awareness gap—limited stakeholder understanding of how DLT can align with sustainable finance principles. This lack of familiarity not only diminishes investor confidence but also hinders engagement from sustainability-focused institutions, despite DLT's potential to improve transparency and traceability in green finance. As the Vesteda case shows, building trust in DGBs requires not only technical knowledge but also practical exposure, emphasizing the need to distinguish clearly between speculative blockchain use and regulated, ESG-compliant instruments.

5.4 Digital Green Bond Enablers

The study revealed that stakeholders present six main adoption enablers for Digital Green Bonds: Policy, Capacity and Awareness enablers, which are all interrelated to each other. This chapter will discuss these enablers, their interrelations and how these might overcome certain identified DGB barriers.

5.4.1 Policy enablers

The findings suggest that, through cooperation between market participants and regulators, clear regulations should be established for DLT usage, especially in post-trade processes, enabling on-chain clearing and settlement instead of depending on certain CSD procedures. The findings also indicate that technology-neutral yet transparent regulation can help reduce uncertainty without stifling innovation. This supports the existing literature by Priem (2020), highlighting the tension between flexibility and clarity. Finally, EU-level regulatory harmonization is seen as an enabler for addressing cross-border issuance challenges and regulatory arbitrage, which is discussed in the literature, such as Hyun et al. (2023), who mention fragmentation as a major barrier.

5.4.2 Capacity enablers

The findings show that programmable settlement is a promising tool for increasing automation, efficiency, and transparency in green bond issuance and settlement processes. But, its benefits are limited unless two interconnected barriers are addressed: regulatory constraints (policy) and infrastructure gaps (capacity). These currencies and smart contract-based automation cannot be effectively implemented without regulatory approval and supporting infrastructure, including digital wallets, custodial arrangements, and on-chain fiat or stablecoins. Moreover, Interconnected ecosystems are essential not only for programmable settlement but also for expanding market participation. With support from central bank experiments and pilot programs, like those discussed by the DNB. Capacity building also aims to overcome the barrier of a limited track record. As mentioned in the capacity barrier section, institutions remain hesitant to invest in unproven technologies. Therefore, proofs-of-concept experiments in programmable and interoperable systems will serve as both operational testing and market signaling.

5.4.3 Awareness enablers

Findings reveal significant misconceptions or a lack of awareness about blockchain and sustainable financing. These awareness-related barriers are reinforced by the scarcity of proven examples, especially in the green finance sector. As major issuers participate in pilot transactions, they create a feedback loop: their involvement boosts visibility, attracts regulatory attention, and enhances overall awareness. This increased awareness, in turn, builds trust, reduces risk aversion, and encourages other institutions to get involved, gradually decreasing investor conservatism. While the literature often suggests that awareness issues are primarily about education, the findings indicate that awareness must be built through practical experience—by experimenting with the technology and conducting proofs of concept (PoCs)—to change perceptions through demonstration rather than just explanation.

5.4.4 Interconnected barriers

By analyzing the DGB enablers versus the DGB barriers, several interdependencies become clear. A few of these interdependencies will be discussed: Regarding policy, it is most likely to be adopted when market signals indicate the need for regulatory reform concerning DLT, which depends on PoCs by pioneering institutions, as regulators can engage with their outcomes and strengthen the necessary

regulations. Concerning capacity, programmable settlement can only add value to green bond processes if regulation allows it (policy barriers) and if market participants have the required infrastructure, such as digital currencies and wallets (capacity barriers). Regarding awareness, proofs of concept will only surface if there is a clear motivation to participate in such pilots. This motivation is directly linked to reducing financial barriers, especially those costs associated with implementing DLT processes. These experiments, in turn, help increase market familiarity and institutional learning, thereby addressing awareness-related barriers. Due to these interdependencies, accelerating the DGB market requires a systems-based approach rather than multiple isolated interventions.

6 Conclusions

After thoroughly analysing every sub-question using the stakeholders' insights and their quotes, this chapter will answer the posed research questions and actionable strategies for stakeholders involved in the green bond market will be presented.

To answer the first sub question: “What barriers do stakeholders identify in the issuance and management of traditional green bonds?”, five key barriers emerge. First, stakeholders mention a lack of regulatory enforcement: not complying with the green bond's label conditions may lead to losing the green label, but it rarely carries legal consequences, which lowers the market's trust and increases the risks of greenwashing. Second, market access is constrained by high minimum issuance thresholds and outdated 9-to-5 market infrastructure, which excludes smaller issuers and private investors. Third, the traditional issuance process is costly and inefficient, necessitating coordination with multiple intermediaries, which raises transaction costs. Fourth, capacity barriers are mentioned, as many institutions lack the technical expertise needed to design, monitor, and report on green bonds. Finally, the transparency and credibility of green bonds is lowered due to fragmented reporting processes and the lack of standardized, real-time data, creating key awareness barriers. Together, these barriers reveal several inefficiencies in the current green bond market architecture, which potentially hinder the growth of the green finance market.

By answering the second sub question: “How can Distributed Ledger Technology (DLT) and the development of Digital Green Bonds potentially address the barriers found in traditional green bond processes?”, we can conclude that DLT and the subsequent creation of Digital Green Bonds (DGBs) do have potential to overcome these barriers, especially regarding market, financial and awareness barriers: Policy-related barriers may be mitigated through real-time compliance and standardized reporting; market access can improve via fractionalization and 24/7 trading; financial barriers may be reduced through automation and faster settlement; capacity challenges could intensify due to technical complexity; and awareness barriers are addressed through enhanced transparency and integrated ESG data. However, some of the impacts have not yet materialized in this case and therefore remain theoretical. While the case study confirms the realization of faster settlement and improved transparency, other advantages, such as regulatory streamlining and cost reductions, are either still in development or subject to practical limitations. These limitations are answered through the third sub question in this research.

By answering the third sub-question, “Which barriers currently hinder the broader adoption of Digital Green Bonds in the financial market?”, we can conclude that the adoption of Digital Green Bonds is impeded due to several identified barriers. Policy barriers have shown to be important barriers that have to be overcome, such as outdated regulation and regulatory fragmentation, which limit the potential of DLT-native DGB issuance. Moreover, market related barriers, especially a low market liquidity and the absence of a secondary market limit the DGBs potential benefits, making the instrument less interesting to adopt. Moreover, the high initial costs in combination with a highly institutionalized and profit-driven context work as a deterrent for adoption. Also capacity-related barriers arise due to outdated IT systems, Capacity-related obstacles emerge from outdated IT systems, technical fragmentation, and the lack of programmable money and wallets, all of which curtail full-scale implementation. Finally, awareness barriers also act as a key deterrent to adoption, as a certain stigma surrounding DLT and a

limited understanding of sustainable finance applications deter potential market participants who lack knowledge about the topics. The Vesteda case shows that, although some progress has been made, many barriers remain unresolved, underscoring that the transformative potential of DGBs remains largely unrealized in current market conditions.

