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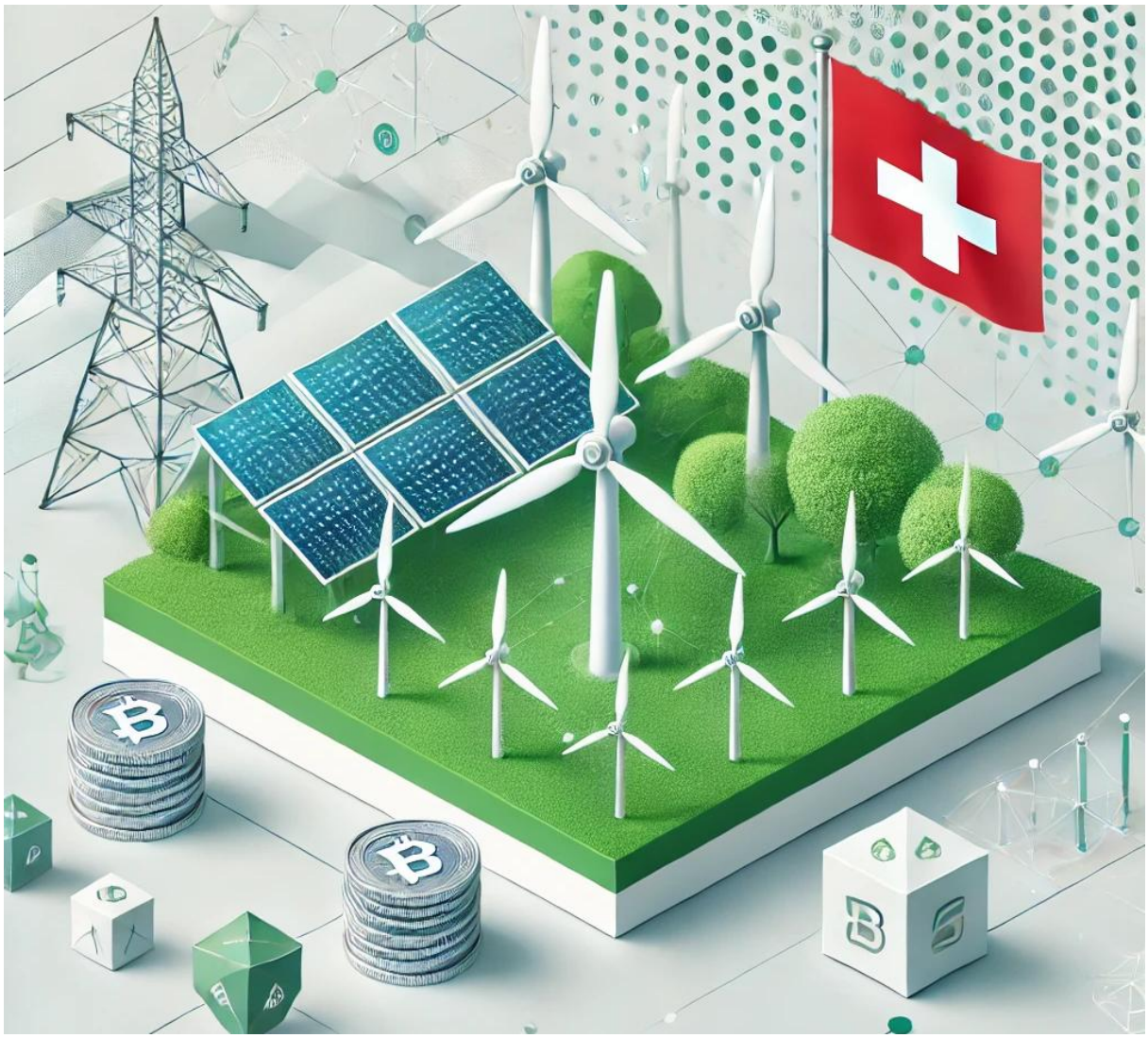
SDF-SET

Swiss Digitalization Framework for the Sustainable Energy Transition — Scaling Green Loans with Decentralized Finance



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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.

Summary

The project focuses on addressing one of the critical challenges of the energy transition: the financing of renewable energy infrastructure. In the context of Switzerland's commitment to achieving its climate goals and supporting the global shift towards a low-carbon economy, this project investigates the potential of digitalized finance powered by blockchain technology to overcome the limitations of traditional finance, more specifically the difference between digitalized versus traditional green investment instruments. The limitations of traditional green investment instruments, such as high transaction costs, long payback periods, and the perceived risk associated with renewable energy projects, have created a significant financing gap that hampers the timely development and deployment of renewable energy projects. The project seeks to explore whether digitalized green investment instruments, with its promise of increased efficiency, transparency, and accessibility, can offer an innovative solution to close this gap.

The objectives of the project are twofold: first, to map out the financing costs associated with green bond issuance in both traditional green investment instruments and digitalized green investment instruments frameworks, and second, to identify the necessary regulatory improvements that would facilitate the scaling up of tokenized green bonds. The approach taken to meet these objectives involved a literature review, surveys, and interviews with key stakeholders along the green finance value chain—originators, distributors, and investors. The research focused on understanding whether digitalized green investment instruments could reduce financing costs and risk premiums for renewable energy projects compared to traditional green investment instruments and whether it could help mobilize new sources of capital for green investments.

Our review of the literature shows that digitalized green investment instruments offer potential advantages in terms of lower transaction costs and improved transparency, which could help reduce the perceived risks associated with green bonds and attract a broader base of investors. The study introduces the concept of "tokenium" as a measure of the risk premium in digitalized financial markets. The findings suggest that regulatory frameworks can be adjusted by embedding disclosure directly into the architecture of the financial instrument to support digitalized green investment instruments. This way tokenized green bonds could become a viable alternative to traditional green bonds, offering new opportunities for financing the energy transition. In conclusion, the project relies on surveys to highlight the critical need for innovative financing mechanisms to bridge the renewable energy funding gap, emphasizing how digitalized green investment instruments—like tokenized green bonds—can reduce costs, enhance transparency, and attract diverse investors, accelerating Switzerland’s transition to a low-carbon economy.

Zusammenfassung

Das Projekt konzentriert sich auf eine der zentralen Herausforderungen der Energiewende: die Finanzierung von Infrastrukturen für erneuerbare Energien. Im Kontext von Schwedens Verpflichtung zur Erreichung seiner Klimaziele und zur Unterstützung des globalen Wandels hin zu einer kohlenstoffarmen Wirtschaft untersucht dieses Projekt das Potenzial digitalisierter Finanzierungen, die durch Blockchain-Technologie unterstützt werden, um die Einschränkungen der traditionellen Finanzwelt zu überwinden – insbesondere den Unterschied zwischen digitalisierten und traditionellen grünen Anlageinstrumenten. Die Einschränkungen traditioneller grüner Anlageinstrumente, wie hohe Transaktionskosten, lange Amortisationszeiten und das wahrgenommene Risiko, das mit Projekten für erneuerbare Energien verbunden ist, haben eine erhebliche Finanzierungslücke geschaffen, die die rechtzeitige Entwicklung und Umsetzung solcher Projekte erschwert. Das Projekt zielt darauf ab zu untersuchen, ob digitalisierte grüne Anlageinstrumente mit ihrem Versprechen erhöhter Effizienz, Transparenz und Zugänglichkeit eine innovative Lösung zur Schließung dieser Lücke bieten können.

Die Ziele des Projekts sind zweifach: Erstens sollen die Finanzierungskosten im Zusammenhang mit der Emission grüner Anleihen sowohl in traditionellen grünen Anlageinstrumenten als auch in

digitalisierten grünen Anlageinstrumenten erfasst werden. Zweitens sollen die erforderlichen regulatorischen Verbesserungen identifiziert werden, die eine Skalierung tokenisierter grüner Anleihen erleichtern würden.

Der zur Erreichung dieser Ziele verfolgte Ansatz umfasste eine Literaturrecherche, Umfragen und Interviews mit zentralen Akteuren entlang der Wertschöpfungskette der grünen Finanzwirtschaft – darunter Emittenten, Distributoren und Investoren. Die Forschung konzentrierte sich darauf zu verstehen, ob digitalisierte grüne Anlageinstrumente die Finanzierungskosten und Risikoprämien für Projekte im Bereich erneuerbarer Energien im Vergleich zu traditionellen grünen Anlageinstrumenten senken können und ob sie dazu beitragen könnten, neue Kapitalquellen für grüne Investitionen zu mobilisieren.

Unsere Überprüfung der Literatur zeigt,, dass digitalisierte grüne Anlageinstrumente potenzielle Vorteile in Form niedrigerer Transaktionskosten und verbesserter Transparenz bieten, was dazu beitragen könnte, die wahrgenommenen Risiken im Zusammenhang mit grünen Anleihen zu verringern und eine breitere Basis an Investoren anzuziehen. Darüber hinaus führt die Studie das Konzept des „Tokenium“ als Maß für die Risikoprämie in digitalisierten Finanzmärkten ein.

Die Ergebnisse legen nahe, dass die regulatorischen Rahmenbedingungen angepasst werden können, indem die Offenlegung direkt in die Architektur des Finanzinstruments eingebettet wird, um digitalisierte grüne Anlageinstrumente zu unterstützen. Auf diese Weise könnten tokenisierte grüne Anleihen zu einer praktikablen Alternative zu herkömmlichen grünen Anleihen werden und neue Möglichkeiten zur Finanzierung der Energiewende bieten. Das Projekt stützt sich auf Umfragen, um den dringenden Bedarf an innovativen Finanzierungsmechanismen zur Überbrückung der Finanzierungslücke im Bereich der erneuerbaren Energien zu verdeutlichen. Dabei wird hervorgehoben, wie digitalisierte grüne Anlageinstrumente - wie Tokenized Green Bonds - die Kosten senken, die Transparenz erhöhen und verschiedene Investoren anziehen können, um den Übergang der Schweiz zu einer kohlenstoffarmen Wirtschaft zu beschleunigen.

Résumé

Le projet se concentre sur l’un des défis critiques de la transition énergétique : le financement des infrastructures d’énergie renouvelable. Dans le cadre de l’engagement de la Suisse à atteindre ses objectifs climatiques et à soutenir la transition mondiale vers une économie bas-carbone, ce projet examine le potentiel de la finance numérisée, alimentée par la technologie blockchain, pour surmonter les limitations de la finance traditionnelle, en particulier la différence entre les instruments d’investissement vert numérisés et traditionnels. Les limitations des instruments d’investissement vert traditionnels, telles que les coûts de transaction élevés, les longues périodes de remboursement et le risque perçu associé aux projets d’énergie renouvelable, ont créé un écart de financement significatif qui entrave le développement et le déploiement rapides des projets d’énergie renouvelable. Le projet cherche à explorer si les instruments d’investissement vert numérisés, avec leur promesse d’une efficacité accrue, d’une transparence améliorée et d’un meilleur accès, peuvent offrir une solution innovante pour combler cet écart.

Le projet poursuit deux objectifs : d’une part, cartographier les coûts de financement liés à l’émission d’obligations vertes, à la fois dans le cadre des instruments d’investissement vert traditionnels et des instruments d’investissement vert numérisés ; d’autre part, identifier les améliorations réglementaires nécessaires pour faciliter l’essor des obligations vertes tokenisées. L’approche adoptée pour atteindre ces objectifs a impliqué une revue de la littérature, des enquêtes et des entretiens avec les principaux acteurs de la chaîne de valeur de la finance verte – émetteurs, distributeurs et investisseurs. La recherche s’est concentrée sur la question de savoir si les instruments d’investissement vert numérisés pouvaient réduire les coûts de financement et les primes de risque pour les projets d’énergie renouvelable par rapport aux instruments d’investissement vert traditionnels et s’ils pouvaient aider à mobiliser de nouvelles sources de capital pour les investissements verts.

Notre analyse de la littérature montre que les instruments d'investissement vert numérisés présentent des avantages potentiels en termes de réduction des coûts de transaction et d'amélioration de la transparence, ce qui pourrait contribuer à réduire les risques perçus liés aux obligations vertes et à attirer une base d'investisseurs plus large. De plus, l'étude introduit le concept de « Tokenium » comme mesure de la prime de risque sur les marchés financiers numérisés.

Les résultats suggèrent que les cadres réglementaires peuvent être ajustés en intégrant la divulgation directement dans l'architecture de l'instrument financier afin de soutenir les instruments d'investissement verts numérisés. De cette manière, les obligations vertes à jetons pourraient devenir une alternative viable aux obligations vertes traditionnelles, offrant de nouvelles possibilités de financement de la transition énergétique. En conclusion, le projet s'appuie sur des enquêtes pour mettre en évidence le besoin critique de mécanismes de financement innovants pour combler le déficit de financement des énergies renouvelables, en soulignant comment les instruments d'investissement verts numérisés - tels que les obligations vertes à jetons - peuvent réduire les coûts, améliorer la transparence et attirer divers investisseurs, accélérant ainsi la transition de la Suisse vers une économie à faible émission de carbone.

Key findings and implications

The Swiss Digitalisation Framework for the Sustainable Energy Transition (SDF-SET) study investigates whether blockchain-based (digitalized) green bonds could offer meaningful advantages in financing renewable energy projects, particularly in terms of reduced transaction costs, lower risk premia, and improved market transparency compared to traditional financial instruments, for issuers of green bonds, financial intermediaries (distributors), and investors. Some key findings and implications are summarized below:

- **Company Size and Focus:** 80% of originators surveyed were **small or medium-sized enterprises** (50% small, 30% medium), and **69% focused on renewable energy**, primarily solar and wind.
- **Green Bond Issuance Costs Are High:** Originators reported **debt issuance costs ranging from USD 50,000 to 200,000**, and average financing closure timelines of **7–8 months**, confirming significant inefficiencies in the traditional issuance process.
- **Preference for Corporate-Level Funding:** A majority of originators preferred **corporate-level funding** over project-specific financing. This was attributed to **greater financial flexibility, reduced transaction costs**, and **broader investor access**.
- **Demand for Immediate Liquidity:** In a scenario offering instant secondary market access, **50% of originators** were willing to **absorb a 20-basis point increase** in cost of capital, showing that immediate liquidity is seen as a high-value feature.
- **Perception of Digital Currency Benefits: 75% of originators** (6 out of 8 respondents to this question) would require a **10 to 30 basis point reduction** in cost of capital to switch from traditional USD settlement to blockchain-based **USD Coin (USDC)** or similar stablecoin payments.
- **Daily Data Sharing Seen as Viable:** When asked about sharing daily project metrics with co-investors, **56% of originators** said they would do so for a **20-basis point reduction** in the cost of capital, and another **22%** would do so for **30 basis points**.
- **No Distributor Participation:** Despite targeted outreach to over **20 financial institutions**, **no responses** were received.
- **High Interest in Digital Green Bonds:** Among 992 investors surveyed, **61% indicated interest** in purchasing tokenized green bonds, with **35% expressing high interest** and **26% moderate interest**, showing strong demand for digital sustainable finance products. Investors with a higher risk tolerance and strong environmental concerns are more inclined to invest in tokenized green bonds.

- **Retail Investors Lead in Innovation Willingness: Retail investors** (approx. 90% of total respondents) were significantly more open to experimenting with **stablecoin settlement**, **non-custodial wallets**, and **real-time impact tracking**, with **48% willing to accept slightly lower returns** for these features.
- **Crypto Experience Drives Adoption:** Among investors with **previous experience in digital assets** (roughly 30% of respondents), **68% expressed willingness** to invest in tokenized green instruments, compared to only **39%** among those with no crypto exposure.
- **Transparency as a Value Driver: 52% of respondents** said they would be more likely to invest in green bonds if they had access to **real-time project metrics** (e.g., via blockchain or oracles), with this figure rising to **64% among investors under 35**.
- **Demographics and Digital Willingness:** Younger investors (age **18–35**, about **42% of the sample**) were nearly **twice as likely** to prefer digital instruments over traditional ones, with **72% of this group favoring tokenized formats** due to accessibility, tech features, and impact verification.
- **Yield Trade-offs for Innovation:** Across the full investor base, **32% of respondents** were willing to accept a **lower yield of up to 0.5%** in exchange for enhanced transparency, faster settlement, and traceability — core benefits of blockchain-based instruments.

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SFOE	Swiss Federal Office of Energy
Blockchain	A decentralized digital ledger that records transactions across a network of computers in a way that makes them secure, transparent, and immutable.
DeFi Protocol	Protocol Rules or standards that govern a specific task or activity within decentralized finance. Digitalized green investment instruments protocols may incorporate rules and principles aligned with real-world institutions to provide financial services to industry participants.
Distributed Ledger Technology (DLT)	A digital system for recording the transaction of assets in which the transactions and their details are recorded in multiple places at the same time. Unlike traditional databases, distributed ledgers have no central data store or administrator.
Real World Assets (RWA)	Digital tokens that represent real-world financial assets such as equity, debt, real estate, and other tangible assets. These assets are tokenized to enable fractional ownership and easier transferability.
Securitization	The process of pooling various financial assets to create a paper or tradable security. It allows the conversion of illiquid assets into liquid, tradable securities.
Smart Contract	A self-executing contract stored on a blockchain-based system, where the terms of the agreement are written directly into lines of code. These contracts automatically govern and enforce the behaviour of tokens based on predefined rules.
Tokenization	The process of converting ownership rights or asset characteristics into a digital token on a blockchain. Tokenization allows for fractional ownership, easier transferability, and increased accessibility to a wider range of investors by representing real world or digital assets as tokens.
Retail Investors	Individual investors who buy and sell securities for their personal accounts, typically in smaller quantities than institutional investors. They invest their personal funds in financial markets.
Originators	Entities or institutions that create or issue financial securities, such as loans or bonds, for the primary purpose of raising capital or transferring financial risks to investors in the markets.
Distributors	Entities that act as intermediaries in the financial system, facilitating the flow of funds between savers and borrowers. They may include banks, brokers, or other financial institutions that distribute financial products to investors.

1. Introduction

1.1. Context and motivation

One of the major challenges in accelerating the adoption and deployment of renewable energy is the difficulty in securing adequate financing (Egli et al., 2018; Kim & Park, 2016; Ozcan, 2021). The traditional financial system (Traditional green investment instruments) often struggles to support renewable energy projects effectively due to a range of inherent limitations, including low efficiency, high transaction costs, and protracted transaction times (Aquilina et al., 2023). These issues collectively contribute to a significant financing gap, impeding the timely development and deployment of essential renewable energy infrastructure (Ferrari et al., 2016).

Renewable energy projects typically require substantial capital investments, both up front and over their lifecycle. Projects such as large-scale solar farms, wind parks, offshore wind turbines, and hydroelectric plants involve high initial costs for equipment, installation, grid integration, and regulatory compliance. This capital intensity can make it difficult for project developers to secure the necessary funding through traditional financial channels, such as banks or institutional investors, which often have rigid lending criteria and risk-averse investment strategies.

Despite growing awareness of the need for sustainable energy and increased commitments to addressing climate change, the allocation of funds to renewable energy projects remains insufficient. While global investment in renewable energy has seen notable growth over the last decade, the current pace of capital deployment is inadequate to meet the rapidly increasing demand for clean energy solutions. According to recent estimates, clean energy investments need to be scaled up by a factor of six to achieve international climate targets and support the transition to a low-carbon economy (International Renewable Energy Agency, 2017).

Several challenges limit the ability of traditional green investment instruments to finance renewable energy projects effectively:

- Long-Term Investment Horizons: Renewable energy projects often require substantial upfront capital and have extended payback periods before generating consistent returns. Many traditional financial institutions prioritize short- to medium-term returns, making them reluctant to commit capital to projects that may take decades to break even (Ferrari et al., 2016). The financing models used in conventional infrastructure investment tend to favor projects with predictable, near-term cash flows, whereas renewable energy developments often depend on external factors such as government incentives or long-term Power Purchase Agreements (PPAs).
- High Transaction Costs and Complexity: The traditional financing process for renewable energy projects, and infrastructure projects in general, is frequently inefficient and costly, involving multiple intermediaries such as banks, rating agencies, underwriters, and regulatory bodies. This multi-layered approach increases overhead expenses and lengthens deal timelines, making financing less accessible (Aquilina et al., 2023). Studies have shown that intermediary costs alone can add 10-15% to the capital expense of renewable projects, making smaller-scale developments particularly vulnerable to cost overruns (Egli et al., 2018; Kim & Park, 2016).
- Perceived Risks and Uncertainty: Traditional lenders often categorize renewable projects as high-risk investments due to their reliance on government policies (e.g., feed-in tariffs, carbon pricing), exposure to fluctuating energy prices, and uncertainties surrounding emerging technologies (Wu et al., 2021). Investors typically demand a higher return to compensate for these perceived risks, driving up the cost of capital for developers.
- Lack of Standardization and Liquidity: Unlike publicly traded asset classes, green investment instruments in renewable energy lack standardized structures, making them difficult to trade in financial markets. Each project has unique financial, technological, and regulatory characteristics, reducing comparability across investments. This illiquidity leads to higher required returns,

as investors expect compensation for the difficulty of exiting their positions before maturity (Bongaarts, 1992; Danish et al., 2017).

- Capital Allocation Challenges: Institutional investors, including pend insurance firms, often face regulatory constraints that limit their exposure to renewable energy assets. Many investment mandates prioritize low-risk, highly liquid securities, which green bonds and infrastructure investments may not satisfy (International Renewable Energy Agency, 2017). As a result, despite growing sustainability commitments, capital inflows remain insufficient to meet the required investment levels of $5–7 trillion annually needed to achieve global clean energy targets.

Traditional green investment models thus suffer from high financing barriers, require approaches to improve efficiency, expand investor participation, and reduce costs. Digitalized green investment instruments have emerged as a potential solution to these challenges, offering greater transparency, automation, and accessibility.

The scale of investment required to meet global renewable energy goals is immense. Estimates suggest that to achieve the United Nations Sustainable Development Goals (SDGs) and facilitate a global energy transition, investments in renewable energy infrastructure will need to be between $5 trillion and $7 trillion annually (Wu et al., 2021). This level of investment is crucial not only to build new renewable energy capacity but also to modernize and expand existing energy infrastructure, develop storage and grid technologies, and support innovation in emerging energy solutions like green hydrogen and energy efficiency.

However, the current financing landscape is not equipped to meet this demand. Although there has been a significant increase in global investment in renewable energy, with institutional investors, governments, and corporations making commitments to sustainability, the overall amount of capital flowing into renewable energy projects still falls short of what is required. Traditional finance mechanisms, due to their inherent limitations, cannot adequately bridge this financing gap alone, making it imperative to explore new and innovative financing models.

To address the challenges of financing renewable energy infrastructure, there is a growing interest in alternative and innovative funding mechanisms. Such mechanisms have the potential to provide more efficient capital flows and open new investment opportunities. The most promising approaches include:

- Green Bonds and Securitization: The issuance of green bonds, which are specifically designated for environmentally beneficial projects, has become a popular tool for raising capital in support of renewable energy. Green bonds provide a means to finance or refinance projects with clear environmental benefits, thereby contributing to sustainability goals (International Capital Market Association, 2018). In addition, the securitization of renewable energy assets—which involves bundling and pooling these assets into tradable financial instruments—can help diversify investment risks and attract a broader base of investors.
- Digitalized investment infrastructure: The rise of a digitalized financial system powered by blockchain technology offers a transformative avenue for renewable energy financing. Digitalized green investment instruments facilitate the creation of new financial products and instruments that are more accessible, transparent, and efficient compared to traditional financial instruments. By leveraging blockchain technology, digitalized green investment instruments have the potential to lower barriers to capital access and provide more flexible funding options for renewable energy developers, bypassing the limitations of traditional financial intermediaries.
- Impact Investing: Increasingly, impact investors—those who seek both financial returns and positive social or environmental outcomes—are directing capital toward e.g., renewable energy projects.
- Crowdfunding: Crowdfunding platforms enable the aggregation of small contributions from individual investors. This democratization of investment unlocks new sources of capital.

When these innovative financing mechanisms are combined with supportive policy frameworks and advancements in renewable energy technology, they have the potential to mobilize the required capital to accelerate the shift towards a sustainable, low-carbon future.

Given the limitations of traditional green investment instruments in facilitating the development and scaling of green projects, a two-pronged solution emerges to bridge the funding gap for renewable energy initiatives: the synergy between green bonds and the digitalized investment instruments model. The nexus of these two components offers a promising avenue to overcome the constraints of the current financial system, attracting a broader investor base to close the financing gap within the renewable energy sector.

Green bonds serve as a financial instrument designed to raise capital for environmental sustainability initiatives and the achievement of Sustainable Development Goals (SDGs). (International Capital Market Association, 2018). However, it is crucial to distinguish between financing and refinancing when considering their impact. Financing implies that new projects receive funding, whereas refinancing merely restructures existing financial commitments without necessarily leading to additional environmental expenditure. As noted by the Swiss government, green bonds are merely a financing tool; any rise in environmental expenditure requires parliamentary approval for additional green projects[1]. The same principle should apply to decentralized finance: ensuring that new, impactful projects are funded rather than simply reallocating existing financial resources. A blockchain-based investment approach may ensure that financing only goes to new projects through the implementation of smart contracts that enforce milestone-based fund releases (such as funds being partly released when feasibility study completed & approved or 50% of plant construction completed), and real-world impact verification via oracles (such as physical sensors that measure the produced electricity of the plant post construction). While this could be done without this technology, the immutable nature of blockchain ensures a single source of truth, preventing any alterations, retroactive changes, or fund misallocation, thereby guaranteeing that financing is directed exclusively toward verifiable new projects rather than refinancing existing ones.

By channeling funds specifically toward environmentally friendly projects, green bonds play a key role in promoting the transition to a low-carbon economy. For instance, (Tolliver et al., 2020) investigate the relationship between green bonds and environmental quality across 66 countries from 2008 to 2017. Their analysis confirms that green bonds have effectively promoted the expansion of renewable energy and reduced emissions. Additionally, (Leitao et al., 2021) assess the influence of green bonds on the behavior of the European Union Emissions Trading System (EU-ETS), highlighting their role in shaping the carbon market dynamics. Furthermore, (Wu et al., 2021) examine the impact of green finance on environmental quality within the E7 and G7 economies, finding that a 1% increase in green finance improved environmental quality by 0.37% in G7 countries and 0.39% in E7 economies.