And, lastly, by answering the fourth sub-question: [How can these barriers be addressed to facilitate the broader adoption of Digital Green Bonds?](#), and therefore also the main research question: [What barriers do stakeholders perceive in adopting green bonds, and how could they be overcome to accelerate the green finance market?](#), we can conclude that overcoming the identified policy, market, financial, capacity, and awareness barriers requires a system-wide multi-stakeholder approach due to the interconnections among these barriers. The research recommends tackling policy barriers through collaborative regulation development, which is standardized and provides regulatory clarity without hindering technological innovation. Addressing capacity barriers involves investing in interoperable infrastructures and pilot projects that demonstrate technical feasibility, along with market-wide collaboration and standardization. Lastly, awareness barriers can be addressed through experimentation and successful cases to clarify DLT's role in sustainable finance. Therefore, a comprehensive approach that includes policy reforms, infrastructural improvements, financial incentives, and practical demonstrations will be essential for the widespread adoption of Digital Green Bonds and ultimately accelerate the broader green finance market, further closing the green financing gaps mentioned in the introduction.

7 Limitations and recommendations

7.1 Limitations

Qualitative and exploratory scope

This study employed a qualitative research design centered around semi-structured interviews with a very specific group of stakeholders. Although this approach provided detailed insights into perceptions and experiences, it also limits the extent to which the findings can be generalized to the entire financial sector or regions outside the Netherlands and the EU.

Limited number of proofs-of-concept cases

The empirical analysis focused only on the Vesteda–ABN AMRO PoC as a key case study. The case is informative, the findings may not fully reflect the variety of possible DGB structures, market responses or interpretations in other cases or contexts.

Pioneering market

The DGB market is still in its early stages of development. Therefore, many of the discussed benefits (e.g., cost reductions, liquidity improvements) remain theoretical. This research is thus based on perceived, rather than empirically verified, advantages and barriers.

Potential stakeholder bias

Interviewees may have had strategic or institutional motives influencing their views on DGB adoption. For example, technology providers might emphasize opportunities, while regulators may focus on risks. Although efforts were made to triangulate perspectives (also discussed through relating to literature), these personal biases could have affected the results.

7.2 Recommendations

The recommendations are divided into research and practice suggestions. The research suggestions aim to address the identified literature gap by connecting sustainability with securities digitalization through DLT. The practice suggestions target market participants interested in engaging with green bond processes.

7.2.1 Research recommendations

Quantitative market impact assessments

While this research was qualitative and exploratory, future studies could explore how DLT-enabled features—such as fractionalization, automation, and 24/7 trading—actually affect issuance costs, settlement times, and how diverse the investor base becomes. Conducting these studies with a larger, statistically significant sample would provide clearer insights.

Investor preferences and pricing dynamics

Further investigation is needed to understand how both institutional and retail investors assess the risks and premiums associated with DGBs compared to traditional green bonds. It's important to grasp

whether investors are willing to pay extra for features like better traceability or programmability, as this knowledge is key to developing the market.

Environmental performance verification using DLT

Future work could assess how DLT can enhance post-issuance environmental performance reporting, and how regulators and third-party reviewers might interact with tokenized ESG data in practice.

7.2.2 Practice recommendations

Following the main conclusions for the research, several stakeholder-coded actionable strategies are presented, which, when implemented collectively, have the potential to address the identified barriers and accelerate the broader adoption of Digital Green Bonds (DGBs) and the subsequent green finance market. These strategies reflect stakeholders' practical insights into how different market participants can contribute to the successful implementation and scalability of DGBs:

Issuer

Issuers should participate in proofs-of-concept transactions and take on a pioneering role to build experience and signal to the market that the concept is viable. By building expertise and increasing knowledge about the issuance of digital green bonds, subsequent transactions are likely to have a lower implementation cost and reduced process complexity. Moreover, by conducting these proofs of concept, issuers signal to the market that the idea is usable, which further increases investors' trust, mobilizes market liquidity, and boosts regulators' confidence, incentivizing them to support the market through permissive regulation.

Investor

Moreover, the investors should also start participating in these proof-of-concept transactions. In their case, they could signal market demand and improve liquidity by beginning to invest in these types of bonds. However, they depend on the regulators, who should create regulations for the tradability of these bonds, aligning with the investors' liquidity demands. Furthermore, technology providers are also important to investors, as they provide the digital infrastructure necessary for investing in these bonds, including wallets and a secondary trading market.

Underwriter

The underwriters share a stance like that of the issuer; however, as large banks, they tend to have a greater impact on the market. By conducting proofs of concept and pioneering, they can create a significant signaling effect in the market, greatly enhancing trust. Hesitant investors may be persuaded to start investing, partly due to the network of these underwriters.

Technological providers

According to stakeholders, technological providers play a crucial role in the market. They are essential for realizing the full potential of digital green bonds by enabling the programming of the settlement leg and facilitating the creation of a decentralized trading exchange for digital securities. This development is vital for enhancing market liquidity and attracting new investors who require a certain level of liquidity, further boosting the market's overall liquidity. These providers are dependent on regulators, who should have technology-neutral regulation, not hindering the development of innovative technologies that could further mobilize the market.

CSDs

CSDs may have the lowest interest in the digitalization of the market, due to the potential of DLT to disintermediate the Clearing and Settlement process and the storage of security ownership. However, to retain a place in the transaction, they should create interoperable systems for digital issuance and trading, adapting their business operations and roles, and contributing to surpassing the barrier due to reliance on traditional systems.

Custodian

As stated by stakeholders, custodians should acquire digital custody licenses and offer wallet services as an additional business operation, allowing the possibility for their clients (issuers or investors) to engage with the digital green bond market. However, these custodians are dependent on the market regulators, often giving these licenses slowly.

Market regulators

Stakeholders are all in favor of regulatory reform, which harmonizes regulations and clarifies the current framework surrounding digital, DLT-based securities, making it clearer, unambiguous, and technology-neutral. This reform reduces the risk of legal interpretation for issuers and investors, while fostering innovation by not hindering technology providers.

Overall

Overall, all stakeholders have emphasized the importance of collaboration among market parties in the green bond market, aiming to reduce fragmentation and promote standardization, in search for strategies to surpass the most significant barrier of the market: market illiquidity.

8 Theoretical background

8.1 Finance

8.1.1 Bonds

A bond is a common financial instrument in debt capital markets. It is a loan of funds by the buyer to the bond issuer, in return for regular interest payments up to the termination date of the loan. A bond has two payments up to maturity, meaning the number of years after which the issuer will repay the obligation: the principal and coupon payments. The principal is the amount the issuer agrees to repay the bondholder on maturity. This is also known as the redemption value, maturity value, par value, or face amount. The coupon payment is the coupon rate, the interest rate that the issuer agrees to pay periodically, multiplied by the bond's principal. The coupon payment is the amount that has to be paid periodically (Choudhry, 2011; Fabozzi & Fabozzi, 2021).