While green bonds are increasingly prevalent within Traditional green investment instruments, this financial model faces inherent challenges, including information asymmetry, a plethora of intermediaries, and regulatory complexities, all of which hinder the efficient flow of capital to green projects (Aquilina et al., 2023; Uzsoki, 2019). These obstacles can slow down the transition to a sustainable economy and prevent green projects from accessing the funds they need. This underscores the need for a complementary solution in the form of Digitalized green investment instruments. Built on blockchain technology, Digitalized green investment instruments provides a novel alternative to traditional finance. They enable permissionless access to a wide range of financial services without intermediaries, thus reducing friction in the financial system (Schär, 2021).

[1] https://www.efv.admin.ch/efv/en/home/aktuell/a/greenbonds.html

By harnessing smart contracts[2] and tokenization[3], digitalized green investment instruments have the potential to enhance liquidity (Uzsoki, 2019) improve transparency compared to the structures of traditional finance (Takanashi et al., 2020), streamline transaction efficiency (Uzsoki, 2019), and reduce barriers to entry (Cong et al., 2021b). This approach addresses some of the key challenges faced when providing funding, be it equity or debt, towards renewable energy projects through traditional green investment instruments, ultimately fostering a more inclusive and efficient financial ecosystem conducive to sustainable development.

Digital finance innovations—especially blockchain technology and decentralized finance platforms—are increasingly seen as a way to unlock new capital for sustainable energy by addressing the shortcomings of traditional financing. Blockchain's core attributes of transparency, security, and automation can markedly improve the investment process[4]. Recording green assets on a distributed ledger creates an immutable and openly verifiable record, giving investors' confidence that funds are used as intended (e.g. tracking that bond proceeds finance the promised renewable projects). Smart contracts can automate complex processes like bond coupon payments or power purchase agreements, reducing the need for intermediaries and substantially lowering costs. For instance, a recent tokenized green bond issuance in Hong Kong demonstrated how DLT can streamline operations: settlement was completed in T+1 day instead of the typical 5 days, thanks to instant on-chain delivery-versus-payment[5]. The process brought bond issuance, trading, and payment onto a single platform, cutting out reconciliation steps and associated. Such efficiency gains can make sustainable projects more economically viable.

Digital platforms also democratize access to green investments by allowing fractional ownership and lower investment minima. The BIS's Project Genesis pilot showed benefits like low-denomination bonds and app-based investor access, which enable a wider pool of retail investors to participate in financing renewable infrastructure[6]. Early case studies illustrate these advantages: for example, already in 2018, WePower[7] opened up European solar and wind project financing to the general public through blockchain, claiming that end-to-end smart contract execution significantly lowers transaction costs for each deal. Likewise, The Sun Exchange in South Africa uses a blockchain-based micro-leasing marketplace to connect individual investors with solar projects, bypassing traditional banks and their fees.[8] Cross-border solar investments are facilitated with cryptocurrency payments, eliminating intermediaries "at negligible cost" and expanding the investor base globally. These examples underscore how digitalized green investment instruments – through improved transparency, efficiency, and inclusivity – can mobilize new sources of capital for the energy transition that were previously inaccessible or too costly under traditional frameworks.

To investigate whether digitalized green investment instruments could become a viable alternative of Traditional green investment instruments for green project financing, we conduct multi-stakeholder surveys. Our surveys cover the entire financial system value chain, namely all the different actors involved

[2] Smart contracts are self-executing agreements that automate the enforcement and execution of contractual terms on a blockchain without intermediaries, ensuring transparency and security. The interdependency between signing a smart contract—and obtaining the desired information lies in the automated execution of contractual terms. Unlike traditional agreements that require intermediaries for enforcement, smart contracts operate as self-executing programs on a blockchain, ensuring that pre-defined conditions are met before specific actions are carried out. For instance, if a smart contract governs access to a database, digital content, or a service, it will only release the requested information once the stipulated criteria have been satisfied—such as payment, identity verification, or agreement to specific terms.

[3] Tokenization, a core aspect of DeFi, involves converting real-world assets, such as green bonds linked to renewable energy projects, into digital tokens tradable on a blockchain network.

[4] https://www.hkma.gov.hk/eng/news-and-media/insight/2023/02/20230216.

[5] https://www.hkma.gov.hk/eng/news-and-media/insight/2023/02/20230216.

[6] https://www.bis.org/publ/othp43_report2.pdf

[7] https://www.projectfinance.law/blog/2018/january/new-startup-applying-blockchain-to-renewable-energy-financing/

[8] https://www.socialalphafoundation.org/wp-content/uploads/2022/01/saf-blockchain-report-final-2022.pdf

in the process of allocating resources to green projects. In particular, we interviewed originators[9], distributors[10], and investors[11] about their attitudes towards Digitalized green investment instruments. Our focus is on whether the risk premia[12] and cost of financing for a given financing instrument used to fund a renewable energy project differ depending on whether the instrument is issued through the traditional- or digitalized financial system.

The risk premia are an important indicator as it represents the excess return that investors demand as compensation for the uncertainty and potential losses associated with an investment and in the end affects the funding costs of the issuer of a (green) asset. We define the risk premia generated by relying on Digitalized green investment instruments *"tokenium"*. The tokenium will serve as an indicator for whether investors perceive a lower risk when an asset is traded in a decentralized or in a traditional financial system. At the same time, if digitalized green investment instruments have the potential to reduce the cost of financing for originators, it should enable them to undertake additional green investments.

In unlocking the potential of digitalized green investment instruments to spur the transition to a low-carbon economy, the regulatory environment plays a crucial role. We discuss the current stage of the legal framework development for green bonds funding within both the traditional- and digital- financial systems, as well as the limitations in both. When issuing investment instruments backed by green projects, both hard-wired regulatory context, and soft laws, for instance in the form of ESG compliance, need to be considered. However, given a choice between traditional green investment instruments and digitalized green investment instruments, actors involved (originators, distributors, investors) meet even more uncertainties from the legal standards perspective. While traditional green investment instruments relies on the authorities' governance, digitalized green investment instruments evolving governance must rely on three pillars: regulation, self-regulation and peer monitoring, and partnership vis-`a-vis decisions making (Avgouleas & Kiayias, 2020).

1.2. Project objectives

The Swiss Digitalisation Framework for the Sustainable Energy Transition (SDF-SET) project aims to assess whether digitalized green investment instruments can address key limitations of traditional green investment instruments by improving financing efficiency, reducing transaction costs, and enhancing transparency. The study focuses on the potential of blockchain-based finance to streamline capital flows into renewable energy investments and support the scale-up of green finance.

The original objectives of the project were twofold. The first goal was to map out end-to-end financing costs associated with traditional and digitalized green investment instruments, particularly in the issuance of green bonds, to examine differences in transaction fees, cost of capital, and market accessibility. The second objective was to identify regulatory improvements that could facilitate the scaling up of tokenized green bonds, including necessary adaptations in legal frameworks, investor protection mechanisms, and smart contract-based governance.

To achieve these objectives, the study employed a three-phase research approach. The first phase involved a literature review to critically analyze existing research on green finance models, blockchain applications, and financial regulation. The second phase consisted of stakeholder engagement through surveys and interviews with green bond originators, financial intermediaries, and investors to assess market perceptions, regulatory concerns, and the feasibility of tokenization. The third phase focused on

[9] We refer Originators to the entities or institutions that create or issue financial securities for the primary purpose of raising capital or transferring risk in financial markets.
[10] We refer Distributors to the entities that act as intermediaries in the financial system by facilitating the flow of funds between savers and borrowers.
[11] We refer Investors to the individuals who invest their personal. To conduct the investors' survey, the research of Engler et al. (2023) was used as a polar star.
[12] Risk premia is an additional return or compensation that investors require for taking on additional risk compared to a risk-free investment.

empirical financial analysis to evaluate transaction costs, risk premia, and liquidity characteristics of tokenized versus traditional financial instruments, drawing insights from real-world case studies and survey data.

While the project successfully addressed key aspects of these objectives, some areas could only be partially fulfilled due to market constraints and regulatory challenges. The analysis of risk premia, particularly the concept of "tokenium," sought to determine whether investors demand a different risk premium for tokenized green assets. However, the empirical validation of tokenium remains complex due to the nascent state of tokenized bond markets and the lack of sufficient historical data. Preliminary results suggest that investor sentiment is mixed, with some willing to accept lower yields in exchange for improved transparency and liquidity, while others remain cautious due to concerns over regulatory uncertainty and market stability. Further research is needed to track how risk premia evolve as the market matures and as regulatory frameworks become more established.

The study also examined the regulatory environment for tokenized green bonds, identifying key gaps and inconsistencies across jurisdictions. Moreover, despite Switzerland's relative legal maturity, the absence of regulatory harmonization across regions like the EU and U.S. increases perceived risk for issuers targeting cross-border capital. The evolving legal landscape poses challenges for issuers and investors navigating compliance requirements, making it difficult to implement harmonized tokenized green bond standards in the short term. As a result, while the study successfully analyzed existing frameworks and proposed regulatory disclosure improvements for 1) real-time impact reporting, 2) milestones-based fund disbursement, 3) traceable "use-of-proceeds", 4) automated audit trail, and a 5) public digital registry (see section 2.5), full-scale adoption remains contingent on further legal clarity around blockchain-based financial instruments and financial intermediaries infrastructure development.

Stakeholder engagement efforts provided important insights into adoption barriers and market readiness. The study asked for responses from over fifty green bond originators (ten of which responded), twenty financial intermediaries (none of which responded), and one thousand retail and institutional investors (992 respondents). While originators expressed strong interest in digitalized green finance models due to potential cost savings and efficiency gains, financial intermediaries were more reluctant to engage. The limited participation from financial distributors suggests that traditional intermediaries remain hesitant about tokenized models, likely due to uncertainties in regulation, liquidity, and client demand. This highlights the need for broader market education, pilot projects, and clearer regulatory pathways to enhance stakeholder confidence and encourage greater adoption of digitalized green investment instruments.

The research primarily focused on green loans and bond structures designed to fund unlisted renewable energy assets, ensuring that capital flows were directly linked to new infrastructure projects rather than secondary market trading. The findings of our surveys demonstrate significant potential for blockchain-based financing mechanisms to reduce costs and improve transparency: originators reported high issuance costs and long financial closure timelines under traditional models yet showed willingness to adopt digital features—such as stablecoin settlement or automated liquidity access—for relatively modest adjustments in capital cost. In parallel, both originators and investors expressed strong interest in real-time project metrics and impact reporting, suggesting that blockchain-enabled transparency could increase market trust and engagement. However, the study also underscores the need for further development in market liquidity, investor protections, and legal harmonization to achieve the full-scale adoption of digitalized green investment instruments.

By documenting both the achievements and the areas requiring further research, this study provides a comprehensive foundation for ongoing discussions on how digitalization can enhance sustainable finance. It also identifies key policy and market developments that will be necessary to fully realize the potential of blockchain-based green finance models. These include: (1) the establishment of regulatory frameworks that explicitly accommodate blockchain-based settlement and tokenized securities; (2) clearer legal guidance on the use of smart contracts for milestone-based fund disbursement and automated impact reporting. The findings contribute to a growing body of research on the intersection of digital finance and sustainability, emphasizing the importance of continued innovation, regulatory adaptation, and market engagement to support the energy transition.

1.3 Relation to the literature

The projects builds and adds on the existing literature on the comparison between traditional versus digitalized green finance. Traditional financing mechanisms for green bonds and sustainability-linked loans rely on multiple intermediaries, each introducing additional layers of fees and administrative complexity. Conventional bond issuance and settlement require investment banks, underwriters, legal advisors, and custodians, which increases the cost of capital for green projects (Egli et al., 2018; Kim & Park, 2016; Ozcan, 2021). (Ferrari et al., 2016) find that these additional costs can range from 1.5% to 4% of the capital raised, with higher fees disproportionately affecting smaller issuances. The presence of these intermediaries also extends transaction timelines, as traditional bond settlements typically operate on a T+3 to T+5 cycle.

Blockchain-based issuance mechanisms offer an alternative model that removes intermediaries by leveraging smart contracts to automate compliance, interest payments, and asset transfers (Avgouleas & Kiayias, 2020). Empirical evidence from recent tokenized bond pilots indicates that blockchain-based issuance can reduce transaction costs by 30% to 50%, lowering overall financing expenses by up to 1.2 percentage points (Hong Kong Monetary Authority, 2023). The HKMA's tokenized green bond issuance in 2023 reported a reduction in issuance costs of approximately 0.8%, demonstrating how automation and direct settlement can enhance efficiency (HKMA, 2023). These results are consistent with earlier findings from the European Investment Bank's €100 million blockchain bond issuance, which successfully reduced administrative costs and enabled real-time transaction tracking. Similarly, the BIS Innovation Hub's Project Genesis 2.0 demonstrated that smart contract-based carbon credits attached to green bonds can further reduce compliance and reporting costs, improving overall financing accessibility (BIS, 2022).

Liquidity constraints have long been a challenge in green bond markets, as sustainable finance instruments are often structured as buy-and-hold assets with limited secondary market trading. The lack of liquidity contributes to a higher liquidity premium for investors, which, in turn, raises the overall cost of financing for issuers (Danish et al., 2017). In traditional markets, liquidity risk is particularly pronounced in emerging economies, where investors face additional regulatory hurdles and operational inefficiencies when attempting to exit investments (Wu et al., 2021). Tokenization of green assets provides a potential solution by enabling fractional ownership and broader investor participation. Tokenized bonds can be listed on decentralized trading venues, allowing for peer-to-peer transactions and 24/7 market access. Real-time settlement further reduces counterparty risks and minimizes bid-ask spreads, making it easier for investors to trade these assets without incurring significant losses due to market illiquidity.

Recent case studies support these findings. A study on liquidity premia in digital assets reveals that tokenized bonds exhibit bid-ask spreads that are 5% to 10% tighter than their traditional counterparts (Engler et al., 2024). In Hong Kong's pilot tokenized green bond issuance, the ability to issue and settle transactions instantaneously resulted in increased investor demand, particularly among retail and impact-focused institutional investors (HKMA, 2022). Evidence from green bond ETFs further reinforces the idea that demand for more liquid sustainable finance products is rising, suggesting that the ability to fractionalize green bond investments through blockchain technology could significantly enhance market depth.

Beyond financing costs and liquidity, risk premia play a crucial role in determining investor appetite for green investment instruments. The yields on traditional green bonds are influenced by several factors, including creditworthiness, liquidity risk, and policy support for sustainable finance initiatives. Many studies have found that traditional green bonds enjoy a pricing advantage, often referred to as the "greenium," where investors accept slightly lower yields due to strong demand for sustainability-oriented assets (Danish et al., 2017; Wu et al., 2021). However, the impact of digitalization on risk premia remains an area of ongoing research.

2. Approach, method, results and discussion

We conduct a multi-stakeholder interview along the value chain of the securitization industry (Engler et al., 2024) to investigate whether Digitalized Green Investment Instruments could reduce frictions in the financial system. In particular, we assess whether the risk premia required by investors differs between Traditional Green Investment Instruments and Digitalized Green Investment Instruments when applied to the same underlying assets. We introduce the term “tokenium” to define the risk premia differential attributable to issuing an asset via blockchain rather than traditional financial mechanisms.

Several key aspects influence the cost of financing, investor willingness, and the comparative attractiveness of these two financing mechanisms. Empirical research has demonstrated that tokenized financial instruments can potentially lower transaction costs, improve liquidity, and streamline the investment process for sustainable energy projects (Finews, 2023; Engler et al., 2024). However, the extent of these benefits is still under investigation, as the adoption and regulatory frameworks of digitalized finance evolve.

To explore stakeholder perspectives on digitalized green investment instruments, we conducted open-ended surveys targeting three key groups in the green finance value chain: green bond originators, financial distributors, and investors. The aim was to gather insights into their experiences, expectations, and concerns regarding tokenized financial instruments, including attitudes toward asset tokenization and the potential use of cryptocurrencies for settlement. The surveys were designed to surface opportunities and barriers from the viewpoint of each stakeholder group, rather than to validate pre-defined hypotheses. Sections 2.2, 2.3, and 2.4 describe the design and focus of each survey in detail, along with the resulting findings. The approach was informed by the stakeholder framework used in Engler et al. (2024), which served as a methodological reference point.

We engaged over 50 originators and 20 distributors globally through direct and partnership efforts facilitated by the Enterprise for Society (E4S) network. Originators featured prominent Swiss entities like Axpo and Alpiq. Notable distributor entities involved include Vontobel, Zürcher Kantonalbank, UBS, and others. However, despite multiple outreach efforts, only 10 originators responded to the survey, and none of the distributors participated. Additionally, we conducted a large-scale survey with approximately 1,000 end investors.

We sought to identify pain points and willingness to pay premiums for blockchain-based options, given its regulatory compliance for claim and asset transfers. However, before we delve into the setup of our study, we briefly revisit the current state of the discussion about traditional vs digitalized green finance.

2.1. Comparing Financing Costs and Risk Premia: Traditional vs. Digitalized Green Finance

To rigorously assess the viability of tokenized green finance, this study examines key aspects influencing financing costs, liquidity, and risk premia. The primary research objective is to determine whether digitalized green investment instruments reduce transaction costs, improve market liquidity, and lower financing risk compared to traditional green bonds and loans.

Empirical research suggests that tokenized financial instruments have the potential to lower transaction costs and streamline the investment process. To better understand this dynamic, this study introduces the concept of "tokenium," which represents the risk premium differential between tokenized green investment instruments and traditional green bonds. If digitalization enhances liquidity, transparency, and automation, investors may demand lower returns, resulting in a negative tokenium that reduces the cost of capital. Conversely, if investors perceive blockchain-based securities as riskier due to regulatory uncertainty, cybersecurity concerns, or market immaturity, tokenium may be positive, requiring issuers to offer higher yields to attract investment.

In what follows we present the originators, distributors and investors surveys and discuss our findings. Survey data reveals a clear divergence in investor attitudes toward tokenized green instruments. Retail

investors and technology-driven investors demonstrate a higher willingness to invest in tokenized green assets, often accepting lower yields in exchange for greater transparency and real-time tracking of environmental impact. These investors' view blockchain-based green finance as an innovative mechanism for ensuring that sustainability-linked bonds achieve their intended environmental outcomes. Institutional investors, however, remain more cautious, citing concerns about regulatory clarity and the lack of long-term performance data for tokenized securities. Their hesitancy is consistent with broader trends observed in digital asset markets, where large institutional investors often require a more established legal and operational framework before committing capital at scale (Finews, 2023). Government-backed digital bond pilots, such as those conducted by the HKMA and BIS, have demonstrated that regulatory endorsement can help mitigate these concerns. As market infrastructure stabilizes and clear legal guidelines emerge, institutional adoption of tokenized green finance instruments is expected to increase, potentially leading to a further decline in tokenium.

2.2. Originators survey

In this survey, originators are defined as the legal entities that receive the proceeds from a green bond—effectively acting as borrowers—to raise capital for environmentally sustainable projects. This study focused on a series of in-depth interviews with ten originators who possess significant expertise in the renewable energy and energy efficiency sectors. The selection of participants was based on rigorous criteria, ensuring that interviewees held senior roles such as finance directors, investment strategists, or project leads and had at least five years of professional experience in the space of financing sustainable projects. Their companies, all of which are for-profit business entities, operate within renewable energy and/or energy efficiency markets, with a strategic focus on scaling up sustainable investments through financial innovation.

By engaging with experienced industry professionals, this study directly contributed to the project's first objective: mapping out end-to-end financing costs associated with traditional versus digitalized green investment instruments. Through the originator survey, we collected empirical data on financial structuring, capital allocation strategies, and the perceived barriers to issuing green bonds. In line with the second objective—identifying regulatory improvements needed to scale tokenized green bonds—the survey also examined whether originators view tokenized instruments as a viable alternative, and how they evaluate the associated cost savings, liquidity enhancements, and regulatory uncertainties. These insights help contextualize how digital issuance models might address financing inefficiencies across the green finance value chain.

Table 1: Socio-demographic responses for the Originator survey is shown in the below table.

	Count	***%***
What is your corporate classification?		
Nonprofit corporation	1	*10*
Public / government entity	0	*0*
Business corporation	9	*90*
What stage of projects does your company target?		
Development	2	*20*
Operating	1	*10*
Both	7	*70*
What is your company's technology focus? *More than one answer is applicable*		
Renewable energy	9	*69*

Energy efficiency solutions (e.g., waste-to-energy)	4	*31*
Green building	0	*0*
Electric transportation	0	*0*
Carbon removal	0	*0*
Other	0	*0*
What is the size of your company?		
Small (less than 100 employees)	5	*50*
Medium (less than 250 employees)	3	*30*
Large (more than 250 employees)	2	*20*

As the table above suggests, the survey participants represented a diverse group of green bond originators, primarily composed of for-profit business corporations rather than public or nonprofit entities. The vast majority of respondents, 90%, were private companies focused on renewable energy and energy efficiency projects, while only 10% operated as nonprofit organizations. Notably, no public or government entities participated in the survey, indicating that the issuance of green bonds remains largely driven by private-sector initiatives rather than direct government-led efforts.

The respondents' project focus was distributed across different stages of development. While 20% of companies specialized solely in early-stage project development, the majority, 70%, were involved in both development and operational phases, suggesting that most originators prefer to maintain long-term involvement in the lifecycle of their renewable energy assets. Only 10% exclusively managed operational projects, which may indicate that firms see greater financial and strategic advantages in controlling both the development and post-construction phases of their investments.

In terms of technological specialization, nearly 70% of respondents were engaged in renewable energy generation, primarily in sectors such as solar and wind energy. A smaller proportion, 31%, focused on energy efficiency solutions, including waste-to-energy technologies and demand-side efficiency innovations. Interestingly, none of the respondents reported activities in green building, electric transportation, or carbon removal, highlighting a predominant focus on electricity generation rather than broader decarbonization strategies.

The participating companies varied in size, but the majority fell into the small to medium-sized enterprise (SME) category, with 50% employing fewer than 100 people and an additional 30% categorized as medium-sized firms with 100 to 250 employees. Only 20% of respondents represented large enterprises with more than 250 employees. This suggests that the green bond market is not dominated by large corporations but instead features a strong presence of mid-sized and smaller firms seeking alternative financing solutions to scale their renewable energy initiatives.

Most companies surveyed operated on an international scale, with a particular emphasis on projects within Europe and Africa. Their activities spanned both development and operational phases, underscoring the importance of long-term investment strategies in the renewable energy sector. To better understand their financial structures and capital allocation strategies, the survey also examined the roles and decision-making responsibilities of key personnel within these firms. The interviews revealed that senior finance and strategy executives are the primary drivers behind green bond issuance decisions, reflecting the central role of financial expertise in structuring sustainable investment instruments.

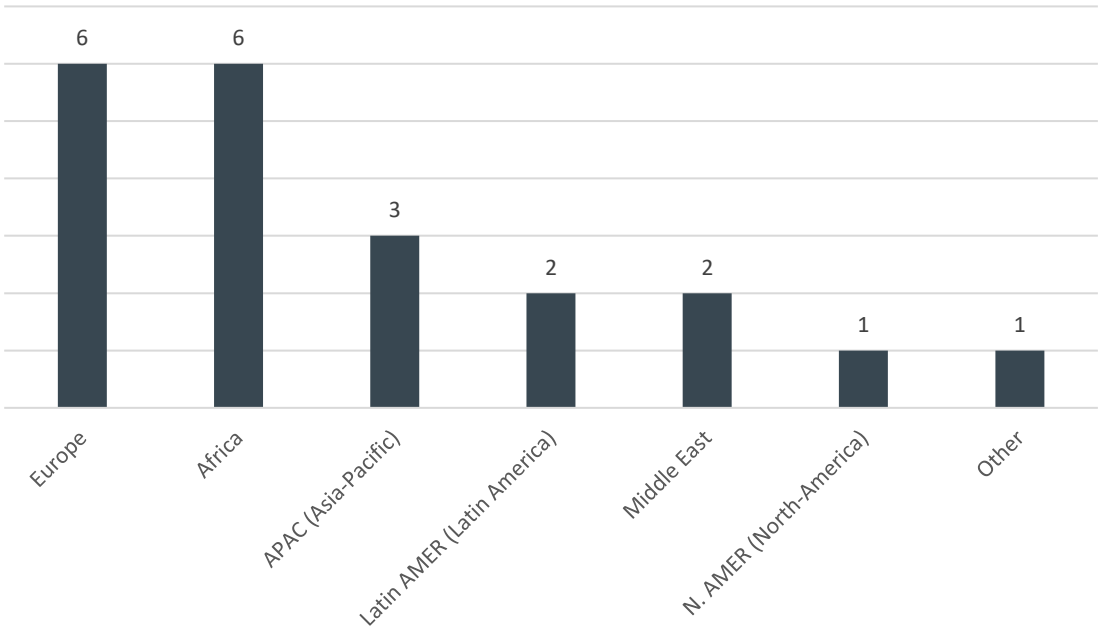

Figure 1: Originator Survey on their regional focus for project origination (number of respondents). Source: authors.

In discussing asset and portfolio management, participants provided details on the types of assets they manage, their portfolio compositions, and the strategies they employ, particularly in relation to renewable energy financing. The study examined structuring and underwriting processes to identify best practices in formulating financial products such as green bonds. Additionally, finance workflows were analyzed to highlight crucial phases in capital deployment, the integration of sustainability objectives, and the metrics used to measure impact.

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A key finding from the survey (Table 2 reports the results) was that four out of ten originators expressed a strong preference for using green bonds as their primary debt financing instrument, underscoring the role of capital markets in financing sustainable projects. Capital market investors were favored due to their ability to offer lower financing costs, allowing originators to bypass traditional illiquidity constraints often faced when relying on bank lending. However, despite the attractiveness of green bond financing, high issuance costs and protracted financial closure periods remain major bottlenecks. Hence, the results inform the comparison of the costs of traditional versus digitalized green investment instruments. Moreover, the preference for green bonds as a primary financing tool supports the importance of exploring digitalized green investment instruments (e.g., tokenized green bonds) as a way to reduce costs, improve liquidity, and streamline the financing process. Finally, the bottlenecks identified (high costs and long timelines) point to the need for regulatory and technological innovations to make green financing more accessible and efficient, which aligns with the project's objective of identifying necessary regulatory improvements to scale tokenized green bonds.

Table 2: Cost of capital delta: determinants of imposing Digitalized green investment instruments characteristics on Originators project financing is shown in the below table.