8.1.2 Bond lifecycle

A bond's lifecycle depends on the type of bond, stakeholders, and jurisdictional requirements. However, a universal process can be depicted. This section of the literature review will provide an understanding of the lifecycle of a plain vanilla bond. **See appendix A for a detailed overview of a bond's lifecycle.**

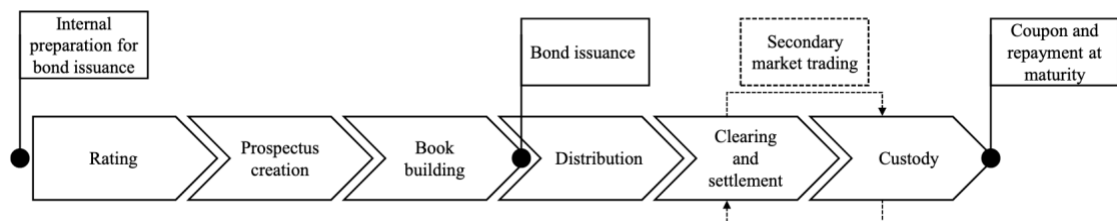


Figure 9: Plain vanilla bond lifecycle (Grossmann, 2024)

Issuance

Internal preparation

In practice, the issuing party will appoint an investment bank to execute the issuance process. This investment bank is a [bond underwriter](#), responsible for structuring the green bond process, pricing, and distributing the bond to potential investors. Green bond underwriters are typically large investment banks or specialized financial firms with expertise in sustainable finance. The top underwriter in Europe is the ING Group, with approximately 13.6 million euros (Statista, 2024b). The issuing party and legal consultants must decide whether they need to raise capital, after which a suitor will be chosen to lead-manage the deal, called a mandate (W. Chen & Wang, 2019; IFC, 2022). Moreover, the issuing party should contact its [auditors](#) to ensure they are prepared to audit or provide some form of attestation for the process where the issuing bank seeks to demonstrate robust best practices (IFC, 2022).

Rating

The following step involves rating the issuing company to receive a credit risk rating from a [credit rating agency \(CRA\)](#). Agencies such as Moody's, Standard & Poor, and Fitch assess the company's trustworthiness and credit risk. These bond ratings can be split into "investment grade," indicating lower

credit risk, and “speculative grade,” showing a significantly higher default risk. Standard & Poor’s, for instance, considers all ratings from AAA to BBB– “investment grade” and BB+ to D “speculative grade” (Grossmann, 2024).

Prospectus creation

After assessing the issuing party's credit rating, a bond prospectus must be created, clarifying the bond's contents related to investor protection, such as protection mechanisms, debt repayment plans, and safeguard measures. The disclosures' sentiment reflects the issuer’s emphasis on risk management and investor equity and is an essential reference for investors determining risk compensation (Deng et al., 2024). Creating an issuance program governed by a single prospectus is also possible, making it possible to issue multiple bonds without creating multiple prospectuses. However, the prospectus has to be supervised by the relevant national markets authority (Grossmann, 2024).

Book building

Book building is a price discovery mechanism for Initial Public Offerings (IPOs). It limits the choice of issuers, and it is often done in two methods: the ‘open offer/auction’ or ‘fixed price’ method (Sherman, 2000). In an open offer or auction method, the lead underwriter and the issuer communicate the indicative price range for the bond shares, and then select a group of institutional investors to submit bids. Underwriters are also free to do road shows and to ask for indications of interest. Here, the underwriter presents the offering to potential investors through a roadshow. A roadshow is a series of meetings (in virtual or face-to-face format) with key investors in the market that the issuer is targeting to attract investors for the bond (Malamas et al., 2024). Typically, the focus is on institutional investors, such as banks and insurance companies, who purchase large volumes. Through these meetings, initial investment interest is identified (book building), which is crucial for discerning market preferences and, if necessary, adjusting the bond’s pricing or yield to align supply with the identified demand. (Grossmann, 2024). The investor’s bids are finally collected in a book, with the underwriter determining the bond’s final pricing (Cornelli & Goldreich, 2022).

Distribution

Bonds can be distributed to investors in various ways. The bank’s involvement can range from underwriting the bond issue, buying the bonds from the issuer, to reselling them, to working on a best-efforts basis, which entails facilitating sales directly from the issuer to the investors without assuring the full placement of the bonds’ amount (Grossmann, 2024). For underwritten deals, dealers underwrite at an agreed price, coupon structure, and yield to maturity (YTM). After an investor has purchased the bond, the bond is registered in book-entry form with a Central Securities Depository CSD against the initial issuance registration record (AFME, 2024b).

Trading

Secondary market trading can also be divided into pre-trade, at-trade and post-trade (BCG et al., 2023).

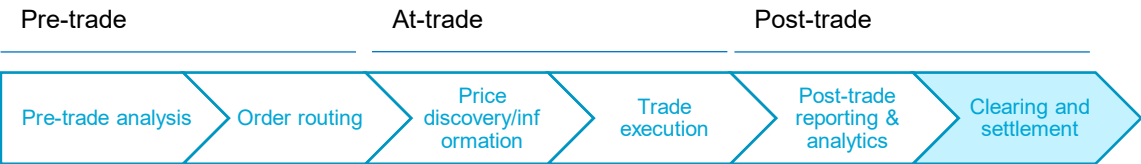


Figure 10: Secondary market trading sections (BCG et al., 2023)

Pre-trade

Before a trade is executed, traders conduct a pre-trade valuation and analytics to determine [order routing](#) and trading tactics, using information while remaining within the regulatory requirements. For this analysis, market data, which can be low-quality or absent, is needed, making it difficult to integrate it into pre-trade workflows (BCG et al., 2023).

Order routing is the process by which an order goes from the end user to an exchange. A sell-side order-management system (OMS) controls orders as they are received. The OMS may include an internal market to execute orders against the firm's inventory or provide order-routing algorithms to send the order to execution venues (Williams, 2011). Decisions are made in a combination of pre-set rules, algorithms (smart order routing), or manual direction (expert trading) (BCG et al., 2023). Smart routing systems (SRS) employ algorithms to choose the place and timing of executions (Williams, 2011), however, market inefficiencies exist in markets with low electronic penetration due to the need for manual trade direction (BCG et al., 2023).

At-trade

Price discovery can occur in a variety of ways. The first is the “order book protocol,” where a public list of buyers and sellers posts their prices. When a buyer's price matches a seller's, a trade occurs automatically (BCG et al., 2023). The second method is the request-for-quote (RFQ) protocol, which is increasingly prevalent in green bond trading (Bongaerts & Schoenmaker, 2024). Instead of posting prices on a list, a buyer contacts the seller to request their price or quote. The best price is then selected, and the trade is confirmed. Dealers and end-investors trade on their electronic trading platform in response to request-for-quotes (RFQs). Typically, a quote is requested for a bid or ask price on a given volume of a specific corporate bond within a set timeframe (BCG et al., 2023; Dekker et al., 2024)

Post-trade

Execution venues and market participants record, monitor, and report trade data for risk management and regulatory purposes (BCG et al., 2023). The following steps will be discussed in the following green bond lifecycle step, which occurs after a trade is executed.