Suppose there is a cost to the project entity to provide daily indicators to the co-investors. How much would you expect the cost of capital would decrease to provide these metrics? *Assume that the cost of capital is 5.0%.*	**Count**	**%**
0 pp – we would not be interested in sharing daily reporting indicators	1	11
10 pp – the cost of capital goes **down** to 4.90%	0	0
20 pp – the cost of capital goes **down** to 4.80%	5	56
30 pp – the cost of capital goes **down** to 4.70%	2	22
>30 pp – the cost of capital goes **below** 4.70%	1	11

Suppose there is a premium option that allows the project entity to trade in its own bond (i.e., participate in the secondary market) instantly w/o delay. How much increase in the cost of capital would you be willing to absorb to attain this feature? *Assume that the cost of capital is 5.0%.*	**Count**	**%**
0 pp – we are not interested in the immediate liquidity	1	13
10 pp – the cost of capital goes **up** to 5.10%	1	13
20 pp – the cost of capital goes **up** to 5.20%	4	50
30 pp – the cost of capital goes **up** to 5.30%	1	13
>30 pp – the cost of capital goes **above** 5.30%	1	13

By how much does your company require the cost of capital to be reduced for settling the bond using USD-coins (digital currency equivalent to USD), compared to a traditional/USD-denominated settlement?[13] *Assume that the cost of capital is 5.0%.*	**Count**	**%**
0 pp – we do not require any reduction in the cost of capital	2	25
10 pp – the cost of capital goes **down** to 4.90%	2	25
20 pp – the cost of capital goes **down** to 4.80%	2	25
30 pp – the cost of capital goes **down** to 4.70%	1	13
>30 pp – the cost of capital goes **below** 4.70%	1	13

Strategic Financing Preferences: Corporate vs. Project-Level Funding

A central theme emerging from the survey was the preference for corporate-level funding over project-specific financing. Most respondents indicated that they prioritize securing funds at the parent-entity level rather than issuing debt tied to individual projects. This preference aligns with broader trends in sustainable finance, where large-scale issuers increasingly favor corporate-level green bonds over traditional project finance structures.

There are several reasons why corporate-level funding is preferred. First, it offers greater financial flexibility. Instead of restricting capital to a single project, corporate-level bonds allow firms to reallocate

[13] This question assesses how much financial incentive (in terms of reduced capital costs) a company would require switching from traditional USD settlements to blockchain-based stablecoin settlements (e.g., USDC) for green bonds. It aims to measure corporate willingness to adopt digital currency payments by evaluating perceived risks, cost-saving expectations, and potential barriers to adoption.

proceeds across multiple renewable energy initiatives, depending on strategic priorities and investment opportunities. This is particularly advantageous in sectors where projects have varying capital expenditure timelines, such as solar and wind energy. Academic research supports this preference, showing that issuers who operate at the corporate level benefit from lower financial constraints and greater adaptability in capital allocation (Busch et al., 2021).

Second, corporate financing typically leads to lower administrative and transaction costs. Unlike project-specific bonds, which require bespoke risk assessment and underwriting processes, corporate green bonds spread risk across a diversified asset portfolio, reducing the due diligence burden on investors. Studies indicate that corporate green bonds often trade at tighter spreads than project bonds, as investors perceive them to be backed by a more stable financial structure (Dorfleitner et al., 2022).

Third, corporate bonds provide broader access to capital and better credit ratings. In project finance, investors assess only the risks and returns of a specific asset, whereas corporate bonds are backed by the issuer's entire balance sheet. This means corporate green bonds are more likely to secure investment-grade ratings, allowing issuers to borrow at lower interest rates. Research by (Bachelet et al., 2019) suggests that corporate green bonds enjoy stronger demand and lower risk premia than their project-level counterparts.

The preference for corporate-level funding also has implications for the design of tokenized green bonds. If digitalized financial instruments are to replace traditional green bonds, they should be structured in ways that support flexible capital allocation, rather than being limited to single-asset financing models. Tokenized instruments may offer an opportunity to replicate the flexibility of corporate-level finance while enhancing liquidity and transparency, which are key challenges in the current market.

Funding Costs and Financial Bottlenecks in Green Bond Issuance

A significant obstacle identified by survey respondents was the high transaction costs associated with green bond issuance. On average, participants reported that financial closure takes between seven and eight months, a timeline that aligns with broader findings on slow and expensive financing processes in green finance (Egli et al., 2018).

Issuance costs were found to be highly variable. Equity funding-related expenses, including legal, tax, and accounting fees, as well as auditor costs, were generally below $50,000, while debt financing costs ranged from $50,000 to $200,000. This aligns with previous research indicating that green bond issuance costs are often 15-30% higher than those of conventional bonds, due to additional compliance, verification, and certification requirements (Flammer, 2021).

Comparative studies suggest that traditional green bond issuance timelines are significantly longer than what is possible with blockchain-based bond issuance models. For example, a 2023 report by the Hong Kong Monetary Authority (HKMA) found that tokenized bond issuance could reduce issuance costs by up to 50% and shorten settlement times from T+5 days to T+1 day (HKMA, 2023). Similar findings were reported in pilot studies by the Bank for International Settlements (BIS), which demonstrated that tokenized green bonds could be issued in under a week, significantly improving capital deployment timelines (BIS, 2022). While these examples stem from specific jurisdictions, the underlying blockchain infrastructure is borderless by design. Because national clearing systems do not bind settlement processes on distributed ledgers, the observed efficiencies—such as faster settlement and reduced intermediary overhead—are technically replicable across geographies, including Switzerland. This reinforces the relevance of digital issuance models for jurisdictions facing similar cost and time barriers, as highlighted by our survey respondents.

The findings from this survey reinforce the idea that digitalized green investment instruments have the potential to address cost inefficiencies in traditional green finance. If issuers can lower their financing costs by 1-2 percentage points, as some case studies suggest, this could make green bonds more accessible to mid-sized renewable energy firms that currently struggle with high issuance costs.

Risk Premia ("Tokenium") and Investor Perceptions of Tokenization

Another core area of investigation was the perceived risk premium of tokenized green bonds, referred to in this study as "tokenium." The survey explored whether originators believe that issuing bonds on blockchain would reduce or increase the cost of financing, based on investor demand.

Participants expressed divergent views on tokenium. Some anticipated lower borrowing costs, arguing that enhanced transparency and liquidity in tokenized markets could lead to tighter credit spreads. Empirical studies support this idea—data from HKMA (2023) found that tokenized green bonds achieved an average yield reduction of 0.78 percentage points compared to similar traditional bonds.

However, others raised concerns about potential risk premiums, citing regulatory uncertainty, investor unfamiliarity, and technological risks as possible barriers to adoption. This is consistent with broader market trends: while some institutional investors have begun exploring tokenized debt markets, others remain hesitant due to operational and compliance risks (EY-Parthenon, 2023).

The survey also revealed that greater transparency in reporting could help mitigate perceived risks. If financial instruments were structured to automatically share real-time sustainability metrics with investors, 56% of originators stated they would accept a 20-basis-point reduction in the cost of capital. Many also expressed interest in using digital currency for payments, indicating that they would settle transactions on the blockchain if it lowered financing costs by 15.6 percentage points. Additionally, originators would accept a 14.3 percentage point increase in the cost of capital in exchange for improved liquidity, highlighting that they value the ability to trade financial instruments more freely in secondary markets.

Findings from the originator survey and their relevance to financing cost mapping

The objective of the project was to compare end-to-end financing costs of traditional vs. digitalized green investment instruments, focusing on transaction costs, risk premia ("tokenium"), and operational efficiency. The originator survey contributes directly to this goal by offering empirical insights from 10 experienced issuers of green bonds. Key findings are:

Originators expect cost of capital reduction from investors for increased transparency
• 56% of originators would accept a 20-basis point (0.2%) cost reduction in return for daily sustainability metric sharing. • Another 22% would do so for a 30-basis point reduction.

Originators are willing to pay a premium to attained liquidity for their issued bonds
• 74% of originators were willing to accept a 10–30 basis point increase in cost of capital in exchange for immediate secondary market liquidity.

Originators expect clear cost advantage from digital currency settlement
• 75% of originators said they would require a 10–30 basis point reduction in cost of capital to adopt stablecoin (USDC) settlement instead of USD.

By detailing the costs, perceived risks, and benefits associated with both traditional and digitalized instruments, the originator survey directly supports the mapping of end-to-end financing costs—

highlighting how digital green bonds could influence risk premia and originators' willingness to pay for blockchain-based features. The strong appetite for secondary market liquidity, coupled with the expected reduction in capital costs through enhanced transparency and digital currency settlement, underscores a growing awareness among originators of how innovative financing models and infrastructure shifts can reshape financing dynamics.

2.3. Distributors survey

Distributors play a critical role in the green finance value chain, acting as intermediaries between green bond originators and investors. Their engagement is essential for expanding market access, improving liquidity, and ensuring the successful placement of sustainable investment products. Given their central role, this study sought to examine the perspectives of distributors on digitalized green investment instruments, particularly regarding asset tokenization, cost of capital implications, and balance sheet allocation between brown and green assets.

The survey aimed to assess the level of interest among financial distributors in tokenized green bonds and to identify potential barriers to adoption. A key research question was whether distributors perceive differences in the cost of capital between Traditional Green Investment Instruments and Digitalized Green Investment Instruments. Additionally, the study sought to explore the composition of bank balance sheets, investigating how distributors allocate capital across traditional green assets versus tokenized sustainable investments.

The discussions focused on the potential cost efficiencies that financial intermediaries could realize by integrating blockchain-based solutions into their workflows for storage, settlement, and distribution of green bonds. Given the growing emphasis on financial digitalization, the study was designed to capture the extent to which distributors recognize blockchain as an enabler of efficiency and liquidity in sustainable finance.

Despite extensive engagement efforts, including outreach to over 20 financial distributors, the study was unable to secure any survey responses. This outcome highlights significant challenges in engaging financial intermediaries on emerging financial technologies, suggesting that distributors may currently perceive limited relevance or urgency in exploring digitalized green investment instruments. The absence of participation may also reflect broader barriers identified in academic research, including regulatory uncertainty, operational risks, and a perceived lack of immediate relevance of blockchain applications in certain financial services.

Regulatory Uncertainty as a Key Barrier

One of the primary barriers to blockchain adoption in financial distribution is regulatory uncertainty. The evolving nature of blockchain-based investment instruments often outpaces the development of comprehensive regulatory frameworks, making financial institutions hesitant to engage due to compliance risks (Jena, 2022). Many distributors are bound by stringent know-your-customer (KYC) and anti-money laundering (AML) regulations, and without clear legal recognition of tokenized securities, they may avoid engaging with these assets altogether.

Existing research suggests that financial intermediaries tend to adopt a wait-and-see approach when faced with regulatory ambiguity, preferring to operate within well-established compliance frameworks rather than risk exposure to uncertain legal conditions (Kaur et al., 2023). The lack of clear regulatory guidance for digitalized green bonds may therefore be a primary factor behind distributors' lack of engagement in this study.

Operational and Technological Challenges in Blockchain Integration

Another significant factor limiting distributor participation may be the operational complexities associated with integrating blockchain-based solutions into existing financial systems. Adopting blockchain technology requires substantial changes to settlement, custody, and compliance mechanisms, which can be resource-intensive and complex (Kaur et al., 2023). Unlike traditional green bonds, which rely on

centralized clearing systems, tokenized bonds necessitate new infrastructure for digital custody, smart contract execution, and decentralized identity verification.

Academic literature suggests that financial institutions only adopt blockchain-based models when clear cost-saving benefits can be demonstrated (Nakhcha and Tlaty, 2023). Since the tokenized green bond market remains in its early stages, distributors may not yet see a compelling business case for transitioning to blockchain-based distribution, particularly if their current processes are functioning effectively. This aligns with findings from other sectors, where blockchain adoption has been hindered by legacy system incompatibilities and limited internal expertise in digital asset management.

Perceived Lack of Immediate Market Relevance

Beyond regulatory and operational challenges, distributors may also perceive limited immediate relevance of digitalized green investment instruments. Studies on blockchain adoption in financial markets indicate that many intermediaries remain skeptical about the scalability of tokenized bonds, particularly given that traditional green bond markets are still growing (Ibrić et al., 2024). Distributors may prefer to wait for institutional investor demand to materialize before adjusting their business models.

Additionally, previous studies highlight that financial intermediaries often act as gatekeepers, influencing the flow of capital based on client demand (Jena, 2022). If institutional clients do not explicitly request tokenized bonds, distributors may deprioritize their adoption. This perspective aligns with survey findings from institutional investors, where regulatory clarity and risk perception remain key concerns before widespread adoption of tokenized securities can occur (Kaur et al., 2023).

Implications for This Study and Future Research Directions

As a result, this lack of input from distributors represents a notable gap in the study, limiting the ability to fully compare stakeholder perspectives across the green finance ecosystem. While the study successfully gathered insights from originators and investors, the perspective of financial intermediaries remains underexplored, which could be an important area for future research. This limitation underscores the need for further engagement with banks, asset managers, and financial intermediaries to understand how tokenization might integrate into existing distribution networks and whether regulatory frameworks need to evolve to support the adoption of digitalized green finance.

Although the absence of distributor responses prevented a complete validation of cost differences between traditional and digitalized models, the findings from the originators and investors' surveys provide valuable insights into potential efficiency gains and market appetite. Future studies could explore alternative engagement strategies—such as structured interviews or industry roundtables—to better capture distributor perspectives on the potential benefits and risks of tokenized green bonds.

By incorporating these academic insights, the study highlights the broader industry challenges facing the integration of tokenized green finance into existing financial markets. Understanding these barriers is crucial for developing strategies to effectively involve financial intermediaries in future research and implementation efforts related to blockchain and sustainable finance.

2.4. Investors survey

Retail investors refer to individuals who invest (professionally or privately) in stocks, bonds, or other securities for their personal investment portfolios. Digitalized green bonds represent a novel financial instrument with substantial potential to channel additional investments toward renewable energy projects, supporting broader sustainability goals (Sangiorgi & Schopohl, 2021)[14]. Despite their theoretical appeal, digital green bonds currently remain rare within both institutional and retail investor portfolios, primarily due to limited familiarity, regulatory uncertainties, and perceived operational risks (Deloitte,

[14] Sangiorgi and Schopohl (2021) conducted a survey of European asset managers and analyzed results by country and size of firm – finding that country-specific factors and the presence of an ESG policy at the firm significantly influenced green bond allocations

2023)[15]. This relative novelty complicates understanding investor preferences, necessitating targeted empirical analysis.

To clarify investor attitudes toward green bonds, digital assets, and specifically digitalized green bonds, we conducted a comprehensive online survey of retail investors. The initial outreach successfully reached 992 investors. From this initial respondent pool, we conducted rigorous data quality screening, excluding approximately 5% of respondents who failed attentiveness checks. Additionally, we excluded respondents who declined to specify their educational level or provided inconsistent responses throughout the survey, totaling less than 1% of the sample. This screening process yielded 821 valid responses suitable for analyzing preferences related to green bonds, digital assets, and digital bonds, with a subset of 763 respondents specifically analyzed for digital green bonds.

The survey methodology employed a two-tiered approach utilizing Prolific, an academically-founded online research platform co-founded at Oxford University. The first survey adopted a broader scope, engaging respondents from 39 different countries to capture a diverse range of investor profiles and experiences. The second survey, however, had a more targeted approach, specifically selecting respondents with advanced knowledge or experience in green bonds and related digital investments. Participants were carefully screened based on explicit criteria, justified by prior academic research indicating these factors' relevance in shaping investor preferences. These criteria included educational background—ranging from undergraduate to doctoral degrees—given the documented association between education level, financial literacy, and openness to complex financial instruments (Engler et al., 2024). Respondents were further screened based on their experience using financial trading platforms (e.g., eToro, Robinhood) and cryptocurrency exchanges (e.g., Binance, Coinbase), reflecting findings that prior investment experience is positively correlated with openness to digitalized investments (Riedl & Smeets, 2017).

Participants were selected from specific geographic regions (primarily Europe and North America), ensuring representative coverage of investors from markets with advanced financial infrastructure and growing interest in sustainable finance. Additionally, respondents were required to have previous experience in equity investment and to occupy roles involving financial decision-making or relevant business expertise, such as financial advisors, portfolio managers, traders, or data scientists. This requirement was implemented to ensure that respondents possessed a baseline level of familiarity with financial markets, enhancing the validity and reliability of their expressed preferences regarding innovative financial instruments. Furthermore, given the role of behavioral and social preferences documented in the sustainable finance literature (Riedl & Smeets, 2017), respondents were screened based on their expressed concern for environmental issues and their beliefs in climate change solutions. Such attitudes have consistently been identified as key predictors of investors' willingness to engage in sustainable investing (Heeb et al., 2021).

The survey was systematically structured into distinct sections to capture nuanced aspects of investor preferences. Sections 1 and 2 explored investor perceptions of ESG metrics and foundational principles of sustainability investing. Section 3 investigated preferences regarding investment platforms. Sections 4 and 5 specifically examined investor attitudes towards green bonds and digital bonds using hypothetical investment scenarios designed to elicit investors' explicit willingness to pay for various digitalized features. These features included enhanced transparency, improved liquidity (instant bond trading capabilities), and the option to denominate bonds in digital currencies. We posited that these attributes, enabled by blockchain technology, would address commonly cited limitations of traditional bonds, such as information asymmetry and illiquidity (HKMA, 2023). The final section (Section 6) gathered socio-demographic data to facilitate a detailed segmentation analysis of investor trends.

Furthermore, the survey examined preferences for digitalized investment. In a nutshell, we presented investors with features of green bonds that could be achieved only through digitalized financial system. As we presented such features, we only proposed them as possibilities, without mentioning that they could not be offered through the traditional financial system (and that a digitalized financial infrastructure would be necessary). Such features are a specific degree of increased transparency, enhanced liquidity,

[15] See https://www2.deloitte.com/content/dam/Deloitte/us/Documents/audit/us-green-bonds-pov.pdf

and holding the bond in digital currency. We assumed for this study that these features could be achieved with digitalized finance. It also explored the extent to which investors would be willing to pay a premium for these benefits. Through these detailed investigations, the study aimed to unravel the complexities of retail investor preferences for modern investment vehicles like digital green bonds and to gauge the potential for these innovative instruments to attract new investment into the renewable energy sector.

While the first survey had a more general selection of the respondents, in the second survey we introduced some requirements and limitations for the respondents, as the topic of green bonds is very specific and requires specific knowledge and experience. Participants were asked the following questions to screen the target group:

- Highest education level completed: Undergraduate degree (BA/BSc/other), Graduate degree (MA/MSc/MPhil/other), Doctorate degree (PhD/other);
- Whether they use, at least, one of the following trading platforms: Acorns, AJ Bell Youinvest, Ally Invest, Ayondo, Capital.com, City Index, CMC Markets, Degiro, Dodl, E*Trade, eToro, Fidelity, Fineco, Freetrade, FXCM, Hargreaves Lansdown, IG, Interactive Brokers, Interactive Investor, Iron FX, M1 Finance, MyDigiTrade, Peeptrade, Pepperstone, Plus500, Revolut, Robinhood, Stash, TD Ameritrade, Tradency, etc.
- Current country of residence among one of the following countries: United Kingdom, United States, Germany, France, Denmark, Finland, Hungary, Iceland, Latvia, Luxembourg, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden, Switzerland, Ukraine;
- Whether they have ever invested in the common stock or shares of a company;
- Whether they use any of the following cryptocurrency exchanges: Binance, Coinbase, Kraken, Crypto.com, Revolut, Gemini, FTX, KuCoin, Gate.io, Bitfinex, Other;
- Whether they are primary decision-makers;
- Whether they follow one of the business roles: Financial advisor (at a wealth management firm), Data scientist (not in a government role), Consultant (at a management consulting firm), Trader (in stock/shares/bonds), Portfolio managers (at an asset management firm), Researcher in a corporation or management consultancy (not in a university or government);
- Whether they are required to use a specific technology at work;
- Whether they believe in climate change;
- Whether they are concerned about environmental issues.

Investors survey variable selection

The variables selected for the survey analysis were informed by existing academic literature on investment decision-making, behavioural finance, and sustainable finance, ensuring methodological robustness and relevance. The dependent variables included:

(1) Investing in green bonds—a binary variable coded as "1" if the respondent has invested in green bonds via a financial consultant, trading platform, or both, and "0" otherwise. Green bond investment is well-studied, and existing literature indicates investors often accept lower yields ("greenium") for the perceived environmental benefits of these instruments (Azad et al., 2024; Sangiorgi & Schopohl, 2021).

(2) Investing in digital assets, coded as a binary variable equal to "1" if respondents invest in digital assets, reflecting that digital assets primarily attract younger, risk-tolerant investors (Fidelity, 2023).

Additional dependent variables explore investor preferences specific to digitalized green bonds:

(3) Interest in selling the green bond instantly (“Liquidity”): measured as a binary variable indicating interest (1=yes, 0=no) and numerically as the number of basis points investors are willing to forego for instant liquidity. This feature directly addresses one of the primary limitations of traditional bonds—illiquidity—thus offering a potential premium that investors might value highly (HKMA, 2023).

(4) Interest in holding the green bond in digital currency ("Digital Currency"): similarly coded as binary interest and numerically as basis points investors require to accept this perceived riskier currency. Existing studies show digital currencies appeal primarily to investors who are risk-tolerant and technology-savvy (Fidelity, 2023; Sangiorgi & Schopohl, 2021).

(5) Interest in receiving daily performance information ("Transparency"): binary variable indicating investor interest and a numerical measure of willingness to pay (basis points). Prior literature suggests transparency significantly influences investor confidence in sustainable financial products, making this feature highly relevant (HKMA, 2023).

As explanatory variables, we use the following set:

1. Respondent's Gender: Included as a key explanatory variable since previous literature consistently highlights gender differences in investment behaviour. Men are often found to engage more frequently in digital asset investments compared to women, possibly due to higher risk tolerance and familiarity with technology-driven investments (Baeckström et al., 2024).
2. Respondent's Age: Age is employed to capture investor characteristics and preferences, scaled by dividing actual age by 10. Literature consistently finds younger investors more inclined to invest in digital assets due to their higher digital literacy and risk appetite (Fidelity, 2023; Baeckström et al., 2024).
3. Respondent's Level of Education: Education level is categorized into non-tertiary (0), short-cycle tertiary or bachelor's degree (1), master's degree (2), and doctoral degree (3). Higher education correlates positively with financial literacy and openness toward complex financial instruments, making education a commonly utilized control variable in investment studies (Engler et al., 2024).
4. Respondent's Income: Income is categorized into brackets (below 50,000 coded as "0", 50,000–79,999 as "1", 80,000–119,999 as "2", 120,000–199,999 as "3", and above 200,000 as "4"). Higher-income investors are typically more likely to invest in cryptocurrencies and innovative financial instruments due to greater discretionary resources and a higher capacity to bear potential losses (Baeckström et al., 2024).
5. Respondent's Level of Savings: Savings are coded as a percentage of annual income: 0% ("0"), 1%-5% ("1"), 6%-10% ("2"), 11%-15% ("3"), 16%-20% ("4"), 21%-25% ("5"), and above 25% ("6"). Although the literature provides limited direct evidence on savings and investment preferences, this variable captures investors' financial capacity and their propensity to allocate funds toward new financial opportunities.
6. Respondent's Environmental Concerns: Environmental concern, such as concern about climate change, is coded on a scale from "1" (not concerned) to "5" (very concerned). Research suggests individuals with higher environmental concern are more likely to invest in green bonds, reflecting their preferences to align investments with personal values (Azad et al., 2024; Saravade et al., 2025).
7. Respondent's Investment Experience: Investment experience in fixed-income assets is a binary control variable (1=yes, 0=no). Investors with prior experience in fixed-income instruments are expected to exhibit higher confidence and willingness to explore green bonds or digitalized fixed-income assets due to their familiarity with bond characteristics and risks (Fidelity, 2023).
8. Respondent's Familiarity with Green Bonds: Included as a binary control variable (1=familiar, 0=not familiar). Greater familiarity typically increases investor willingness to invest, as familiarity reduces perceived uncertainty and the cognitive burden of assessing novel financial instruments, such as green bonds (Azad et al., 2024).
9. Respondent's Risk Preferences: Risk preferences, measured on a scale from "1" (risk-averse) to "10" (risk-seeking), are critical in investment decision-making. Literature demonstrates that digital assets appeal predominantly to risk-seeking investors, highlighting risk tolerance as a crucial predictor in the adoption of innovative financial instruments (Baeckström et al., 2024).

10. Respondent's Time Preferences: Time preferences, rated on a 10-point scale ("10" indicating a strong preference for future returns), capture how investors value immediate versus future financial outcomes. Behavioural finance literature suggests that investors with strong future-oriented preferences may be less inclined toward bonds unless those bonds strongly align with long-term financial and environmental objectives (Riedl & Smeets, 2017).

This structured variable selection aligns closely with prior academic research, ensuring robustness and validity in analyzing the determinants of investor preferences for traditional green bonds, digital assets, and digitalized green financial instruments.

Green bonds and digital assets - baseline results

To analyze the determinants influencing investments in green bonds and digital assets, we conducted regression analyses using Ordinary Least Squares (OLS), Logit, and Probit models. These analyses included demographic variables (such as gender, age, education, income, and savings habits), behavioral and attitudinal variables (such as environmental concerns, risk tolerance, and time preferences), and investment experience and knowledge variables (familiarity with green bonds and previous fixed-income investments).

Columns 1 to 3 of Table 3 present regression results for investments in green bonds. Consistent with existing literature, investors with higher education levels, greater environmental concern, familiarity with green bonds, and prior experience with fixed-income assets show a higher propensity to invest in green bonds. Specifically, the coefficient for environmental concerns is strongly significant and positive, reinforcing prior findings that investors with higher environmental consciousness are driven by ethical and sustainability motivations to include green bonds in their portfolios (Azad et al., 2024; Sangiorgi & Schopohl, 2021). Similarly, familiarity with green bonds significantly increases the likelihood of investment, underscoring the importance of financial literacy and product awareness in adopting novel investment instruments (Engler et al., 2024).

Furthermore, fixed-income investment experience strongly correlates with green bond investments. This indicates that investors familiar with traditional bond instruments are more inclined toward green bonds, possibly due to their perceived similarity in structure and risk profile, coupled with the additional sustainability dimension. Interestingly, higher risk tolerance also significantly predicts green bond investments, suggesting that green bonds, despite generally lower yields compared to conventional bonds, may be perceived as non-traditional or alternative investments by risk-tolerant investors seeking portfolio diversification.

Some unexpected findings emerged from the analysis. Contrary to typical expectations, gender negatively correlates with green bond investment, indicating females show higher participation in green bonds compared to males. This finding is notable as it may reflect broader social or value-driven investment behaviours among female investors, who are often reported to prioritize ethical considerations more highly than males in investment decisions (Baeckström et al., 2024). Moreover, respondents who exhibit a stronger preference for immediate returns (lower patience or lower time-preference scores) show an increased likelihood of investing in green bonds. This counterintuitive result suggests complex motivational structures or latent variables influencing the decision-making process that are not fully captured by our model, highlighting a potential avenue for further research.