Clearing and settlement

Clearing is the preparation of a transaction through matching the recording and processing instructions for settlement. In short, clearing validates and confirms transaction details before settlement (Loader, 2020b). It is a significant component of post-trade processes, playing a crucial role in the financial industry by ensuring the completion and finality of financial transactions. The term clearing was previously easily associated with ‘clearing banks’, which validated cheques and cleared money. However, electronic banking has automated the process, such as electronic payment systems owned by the Central Bank of the Country or currency: Fed Wire and CHIPS in the USA, BACS and CHAPS in the UK, and TARGET2 for the Euro (Loader, 2020b).

Settlement refers to the actual exchange of assets or cash, whether in fiat or another form of currency, between the buyer and the seller, and the transference of ownership of those assets and money (Loader, 2019).

Financial infrastructure providers (FMI) play a pivotal role in facilitating transactions and ensuring the safekeeping of assets. Two main FMI providers are involved in the Clearing and Settlement process: the Clearinghouse and the central securities depository.

Central Security Depository (CSD)

The clearing and settlement process is often linked with another process: the holding of securities records, in electronic or sometimes physical form. The Central Securities Depositories (CSDs) are responsible for this process. **Central securities depositories** (CSDs) manage the documentation of securities, maintain primary securities accounts, and usually supervise the settlement process, especially the financial aspects of securities trading transactions (Grossmann, 2024). Some widely used CSDs and international central depositories (ICDs) are Euroclear, Clearstream, and DTCC.

Clearinghouse

Another key FMI provider is the **clearinghouse**, which serves as an intermediary in post-trade financial activities, ensuring the fulfillment of contracts even if a party defaults (Grossmann, 2024). The clearinghouse doesn't regulate transactions. Still, it does establish the rules with the market regulator by which its members will clear and settle the business they conduct (Loader, 2019).

A clearance and settlement process are started after a buy-side client, such as a broker or a dealer, and a sell-side client agree on the trade, the clearing process is begun by forwarding the buy and sell instructions to the Central Counterparty (CCP), which is a type of clearinghouse that facilitates trading in European derivatives and equities markets. Then, a novation occurs, whereby the CCP acts as a buyer and seller to the buyer. After the novation, the CCP will forward the settlement instruction to the CSD. The CSD will operate the securities settlement system by crediting and debiting the securities accounts of its participants, acting on behalf of the buy side and sell side clients, respectively. Now, most European CSDs outsource their service to the platform operated by the Eurosystem (Priem, 2020)

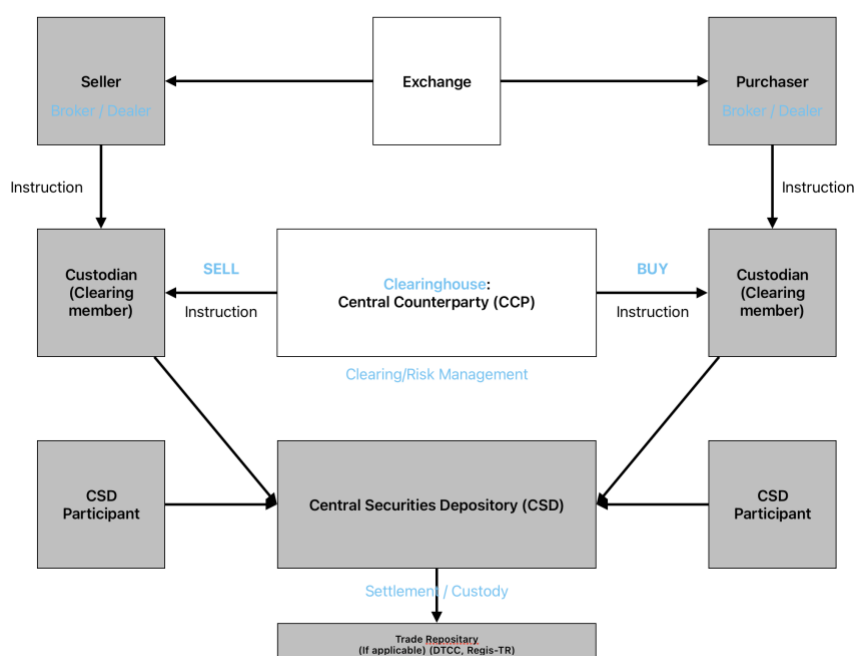


Figure 11: Simplified representation of the security Clearing and Settlement (own work)

Custody

Safekeeping

Some of the custodians' core services are the safekeeping of securities in physical or electronic form, transaction settlements, collection and distribution of dividend and interest payments, assistance in tax-related matters, foreign exchange management, and executing corporate actions (Berry-Johnson, 2025; Loader, 2020a). Custodians, which often operate globally through a network of local sub-custodians, serve as an intermediary for the client. They function between the investors and the CSDs to manage the flow of securities and cash throughout the settlement process.

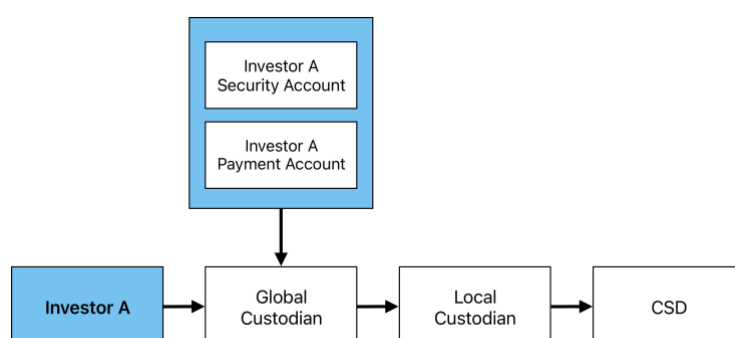


Figure 12: Custody process of a plain vanilla bond

Corporate Actions

One of the other services of a custodian is managing clients' corporate actions: dividend payments, interest payments, capital repayments, rights issues, capitalization, mergers, scrip dividends, conversions, warrant exercises, redemptions, and proxy voting. This ensures that all client entitlements are managed efficiently. Therefore, custodians must quickly and accurately execute and communicate the actions undertaken to prevent financial losses (Loader, 2020a).

8.2 Decentralized Finance

8.2.1 Digital Bonds

Digital bonds, also known as DLT bonds, are debt instruments whose register of ownership is stored using distributed ledger technology (DLT) (ICMA, 2022). Digital bonds are considered as a core instrument of Decentralized Finance (DeFi), which is defined in various ways but can be described as *“the transformation of traditional financial products into products that operate without an intermediary via smart contracts on a blockchain”* (Meegan, 2020) or a *“peer-to-peer financial system, which leverages distributed ledger-based smart contracts to ensure its integrity and security”* (Gudgeon et al., 2020). From these definitions, distributed ledger, blockchain and smart contracts seem to be the three most important concepts of decentralization:

Distributed Ledger Technology (DLT)

Distributed ledger technology is an innovative technology that creates an environment without a central authority for registering, sharing, and synchronizing transactions involving digital crypto assets (Antal et al., 2021). In DLT systems, the peer's transactions are most represented on a blockchain. This blockchain structure consists of a chain formed by linked blocks that keep adding new blocks to the chain over time. Each block contains all the transactions that occur in the system over a short time. To keep the transactions secure and organized, all transactions are compiled into a summary using a

structure known as a Merkle Tree, which generates a type of digital fingerprint or hash that stores all transactions that have taken place. Once a block is added to the blockchain, it cannot be erased or altered, preserving the history of each transaction over time, which the system automatically validates through cryptography (Antal et al., 2021).