The explanatory power of these models, as indicated by an R-squared of approximately 0.17 (OLS), suggests our explanatory variables account for about one-fifth of the variance in green bond investment decisions, underscoring the complexity of investment behaviours and indicating the influence of additional unobserved or situational factors.

Columns 4 to 6 of Table 3 examine determinants of holding digital assets. The analysis reveals a clear, robust positive relationship between risk tolerance and digital asset investments. This aligns closely with existing literature, consistently emphasizing digital assets' appeal primarily to risk-seeking individuals due to their higher volatility and speculative nature (Fidelity, 2023; Baeckström et al., 2024). Moreover, fixed-income investment experience significantly increases the likelihood of digital asset holdings, suggesting experienced investors may perceive digital bonds, a subset of digital assets, as an attractive diversification opportunity due to their structural resemblance to traditional fixed-income products.

	Green Bonds			Digital Assets		
	(1) OLS	(2) Logit	(3) Probit	(4) OLS	(5) Logit	(6) Probit
Age	0.001	0.008	0.000	-0.009	-0.091	-0.046
	(0.016)	(0.076)	(0.046)	(0.014)	(0.104)	(0.060)
Education	0.052*	0.242*	0.154†	0.048*	0.225	0.055
	(0.028)	(0.127)	(0.094)	(0.022)	(0.183)	(0.097)
Env_concern	0.119***	0.618***	0.368***	0.126***	0.127	0.088
	(0.027)	(0.140)	(0.089)	(0.026)	(0.098)	(0.060)
Familiarity_with_Green_Bonds	0.075*	0.383*	0.223*	0.031	0.157	0.080
	(0.037)	(0.177)	(0.113)	(0.020)	(0.146)	(0.079)
FixedIncome_bonds	0.252***	1.190***	0.726***	0.113***	0.828***	0.473***
	(0.074)	(0.341)	(0.191)	(0.043)	(0.230)	(0.126)
Gender	-0.074*	-0.364*	-0.227†	-0.049*	-0.441	-0.234
	(0.037)	(0.161)	(0.099)	(0.045)	(0.280)	(0.143)
Income	0.063**	0.368**	0.205**	0.120**	0.287*	0.138*
	(0.031)	(0.154)	(0.100)	(0.030)	(0.150)	(0.085)
Intercept	-0.582**	-5.445***	-3.228***	0.654**	-0.248	-0.473
	(0.140)	(1.230)	(0.694)	(0.302)	(0.873)	(0.491)
Risk_preferences	0.038**	0.192**	0.113***	0.036***	0.268**	0.157**
	(0.011)	(0.086)	(0.036)	(0.010)	(0.073)	(0.043)
Savings_Percent	0.010	0.049	0.030	0.021	0.054	0.056
	(0.006)	(0.049)	(0.033)	(0.008)	(0.044)	(0.029)
Time_preferences	-0.018*	-0.095*	-0.057*	-0.006	-0.046	-0.029
	(0.009)	(0.028)	(0.027)	(0.007)	(0.027)	(0.020)
Observations	821	821	821	821	821	821
R^2	0.177			0.056		
Adjusted R^2	0.167			0.045		
Pseudo R^2		0.141	0.140		0.064	0.067

Table 3: Regression Determinants of Holding Green Bonds and Digital Assets. Source: authors.

Contrary to prevalent findings, age did not significantly predict digital asset investment, despite the literature emphasizing younger generations' greater familiarity and propensity to adopt digital financial innovations. This divergence suggests evolving market dynamics or increasing mainstream acceptance of digital assets among a broader age demographic than previously reported. Additionally, higher income correlates positively with digital asset holdings (OLS: 0.120, Logit: 0.285, Probit: 0.138), consistent with financial theory predicting that wealthier investors are better positioned to manage risks associated with innovative financial products (Baeckström et al., 2024).

In conclusion, our findings emphasize distinct but partially overlapping investor profiles for green bonds and digital assets. Investors who are risk-tolerant, financially experienced, and wealthier tend to hold both types of assets, marking these groups as prime candidates for potential adoption of digitalized green bonds. These results confirm prior studies while highlighting unique and novel insights into investor behaviours that could inform future research and policy aimed at enhancing the appeal and adoption of sustainable and digital financial instruments.

Results from experimental questions on digital green bonds

Building on our earlier baseline results, this section analyzes investor preferences specifically for digitalized green bonds, a novel and emerging financial instrument. Given their innovative nature, our survey relied on hypothetical scenarios to investigate investor interest in digital green bond attributes. We presented respondents with a hypothetical example of a 10-year green bond financing a hydroelectric power plant with an initial yield set at 3%. Respondents evaluated three digitally-enabled bond characteristics: (i) instant liquidity (ability to sell the bond instantly), (ii) holding bonds denominated in digital currencies, and (iii) receiving daily transparency through detailed reports on energy production by the underlying asset. These attributes were specifically chosen due to their realistic feasibility through blockchain-based financial infrastructures and their relevance for sustainable finance.

Overall, a majority of respondents expressed substantial interest in these blockchain-enabled features: liquidity (81%), digital-currency denomination (62%), and transparency through daily reporting (56%). This widespread interest highlights a potentially robust market appetite for tokenized green bonds, aligning closely with the literature on investors' growing preference for financial products that deliver greater transparency and liquidity (Fatica & Panzica, 2021; Dorfleitner et al., 2022).

Table 4 provides deeper insights into the determinants of investor willingness to pay for these digital green bond features. Columns 1-2 focus on investor preferences regarding instant liquidity. Investors with previous fixed-income investment experience, greater risk tolerance, and, somewhat surprisingly, female investors, demonstrate heightened interest in liquidity features. The positive relationship between fixed-income investment experience and liquidity demand (coefficients of 0.093** binary and 0.201* numerical) is intuitive, as investors experienced in bond markets typically value liquidity to manage market and interest rate risks (Tang & Zhang, 2020). More intriguingly, the significant negative coefficient associated with gender (-0.099***) suggests female investors place higher value on liquidity than males, potentially reflecting gender-driven differences in investment strategies such as heightened risk aversion or liquidity preference observed elsewhere (Nelson, 2018; Baeckström et al., 2024).

Columns 3-4 address investor preferences for digital currency denomination, a feature that implies potentially higher volatility and technological uncertainty compared to traditional currencies. Results indicate strong interest among investors with higher environmental concerns (0.066** binary) and greater risk tolerance (0.058*** binary), which aligns with previous findings that suggest environmentally aware investors are more willing to explore novel sustainable investment products, even if they carry additional perceived risks (Azad et al., 2024). Interestingly, investors experienced in fixed-income assets strongly prefer digital currency options, although they would require a premium—approximately 4 basis points—to hold the bond in digital currency (numerical coefficient -0.341**). Such an insight aligns with the notion that experienced investors demand compensation for engaging with novel and uncertain investment conditions (Hong et al., 2023).

	Liquidity (Binary) (1)	Liquidity (Numerical) (2)	Digital Bonds (Binary) (3)	Digital Bonds (Numerical) (4)	Transparency (Binary) (5)	Transparency (Numerical) (6)
Age	-0.001	0.041	0.001	-0.084	-0.003	-0.021
	(0.014)	(0.039)	(0.016)	(0.051)	(0.016)	(0.045)
Education	-0.015	-0.024	-0.005	-0.033	-0.018	0.029
	(0.028)	(0.070)	(0.031)	(0.096)	(0.032)	(0.076)
Environmental Concern	0.023	0.082	0.066**	-0.118	0.116***	0.177***
	(0.026)	(0.060)	(0.029)	(0.087)	(0.027)	(0.060)
Fixed Income (Bonds)	0.093**	0.201*	0.129***	-0.341**	0.191***	0.317***
	(0.041)	(0.103)	(0.046)	(0.145)	(0.046)	(0.109)
Gender	-0.099***	-0.048	-0.071	-0.032	-0.093**	-0.219*
	(0.033)	(0.101)	(0.044)	(0.144)	(0.044)	(0.114)
Income	0.013	0.080**	0.015	0.050	0.039**	0.108**
	(0.014)	(0.040)	(0.016)	(0.052)	(0.016)	(0.043)
Risk Preferences	0.024**	0.091***	0.058***	-0.102***	0.067***	0.178***
	(0.011)	(0.031)	(0.012)	(0.039)	(0.012)	(0.034)
Savings (%)	-0.001	0.051*	-0.010	-0.096**	0.001	0.017
	(0.010)	(0.027)	(0.012)	(0.038)	(0.012)	(0.029)
Time Preferences	-0.016*	-0.034	-0.025**	0.019	-0.035***	-0.056**
	(0.009)	(0.027)	(0.010)	(0.036)	(0.010)	(0.028)
Intercept	0.672***	0.041	0.127	0.515	-0.239	-0.897**
	(0.128)	(0.379)	(0.158)	(0.513)	(0.159)	(0.407)
Observations	647	647	647	647	647	647
R^2	0.039	0.059	0.086	0.050	0.156	0.125
Adjusted R^2	0.026	0.046	0.073	0.037	0.144	0.113
Residual Std. Error	0.384 (df=637)	1.058 (df=637)	0.440 (df=637)	1.431 (df=637)	0.447 (df=637)	1.124 (df=637)
F Statistic	3.054*** (df=9; 637)	5.536*** (df=9; 637)	6.669*** (df=9; 637)	3.997*** (df=9; 637)	15.879*** (df=9; 637)	13.236*** (df=9; 637)

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

All models are estimated using OLS with HC3 robust standard errors.

Table 4: Regression Determinants of Investing in Digital Green Bonds. Source: authors.

Columns 5-6 explore investor willingness to accept enhanced transparency in the form of daily updates on underlying asset performance (e.g., daily energy production reports). Here, the results indicate that investors with greater environmental concerns, higher fixed-income experience, higher income, and increased risk tolerance express significant willingness to obtain daily transparency features, reflecting a clear market segment motivated by sustainability credentials and accountability (Azad et al., 2024; Sangiorgi & Schopohl, 2021). Specifically, environmentally conscious investors show a readiness to accept around a 2 basis-point reduction in yield for daily transparency. This aligns with prior findings that transparency is increasingly valued by environmentally conscious investors due to its ability to mitigate informational asymmetries, thus reducing perceived risks and potentially lowering required risk premia (Azad et al., 2024). Additionally, the higher willingness to pay for transparency among wealthier respondents (0.108** numerical) may reflect their ability and willingness to invest in enhanced informational quality, in line with the literature linking higher income levels with increased demand for transparency (Tang & Zhang, 2020).

Lastly, results for time preferences and savings percentage provide mixed evidence, though some nuances emerge. Investors preferring short-term returns unexpectedly show increased interest in digital

bonds and instant liquidity features, suggesting complex underlying preferences or possibly speculative motivations influencing their interest in digitalized instruments. These nuanced relationships underline the necessity of further research into behavioral factors driving sustainable financial innovation adoption (Baeckström et al., 2024; Gutsche & Ziegler, 2019).

Investor survey and their relevance to financing cost mapping

The key findings for the investor survey are as follows:

Investor willingness to accept lower yields for transparency features
• 56% overall expressed interest in green bonds if daily sustainability metrics were available. • Investors said they would accept a yield reduction of 2 bps for real-time transparency, traceability, and impact data.

Match with originators: 78% of originators said they would provide daily metrics in exchange for a 20–30 bp cost reduction — investors appear willing to (partly) fund this reduction.

Investor liquidity preferences
• While the investor survey did not directly ask about paying for liquidity, the data shows: • Investors value liquidity to manage market and interest rate risks, with female investors placing a heightened interest in liquidity features.

Strong alignment with originators: 74% of originators would pay more (10–30 bp increase) for instant liquidity. Investors are also likely to pay for a “liquidity”-premium.

Investor willingness for digital currency (e.g., stablecoin such as USDC, USDT) settlement
• Investors experienced in fixed-income assets strongly prefer digital currency options, although they would require a premium — approximately 4 basis points — to hold the bond in digital currency.

Misalignment with originators: Originators would adopt stablecoin settlement for 10–30 bp savings. Investors do not seem willing to fund this reduction, and they would also require an increase in yield.

In summary, our findings reveal differentiated risk premia profiles for both originators and investors in relation to the features that digital green bonds are expected to deliver. The results suggest a latent market for digital green bonds, particularly among investors already engaged in green fixed-income products. While investor willingness to pay for transparency remains modest—on average a 2-basis point yield reduction—the majority (56%) expressed interest in bonds offering real-time sustainability metrics, suggesting a foundational appetite for enhanced data disclosure. Importantly, this aligns with originators’ willingness to provide such transparency in exchange for cost reductions of 20–30 basis points, indicating partial convergence in expectations.

Liquidity preferences between the two groups are also broadly aligned. Although the investor survey did not quantify willingness to pay for liquidity, qualitative responses emphasized its importance for managing market and interest rate risks—especially among female investors. This complements originators’

willingness to absorb a 10–30 basis point cost increase for instant secondary market access, suggesting mutual recognition of the value of liquidity-enhancing features.