Within these DLT systems, blockchains can be categorized into data access types (public or private) and permission structures (permissionless, permissioned or hybrid semi-permissioned) (Antal et al., 2021). A public or private blockchain is based on the level of access that the target audience has to the reading rights of the chain and to who has read access to the blockchain data. In a [public blockchain](#), everyone has chain access, but some restrictions can also be imposed regarding the users' access and permissions. Restricting a group's access to the chain renders the chain [private](#). [Permissionless](#) blockchains like Bitcoin and Ethereum 1.0 are decentralized systems without a central authority. They are governed through consensus mechanisms such as Proof of Work (high energy consumption and secure, but slow) and Proof of Stake (low energy consumption and scalable).

In a [semi-permissioned blockchain](#), anyone can join when certain pre-described rules are met. This type of blockchain lacks public blockchain anonymity but benefits from a faster, energy-efficient mining algorithm. In a [private blockchain](#), transactions are controlled by a single entity or consortium, such as a financial institution. Consensus rules enable instant transaction confirmation with minimal energy use, facilitating supply chain value transfer and asset tracking. An overview of the blockchain types is made in Table 2:

Table 2: Public vs private permissions, adapted from (Antal et al., 2021; Sobe, 2022).

Action	Public Chain – Permission- Less	Public Chain – Semi- Permissioned	Public Chain – Permissioned	Private Chain – Consortium	Private Chain – Enterprise
Chain Access	Everyone	Everyone meeting predefined rules	Everyone	Group Owner	Group Owner
Transactions	Everyone	Rule- compliant users	Owners & Validated Users	Owners & Validated Users	Administrator
Commit to Chain	Everyone	Rule- compliant subset of users	Owners & subset of Validated Users	Owners & subset of Validated Users	Administrator

Smart contracts

Khan et al. (2021) states that “smart contracts are executable codes that run on top of the blockchain to facilitate, execute, and enforce an agreement between untrustworthy parties without the involvement of a trusted third party.” Therefore, smart contracts facilitate automated transactions without the oversight of a central authority, automatically executing the operations defined in the code (Gupta et al., 2023). The contract code governs the execution of the contract in question, while the associated transactions can be tracked but not reversed (Sobe, 2022).

Due to the immutability of these DLT systems, smart contracts are particularly interesting for financial services, such as money transfers that adhere to certain agreed rules. In this context, smart contracts manage, collect, and distribute funds while eliminating a central authority, such as banks, that involves transaction costs (Khan et al., 2021).

Tokens

DLT-based digital bonds' ownership is represented through tokens on said blockchain. These tokens can have different, constantly evolving classifications. The type of tokens can be categorised by ownership, fungibility, purpose and asset representation (Antal et al., 2021; Guseva, 2020; Sobe, 2022):

Ownership

The first distinction made is based on the right of ownership of the token. The two main types are **utility tokens** and **security tokens**: A **utility** token, also known as an investment token, provides access to a product or service, thus representing ownership of an asset (Coinbase, n.d.; Sobe, 2022). These cryptocurrency tokens simply grant token holders access or the right to participate on platform(s). When considering Initial Coin Offerings (ICOs), utility tokens are the tokens offered to investors and confer zero rights to the underlying issuer's business (Tokeny, 2023a). A **security token** is a token that has security-like characteristics (Guseva, 2020). These tokens grant investors rights to tradable securities, encompassing equity, debt, and more. Issuers can conduct Security Token Offerings (STOs) to raise funds; however, security tokens are securities and must comply with traditional securities laws (Tokeny, 2023a). The tokens resemble traditional securities that must also adhere to federal securities laws and regulations, complicating their operation due to legal intricacies (Sobe, 2022).

It is important to note that some virtual assets can be used as a means of exchange and simultaneously have a currency or participation function with embedded voting rights. Therefore, some token infrastructures are a hybrid of several asset classes (Guseva, 2020). In the case of digital bonds, security tokens are used, and funds are raised through STOs.

Fungibility

The second distinction, based on fungibility, is between **fungible tokens and non-fungible tokens**. A fungible token is an interchangeable and tradeable unit that is often used as digital money, whereas a non-fungible token (NFT) is used primarily for identifying objects or data, such as collectable art (Sobe, 2022). Security tokens are regarded as fungible tokens, as traditional securities such as bonds are commonly tradable financial assets (Choudhry, 2004; Guseva, 2020).

Purpose

Lastly, the third distinction is based on the token's purpose. Tokens can have different and multiple purposes. For example, crypto tokens serve as a currency, voting tokens confer a voting right to the token's holder, and payment tokens serve as an internal payment method in an application (Sobe, 2022).

As tokens can have these different purposes and standards, specific standards have been designed for specific purposes. Ethereum's ERC-20 standard is one of the first and main code standards, which ensures uniform performance and transferability of fungible tokens (Guseva, 2020). Security tokens are often implemented through the use of the ERC-1400 standard, and later the new industry standard ERC-3643, which will be discussed later on in the research (Sobe, 2022; Tokeny, 2023).

Asset representation

Considering the previously described token types, digital bonds can be classified as debt instruments whose ownership register is stored using distributed ledger technology (DLT) through **fungible security tokens**. The **purpose** of the tradable bond is to grant investors rights to it. However, the last distinction is to be made based on the type of asset representation: **native or non-native** tokens.

Native tokens are defined within the DLT system and do not exist in the real world. Consequently, they are entirely independent of the real world and its governance, as the system exclusively determines their issuance and transfer. The most popular example is Bitcoin, whose value is based on supply and demand (Antal et al., 2021).

Non-native (asset-backed) tokens are linked to real-life assets, including tangible ones like real estate, money, and art, as well as intangible assets such as patents, trademarks, and copyrights (Antal et al., 2021). Intangible assets also encompass debt instruments like bonds, which tokens are referred to as debt tokens, and values of shares, such as stocks, represented in the form of equity tokens (Schletz et al., 2020).

8.2.2 Digital bond types

Resulting from these two token typologies, DLT-based digital bonds can be categorized by their issuance method into **native** and **non-native bonds (tokenised bonds)**:

Native digital bonds

Native digital bonds are fully issued and settled on DLT and blockchain platforms from the beginning, possibly allowing for reduced intermediaries required in the process (Ma & Steininger, 2025). The digital bond is represented through native tokens.

Non-native digital bonds

Non-native digital bonds are traditional bonds that are transferred to the digital space and represented as digital tokens on blockchain platforms (Ma & Steininger, 2025). The digital bond is represented through non-native, asset-backed tokens.

This transfer is referred to in literature as tokenization, which also results in non-native digital bonds being known as tokenized bonds. Literature defines tokenization in various and sometimes conflicting ways (Heines et al., 2021). For this research, the definition given in the extensive literature study about tokenization by Heines et al. (2021) will be used:

Tokenization is the process of creating a singular identifier on a distributed ledger as a token.

Here, the token created serves as a bearer instrument for representing value or contractual rights. Adding properties to the individual token can be designed to be unique, tradeable, scarce, and much more (Heines et al., 2021). In the case of financial assets, it is the process of representing a fractional ownership interest in an asset with a blockchain-based token (Baum, 2020).

9 Reflection

Writing this thesis has been a very iterative process. This is due to my growing understanding of the challenges in the digital green bond realm, coupled with new insights from the stakeholder's insights from the initial interviews. First, the thesis aimed to describe how a digital green bond issuance was structured and what potential impacts DLT could have on the green bond market. Then, the main goal changed to implementing DLT in the green bond market, as this has been one of the main challenges faced by the stakeholders involved in the green bond market. All stakeholders interviewed stated that it was not the structuring or potential that was interesting to research but rather how that technology could be implemented quickly. My approach to writing this thesis was, therefore, quite fitting for my way of working. First, I indulged in an overly extended literature review, writing down every aspect that had something to do with digital green bonds. This approach cost more time than normal, but it allowed me to deeply understand a topic I wasn't that familiar with. Therefore, it allowed me to have interesting conversations with the stakeholders involved, understanding everything that they stated, enabling me to have a proper conversation and, therefore, also be able to partake in the discussion, which is part of my research.

One thing about my approach is that it takes a lot of time, and it can feel like throwing away valuable time writing chapters that will not make the final thesis report. Therefore, the feedback given by my mentors to make decisions and start finalising was a needed step. Moreover, the feedback from my professors was quite nice, as it isn't feedback that is steering. It could be described as a brainstorming session, finding ideas that would be interesting for my thesis, which works for me. This created an open and unrestricted space to write my ideas.

From writing this research, I've learned a lot. I feel that I have done a super sped-up environmental and technological finance course. I have been reading every day, and the topic has interested me from beginning to end, something that I feel is needed to be able to work on it every day with the same energy. It has also taught me to interview people and to connect with different people in this financial field, as I've done at least half of the interviews physically. It has taught me how to pitch an idea and delve deeper into it with people with more experience in the field I am researching.

Looking ahead, my research should serve as a good description of the status quo and highlight what steps must be taken to accelerate the digitalization of the green bond market, potentially accelerating the broader green finance market. The research could serve as a way to start a conversation with the different parties involved, encouraging collaboration and allowing for discussion between the parties with opposing views.

Bibliography

Artificial Intelligence Use:

Grammarly Grammar Tool

Chat GPT for translation of Quotes to English

1. ABN AMRO. (2023a). *ABN AMRO registers first digital green bond on the public blockchain*. ABN AMRO Bank. <https://www.abnamro.com/en/news/abn-amro-registers-first-digital-green-bond-on-the-public-blockchain>
2. ABN AMRO. (2023b, January 10). *ABN AMRO registers first digital bond on public blockchain*. ABN AMRO. <https://www.abnamro.com/en/news/abn-amro-registers-first-digital-bond-on-public-blockchain>
3. Ackassi, A. (2020). *The growth of the green bond market: A qualitative analysis of the barriers and opportunities*.
4. AFME. (2024). *AFME DLT-Based Capital Market Report 2024*.
5. Alamgir, M., & Cheng, M.-C. (2023). Do Green Bonds Play a Role in Achieving Sustainability? *Sustainability*, 15(13), 10177. <https://doi.org/10.3390/su151310177>
6. Anh Tu, C., & Rasoulinezhad, E. (2022). Energy efficiency financing and the role of green bond: Policies for post-Covid period. *China Finance Review International*, 12(2), 203–218. <https://doi.org/10.1108/CFRI-03-2021-0052>
7. Antal, C., Cioara, T., Anghel, I., Antal, M., & Salomie, I. (2021). Distributed Ledger Technology Review and Decentralized Applications Development Guidelines. *Future Internet*, 13(3), 62. <https://doi.org/10.3390/fi13030062>
8. Aponte-Novoa, F. A., Orozco, A. L. S., Villanueva-Polanco, R., & Wightman, P. (2021). The 51% Attack on Blockchains: A Mining Behavior Study. *IEEE Access*, 9, 140549–140564. <https://doi.org/10.1109/ACCESS.2021.3119291>
9. Arcodia, M., Mazzoni, N., & Papetti, V. C. C. (2025). *Atomic Settlement: Potential Implications of DLT-based Compressed Settlement Cycles*.

10. Axelsen, H., Rasmussen, U., Jensen, J. R., Ross, O., & Henglein, F. (2023). Trading Green Bonds Using Distributed Ledger Technology. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4420803>
11. Banga, J. (2019). The green bond market: A potential source of climate finance for developing countries. *Journal of Sustainable Finance & Investment*, 9(1), 17–32. <https://doi.org/10.1080/20430795.2018.1498617>
12. Benedetti, H., & Rodríguez-Garnica, G. (2023). Tokenized Assets and Securities. In H. K. Baker, H. Benedetti, E. Nikbakht, & S. S. Smith (Eds.), *The Emerald Handbook on Cryptoassets: Investment Opportunities and Challenges* (pp. 107–121). Emerald Publishing Limited. <https://doi.org/10.1108/978-1-80455-320-620221008>
13. Benos, E., Garratt, R., & Gurrola-Perez, P. (2019). The Economics of Distributed Ledger Technology for Securities Settlement. *Ledger*, 4. <https://doi.org/10.5195/ledger.2019.144>
14. Bhutta, U. S., Tariq, A., Farrukh, M., Raza, A., & Iqbal, M. K. (2022). Green bonds for sustainable development: Review of literature on development and impact of green bonds. *Technological Forecasting and Social Change*, 175, 121378. <https://doi.org/10.1016/j.techfore.2021.121378>
15. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
16. Bužinskė, J., & Stankevičienė, J. (2023). Analysis of Success Factors, Benefits, and Challenges of Issuing Green Bonds in Lithuania. *Economies*, 11(5), 143. <https://doi.org/10.3390/economies11050143>
17. Cao, X., Jin, C., & Ma, W. (2021). Motivation of Chinese commercial banks to issue green bonds: Financing costs or regulatory arbitrage? *China Economic Review*, 66, 101582. <https://doi.org/10.1016/j.chieco.2020.101582>
18. Chen, X., Cheng, Q., & Luo, T. (2022). *The economic value of blockchain applications: Early evidence from asset-backed securities*□.

19. Christodoulou, P. (2023). A blockchain-based framework for effective monitoring of EU Green Bonds. *Finance Research Letters*.
20. Cisar, D., Schellinger, B., Stoetzer, J.-C., Urbach, N., Weiß, F. L., Gramlich, V., & Guggenberger, T. (2025a). Designing the future of bond markets: Reducing transaction costs through tokenization. *Electronic Markets*, 35(1), 9. <https://doi.org/10.1007/s12525-025-00753-3>
21. Cisar, D., Schellinger, B., Stoetzer, J.-C., Urbach, N., Weiß, F. L., Gramlich, V., & Guggenberger, T. (2025b). Designing the future of bond markets: Reducing transaction costs through tokenization. *Electronic Markets*, 35(1), 9. <https://doi.org/10.1007/s12525-025-00753-3>
22. Climate Bonds Initiative. (2024, January 5). *Cumulative value of green bonds issued worldwide between 2014 and 2023, by country (in billion U.S. dollars) [Graph]*. Statista. <https://www-statista-com.tudelft.idm.oclc.org/statistics/1284029/green-bonds-issued-worldwide-by-country/>
23. Climate Ledger Initiative. (2018). *Navigating Blockchain and Climate Action*.
24. Cui, H., Zhou, X., & Luo, Y. (2023). Digital transformation and bond credit spread. *Finance Research Letters*, 58, 104553. <https://doi.org/10.1016/j.frl.2023.104553>
25. De Freitas Netto, S. V., Sobral, M. F. F., Ribeiro, A. R. B., & Soares, G. R. D. L. (2020). Concepts and forms of greenwashing: A systematic review. *Environmental Sciences Europe*, 32(1), 19. <https://doi.org/10.1186/s12302-020-0300-3>
26. Deschryver, P., & De Mariz, F. (2020). What Future for the Green Bond Market? How Can Policymakers, Companies, and Investors Unlock the Potential of the Green Bond Market? *Journal of Risk and Financial Management*, 13(3), 61. <https://doi.org/10.3390/jrfm13030061>
27. DNB. (2023, August 31). *The Netherlands European leader in green bonds*. <https://www.dnb.nl/en/general-news/statistical-news/2023/the-netherlands-european-leader-in-green-bonds/>

28. DNB. (2025). *Total outstanding amount and transactions of debt securities*.
<https://www.dnb.nl/en/statistics/data-search/>
29. Doran, & Tanner. (2019). *Critical challenges facing the green bond market*.
30. EIB. (2024, July 3). *CAB SAB Investor Presentation*. European Investment Bank.
<https://www.eib.org/en/investor-relations/publications/all/eib-cab-sab-presentation>
31. Eloul, S., Satsangi, Y., Zhu, Y. W., Amer, O., Papadopoulos, G., & Pistoia, M. (2025). *Private, Auditable, and Distributed Ledger for Financial Institutes* (No. arXiv:2501.03808). arXiv.
<https://doi.org/10.48550/arXiv.2501.03808>
32. European Commission. (2019). *Report on EU Green Bond Standard*.
33. Fatica, S., Panzica, R., & Rancan, M. (2019). *The pricing of green bonds: Are financial institutions special?* Publications Office. <https://data.europa.eu/doi/10.2760/496913>
34. Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics*, 142(2), 499–516. <https://doi.org/10.1016/j.jfineco.2021.01.010>
35. Flourentzou, P. (2025). *Decentralised Sustainability: Integrating Climate Action into Digital Asset Management on Distributed Ledger Technology (DLT)*.
36. G20 Green Finance Study Group. (2015). *Green Bonds: COuntry Experiences, barriers and options* (G20 Green Finance Study Group).
37. Gardiner, J., & Freke, T. (2024, February 8). Green bonds reached new heights in 2023 | Insights. *Bloomberg Professional Services*.
<https://www.bloomberg.com/professional/insights/trading/green-bonds-reached-new-heights-in-2023/>
38. Green Finance Study Group. (2016). *G20 Green Finance Synthesis Report*.
39. Hachenberg, B., & Schiereck, D. (2018). Are green bonds priced differently from conventional bonds? *Journal of Asset Management*, 19(6), 371–383.
40. Hale, G. B., Jones, P. C., & Spiegel, M. M. (2020). Home currency issuance in international bond markets. *Journal of International Economics*, 122, 103256.
<https://doi.org/10.1016/j.jinteco.2019.103256>

41. Hawn, O., & Ioannou, I. (2016). Mind the gap: The interplay between external and internal actions in the case of corporate social responsibility. *Strategic Management Journal*, 37(13), 2569–2588. <https://doi.org/10.1002/smj.2464>
42. Heines, R., Dick, C., Pohle, C., & Jung, R. (2021). *The Tokenization of Everything: Towards a Framework for Understanding the Potentials of Tokenized Assets*.
43. HSBC. (2019). *Gateway for sustainability linked bonds*.
44. Hyun, S., Park, D., & Tian, S. (2023). The price of frequent issuance: The value of information in the green bond market. *Economic Change and Restructuring*, 56(5), 3041–3063. <https://doi.org/10.1007/s10644-022-09417-0>
45. ICMA. (2022a). *Frequently Asked Question on DLT and blockchain in bond markets*.
46. ICMA. (2022b). *Green Bond Principles*.
47. Jiang, K., Xie, X., Xiao, Y., & Ashraf, B. N. (2024). The value of corporate digital transformation: Evidence from bond pricing. *China Finance Review International*. <https://doi.org/10.1108/cfri-05-2024-0241>
48. Ma, S., & Steininger, B. I. (2025). *Digital Bonds: The Role of Costs and Document Information on Trading Volume*. SSRN. <https://doi.org/10.2139/ssrn.5169398>
49. Malamas, V., Dasaklis, T. K., Arakelian, V., & Chondrokoukis, G. (2024a). A blockchain framework for digitizing securities issuance: The case of green bonds. *Journal of Sustainable Finance & Investment*, 14(3), 569–595. <https://doi.org/10.1080/20430795.2023.2275212>
50. Malamas, V., Dasaklis, T. K., Arakelian, V., & Chondrokoukis, G. (2024b). A blockchain framework for digitizing securities issuance: The case of green bonds. *Journal of Sustainable Finance & Investment*, 14(3), 569–595. <https://doi.org/10.1080/20430795.2023.2275212>
51. Maleki, H. (2023). *Leveraging Blockchain Technology in Green Finance*.
52. Maltais, A., & Nykvist, B. (2020). Understanding the role of green bonds in advancing sustainability. *Journal of Sustainable Finance & Investment*, 1–20. <https://doi.org/10.1080/20430795.2020.1724864>

53. Mecu, A. N., Chițu, F., Hurduzeu, G., Marin, G. I., Li, X., & Charles University, Prague, Czech Republic. (2024, September 9). *Green Bonds in EU Countries: Towards Sustainable Finance*. The International Conference on Economics and Social Sciences. <https://doi.org/10.24818/ICESS/2024/070>
54. Migliorelli, M., & Dessertine, P. (Eds.). (2019). *The Rise of Green Finance in Europe: Opportunities and Challenges for Issuers, Investors and Marketplaces*. Springer International Publishing. <https://doi.org/10.1007/978-3-030-22510-0>
55. Moody's Analytics. (2019). *Moody's Market Implied Ratings Whitepaper*. https://www.moody's.com/sites/products/ProductAttachments/MIR_Methodology.pdf
56. Mutua, C. (2025, January 3). Global Sustainable Bond Sales Reach \$1 Trillion for Second Time. *Bloomberg.Com*. <https://www.bloomberg.com/news/articles/2025-01-03/global-sustainable-bond-sales-reach-1-trillion-for-second-time>
57. Nassiry, D. (2018). *The Role of Fintech in Unlocking Green Finance: Policy Insights for Developing Countries*.
58. Nguyen, P.-H., Thi Nguyen, L.-A., Le, H.-Q., & Tran, L.-C. (2024). Navigating critical barriers for green bond markets using A fuzzy multi-criteria decision-making model: Case study in Vietnam. *Heliyon*, 10(13), e33493. <https://doi.org/10.1016/j.heliyon.2024.e33493>
59. OECD. (2025). *Global Outlook on Financing for Sustainable Development 2025: From Addis Ababa to Seville*. OECD Publishing. <https://doi.org/10.1787/753d5368-en>
60. Ojukwu, P. U., Cadet, E., Osundare, O. S., Fakeyede, O. G., Ige, A. B., & Uzoka, A. (2024). *Advancing Green Bonds through FinTech Innovations: A Conceptual Insight into Opportunities and Challenges*.
61. Park, S. K. (2018). *INVESTORS AS REGULATORS: GREEN BONDS AND THE GOVERNANCE CHALLENGES OF THE SUSTAINABLE FINANCE REVOLUTION*.
62. Parra-Moyano, J., & Ross, O. (2017). *KYC Optimization Using Distributed Ledger Technology*.
63. Pavlidis, G. (2022). The digital transformation of the global green bonds market: New-fashioned international standards for a new generation of financial instruments. In J. Lee & A.

- Darbellay (Eds.), *Data Governance in AI, FinTech and LegalTech* (pp. 263–278). Edward Elgar Publishing. <https://doi.org/10.4337/9781800379954.00020>
64. Petrov, T., Neussner, W., & Lackner, M. (2021). *A Review for Digitalization of the Process Landscape for Proprietary Bond Trading*. 3(6).
 65. Pietsch, A., & Salakhova, D. (2022). *Pricing of green bonds: Drivers and dynamics of the greenium*. Publications Office. <https://data.europa.eu/doi/10.2866/345717>
 66. Pinna, A., & Ruttenberg, W. (2016). Distributed Ledger Technologies in Securities Post-Trading Revolution or Evolution? *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.2770340>
 67. Priem, R. (2020). Distributed ledger technology for securities clearing and settlement: Benefits, risks, and regulatory implications. *Financial Innovation*, 6(1), 11. <https://doi.org/10.1186/s40854-019-0169-6>
 68. Pyka, M. (2023). The EU Green Bond Standard: A Plausible Response to the Deficiencies of the EU Green Bond Market? *European Business Organization Law Review*, 24(4), 623–643. <https://doi.org/10.1007/s40804-023-00278-2>
 69. Ramos Muñoz, D., & Smoleńska, A. (Eds.). (2023). *Greening the Bond Market: A European Perspective*. Springer International Publishing. <https://doi.org/10.1007/978-3-031-38692-3>
 70. Saari, A., Junnila, S., & Vimpari, J. (2022). Blockchain's Grand Promise for the Real Estate Sector: A Systematic Review. *Applied Sciences*, 12(23), 11940. <https://doi.org/10.3390/app122311940>
 71. Sangiorgi, I., & Schopohl, L. (2023). Explaining green bond issuance using survey evidence: Beyond the greenium. *The British Accounting Review*, 55(1), 101071. <https://doi.org/10.1016/j.bar.2021.101071>
 72. Santo, A., Minowa, I., Hosaka, G., Hayakawa, S., Kondo, M., Ichiki, S., & Kaneko, Y. (2016). *Applicability of Distributed Ledger Technology to Capital Market Infrastructure*.

73. Saramago, C. (2023). Using Distributed Ledger Technologies to Disintermediate International Bond Markets: The Good, the Bad and the Ugly. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4318795>
74. Sartzetakis, E. S. (2021). Green bonds as an instrument to finance low carbon transition. *Economic Change and Restructuring*, 54(3), 755–779. <https://doi.org/10.1007/s10644-020-09266-9>
75. Schletz, M., Nassiry, D., & Lee, M.-K. (2020). *Blockchain and Tokenized Securities: The Potential for Green Finance*.
76. Schloesser, T., & Schulz, K. (2022). Distributed Ledger Technology and Climate Finance. In F. Taghizadeh-Hesary & S. Hyun (Eds.), *Green Digital Finance and Sustainable Development Goals* (pp. 265–286). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-2662-4_13
77. Shi, X., Ma, J., Jiang, A., Wei, S., & Yue, L. (2023). Green bonds: Green investments or greenwashing? *International Review of Financial Analysis*, 90, 102850. <https://doi.org/10.1016/j.irfa.2023.102850>
78. Sirikanchana, S. (2020). *Digital Securities and Blockchain Technology: Challenges and Impact on Thai Capital Market in Legal Context*.
79. Statista. (2024). *Green Bonds Worldwide Report*. <https://www-statista-com.tudelft.idm.oclc.org/study/108882/green-bonds-worldwide/>
80. Talbot, K. M. (2017). *What Does ‘Green’ Really Mean?: How Increased Transparency and Standardization Can Grow the Green Bond Market*.
81. Teti, E., Baraglia, I., Dallochio, M., & Mariani, G. (2022). The green bonds: Empirical evidence and implications for sustainability. *Journal of Cleaner Production*, 366, 132784. <https://doi.org/10.1016/j.jclepro.2022.132784>
82. Thanasi Boçe, M., & Hoxha, J. (2024). Blockchain Technology as a Catalyst for Sustainable Development: Exploring Economic, Social, and Environmental Synergies. *Academic Journal of Interdisciplinary Studies*, 13(2), 151. <https://doi.org/10.36941/ajis-2024-0041>

83. The World Bank. (2025). *Labeled Sustainable Bonds Market Update*.
84. Varvasovszky, Z. (2000). A stakeholder analysis. *Health Policy and Planning*, 15(3), 338–345.
<https://doi.org/10.1093/heapol/15.3.338>
85. Walker, T., Turtle, H. J., Kooli, M., & Nikbakht, E. (Eds.). (2023). *Fintech and Sustainability: How Financial Technologies Can Help Address Today's Environmental and Societal Challenges*. Springer Nature Switzerland. <https://doi.org/10.1007/978-3-031-40647-8>
86. Walker, T. (with Turtle, H. J., Kooli, M., & Nikbakht, E.). (2023). *Fintech and Sustainability: How Financial Technologies Can Help Address Today's Environmental and Societal Challenges* (1st ed). Palgrave Macmillan.
87. Wang, T., Liu, X., & Wang, H. (2022). Green bonds, financing constraints, and green innovation. *Journal of Cleaner Production*, 381, 135134.
<https://doi.org/10.1016/j.jclepro.2022.135134>
88. Zhang, X., Aranguiz, M., Xu, D., Zhang, X., & Xu, X. (2018). Utilizing Blockchain for Better Enforcement of Green Finance Law and Regulations. In *Transforming Climate Finance and Green Investment with Blockchains* (pp. 289–301). Elsevier. <https://doi.org/10.1016/B978-0-12-814447-3.00021-5>

Appendix A