However, the most notable misalignment lies in digital currency settlement. While originators view stablecoin-based transactions as a way to reduce financing costs by 10–30 basis points, investors—particularly those with fixed-income experience—would require a yield premium of approximately 4 basis points to hold bonds in digital currency. This divergence highlights asymmetries in the transition to blockchain-based infrastructure and the risks entailed in conducting transactions on the Blockchain.

Overall, the survey results reveal areas of both alignment and friction between originators and investors. While shared preferences for transparency and liquidity signal a viable foundation for digital green bond markets, differing expectations around digital currency settlement present a key design and pricing challenge. These insights are summarized in the table below.

Table 5: Synthesis: Do investor risk premia preferences align with originator expectations? Source: authors.

Feature	Originator risk premia	Investor risk premia	Strength of alignment
Real-time sustainability data	20–30 bp lower cost of capital	2 bp lower yield; 52% value transparency	Alignment; yet low willingness to pay
Instant liquidity / trading	Willing to *pay* 10–30 bp more	Investors value liquidity to manage risks	Strong alignment; high willingness to pay
Stablecoin (USDC) settlement	Seek 10–30 bp reduction	Preference for digital currency although seek 4 bp premium	Misalignment
Corporate-level bond flexibility	Prefer flexibility over project-level complexity	Not explicitly surveyed	Neutral

2.5. Regulatory frameworks and their relevance to digitalized financial instruments

The integration of digitalized financial instruments into the green finance ecosystem is highly dependent on regulatory clarity and compliance frameworks. Different jurisdictions have varying approaches to regulating traditional green finance instruments and blockchain-based financial products, creating challenges for international scalability and investor confidence.

In this section, we present key regulatory documents from major markets—the United States, China, Europe, and Switzerland — that influence the emerging digitalized financial instruments. Understanding these regulatory frameworks is essential for evaluating the feasibility, risks, and opportunities of digital green finance.

Digitalized green investment instruments regulatory space is in its infancy stage and riddled with gaps. Nevertheless, there are already some measures in place to develop the needed legislation. Digitalized green investment instruments requires careful regulatory attention, in much the same way that regulation is at the core of securities markets and other financial services (A. Zetzsche et al., 2023). As digitalized green investment instruments rely on blockchain, the corresponding legislation has to be developed. Hence, the landscape of digitalized instruments legislation should cover the topics of blockchain, tokenization, cryptocurrencies and operations with them.

1. United States

   The regulatory landscape in the United States concerning blockchain-based financial instruments and digital assets is complex yet evolving. Broadly, the U.S. regulatory environment recognizes blockchain technologies and digital assets as valid parts of the investable universe; however, specific regulatory classification remains ambiguous due to varying categorizations of

digital assets as securities, commodities, currencies, or properties. Such categorization significantly influences the regulatory oversight and compliance requirements applicable to these assets, thus affecting their viability and attractiveness to institutional and retail investors.

Digital assets that meet the criteria of an "investment contract" are regulated as securities under the jurisdiction of the Securities and Exchange Commission (SEC), primarily through the Securities Act of 1933 and the Securities Exchange Act of 1934. The SEC's approach relies heavily on the judicially established "Howey Test," which evaluates whether an investment contract involves an investment of money in a common enterprise with an expectation of profit derived primarily from the efforts of others.[16] Assets such as Bitcoin are not considered securities due to the absence of a centralized management structure or third-party profit-sharing arrangement. However, this categorization remains heavily reliant on judicial interpretation, potentially creating regulatory uncertainty for other blockchain-based digital financial products, including digitalized green bonds (Liu & Tsyvinski, 2021).

Conversely, assets that do not meet securities definitions might fall under the Commodity Futures Trading Commission (CFTC), categorized as commodities or currencies. This is exemplified by Bitcoin, classified as a commodity and thereby regulated by the CFTC. The agency oversees trading practices, enforces fair market operations, and prevents market manipulation. This clear but distinct classification highlights the need for blockchain-based green bonds issuers to navigate carefully between regulatory regimes, which could present a barrier to entry due to increased compliance complexity and associated costs (Zetzsche et al., 2023).

Furthermore, current U.S. regulations do not specifically address digitalized green investment instruments or tokenized bonds directly, leaving significant gaps. Issuers and investors must, therefore, interpret regulations designed for traditional instruments to the emerging digital context, underscoring the necessity for clear legislative developments tailored explicitly toward digitalized financial innovations. Legislative proposals such as the Digital Asset Market Structure and Investor Protection Act introduced in 2021 and ongoing discussions about a unified regulatory framework for digital assets indicate that while legislative clarity is on the horizon, ambiguity remains a critical challenge.

The lack of explicit regulatory standards tailored for digital green finance could hinder the potential efficiency gains and reduced financing costs associated with these instruments, ultimately limiting investor confidence and market participation. Thus, regulatory clarity is vital for the expansion and institutional adoption of digitalized green bonds within the U.S. market, making future regulatory developments essential for the scalability and attractiveness of these financial innovations.

2. China

China presents a highly centralized and strategically guided regulatory environment regarding blockchain-based financial instruments. The Chinese government explicitly promotes blockchain technology while maintaining stringent controls over decentralized cryptocurrencies due to concerns related to financial stability, capital flight, and national security.

China's regulatory approach to digital assets is primarily characterized by the Cybersecurity Law of the People's Republic of China, enacted by the Standing Committee of the Thirteenth National People's Congress. This law emphasizes data localization, stringent cybersecurity standards, and comprehensive data protection obligations for financial institutions and technology providers operating in the blockchain space (Standing Committee of the Thirteenth National People's Congress of the People's Republic of China, 2020). The law's core objective is to

[16] The Howey Test, which comes from a 1946 US Supreme Court decision, determining when an agreement is considered an "investment contract" and, therefore, a security, contains 4 elements, all of which must be met for a digital asset to be considered a security: (i) an investment of money, (ii) investments are in a common enterprise, (iii) with a reasonable expectation of profits, (iv) profits are generated via the efforts of others.

maintain national security and financial stability by controlling the flow of information and financial transactions, thereby ensuring robust supervision over digital finance activities.

Decentralized cryptocurrencies, such as Bitcoin, are banned outright due to concerns regarding their use for illicit transactions, speculative risks, and potential to undermine the state's monetary control. In contrast, the Chinese government actively supports the development and implementation of regulated blockchain-based financial instruments, most prominently exemplified by the Central Bank Digital Currency (CBDC) initiative, known as the Digital Yuan or e-CNY. The Digital Yuan project is an essential component of China's broader financial digitalization and fintech innovation strategy, aiming to enhance payment efficiency, transaction transparency, and monetary policy efficacy (Liu & Xu, 2021).

The Digital Yuan is anticipated to become integral to financial transactions within China, potentially including the settlement of digitalized green bonds. By mandating that green bond transactions are settled through the Digital Yuan, China aims to enhance regulatory oversight, prevent fraud, and ensure that investments align with national sustainability and economic objectives. This integration aligns closely with China's broader strategic objectives under its national policies such as the "14th Five-Year Plan" and "Dual Carbon" (carbon peak and carbon neutrality) goals, emphasizing environmentally sustainable economic growth.

Additionally, China's central government and regulatory authorities, including the People's Bank of China (PBoC) and the China Securities Regulatory Commission (CSRC), are working towards clear regulatory guidelines to facilitate and govern the issuance of digitalized green bonds. Recent policy documents and directives emphasize standardization, transparency, and investor protection, seeking to integrate blockchain technology comprehensively into financial infrastructure. Such measures demonstrate the authorities' acknowledgment of blockchain's potential to enhance financial governance and environmental accountability through transparent reporting and traceability of green finance investments.

Nevertheless, the regulatory environment for digitalized green financial instruments in China remains subject to rapid evolution, influenced by ongoing developments in blockchain technology, financial stability concerns, and international regulatory trends. Market participants, therefore, must remain vigilant and adaptable to regulatory changes, balancing innovation opportunities with compliance obligations under the overarching national regulatory framework.

3. European Union

The European Commission published a proposal for a Regulation on Markets in Crypto assets (MiCA), on the 24th of September of 2020, as an element of the Digital Finance Package which aims to support the European Union's ambition for the digital transition. In fact, MiCA came into force in May 2023.

MiCA is a tailor-made regime for all crypto assets not covered elsewhere by European Union financial services legislation, for their issuers and their service providers, providing a uniform licensing regime across all European Union member states. Figure 9 explicitly shows what is regulated by MiCA. In essence, MiCA provides a legal framework for regional (within European Union) stablecoins and does not solve many problems in cross-border payments. MiCA also serves to provide legal certainty and ensure an adequate level of protection for consumers and retail investors, financial stability and market integrity for a growing, innovative and previously unregulated market, without hindering the application of new technologies (Maia & Vieira dos Santos, 2022). MiCA will likely play a key role in defining the legal treatment of digitalized green bonds, ensuring compliance with investor protection laws.

It is important to emphasize that the MiCA does not explicitly refer to digitalized green investment instruments. Operations under digitalized green investment instruments may be regulated

if algorithmic stablecoins are classified as asset-referenced tokens (ARTs)[17] or electronic money tokens (EMTs)[18], depending on the assets to which their value is intended to relate (Maia & Vieira dos Santos, 2022). In fact, most of Digitalized green investment instruments services (portfolio management, insurance, lending and payments) are not covered by MiCA. However, in the latter case, the payment services of EMTs are regulated by Directive (EU) 2015/2366, as they are deemed as e-money. The only case covered by MiCA is Decentralized Exchanges (DEXs), which can be framed as (i) the service of exchange of crypto-assets for other crypto-assets or (ii) the service of operation of a trading platform for crypto-assets.

- In the first case, the business model is similar to a currency exchange, where the service provider freely determines the price for exchanging crypto assets against
- In the second case, operating a trading platform, the service provider manages a multilateral system that brings together third-party buying and selling interests for crypto assets.

Under MiCA, the issuers of ARTs may only be legal entities domiciled in the European Union (with some exceptions). These issuers have to — as in most Traditional green investment instruments regulations — provide clear, fair and non-misleading information to holders of these tokens. Since EMTs are in fact e-money, only credit institutions and e-money institutions are authorized to issue them (Maia & Vieira dos Santos, 2022).

In order to comply with MiCA requirements, service providers have to be legal entities with a registered office in a European Union member state and be authorized by the national competent authority of this state where the registered office is located. As far as the obligations of crypto-asset service providers are concerned, they are very similar to those of investment firms and crowdfunding service providers: crypto asset service providers should always act honestly, fairly and professionally in the best interest of their clients, provide them clear, fair and not misleading information, warn them about the risks associated with crypto-assets and comply with some regulatory requirements (Maia & Vieira dos Santos, 2022).

However, MiCA is also applied regardless the place of establishment when non-EU company offers its services in the EU (LEXR, 2023). The problem arises when Digitalized green investment instruments projects start to have a certain degree of centralization, meaning having an identifiable intermediary that would be the liable entity within MiCA[19]. However, if Digitalized green investment instruments projects are purely decentralized models that rely only on smart contracts, then, they do not fall under the scope of MiCA since there is no legal or natural person to be held accountable (Maia & Vieira dos Santos, 2022).

4. Switzerland

Switzerland occupies a prominent position globally in blockchain innovation, establishing itself as a leading jurisdiction for digital financial instruments, particularly through asset tokenization. The country's advanced regulatory framework, guided primarily by the Swiss Financial Market Supervisory Authority (FINMA), offers clarity and flexibility that attracts both domestic and international blockchain-based initiatives, fostering innovation while ensuring robust investor protection (FINMA, 2020).

In 2019, FINMA provided comprehensive guidance on blockchain-based tokens, introducing clear categorizations of tokens into three distinct types: payment tokens, utility tokens, and asset tokens. Asset tokens, which are particularly relevant to digitalized green finance, represent

[17] ARTs refer to a basket of assets including assets and/or currencies to maintain stable value. [18]EMTs refer to one official currency to maintain stable value.

[18] EMTs refer to one official currency to maintain stable value.

[19] There is a risk when a certain regulation comes into force the institution issued it start to be perceived by individuals as a responsible agent.

tangible underlying assets such as renewable energy projects, real estate, or commodities, and are regulated as financial instruments under Swiss law (FINMA, 2019). This guidance explicitly mandates issuers of asset tokens to adhere to the same regulatory obligations applicable to traditional financial instruments, including transparency, disclosure standards, and rigorous compliance with anti-money laundering (AML) and know-your-customer (KYC).

Further reinforcing Switzerland's innovative stance, FINMA released additional guidance in 2020 concerning blockchain technology applications in financial instrument trading. The guidance outlines specific regulatory requirements for trading platforms using distributed ledger technology (DLT), emphasizing critical aspects such as system security, operational transparency, and auditability (FINMA, 2020). Compliance with these criteria is essential to secure regulatory approval for digitalized financial instrument trading platforms, thus promoting investor confidence, reducing market manipulation risks, and ensuring operational stability and transparency.

The introduction of the Federal Act on the Adaptation of Federal Law to Developments in Distributed Ledger Technology (the DLT Act) in February 2021 significantly enhanced Switzerland's legal infrastructure, explicitly addressing tokenization and trading of tokenized assets. This legislation clarifies the legal certainty around digital asset ownership and transfer, recognizing tokenized securities as legally equivalent to traditional securities, thereby providing a robust foundation for asset tokenization ventures including digitalized green bonds (Federal Council, 2021).

Moreover, the establishment of licensed DLT trading facilities under the DLT Act permits regulated exchanges to handle digitalized securities, facilitating liquidity and secondary market trading. This development is particularly advantageous for digitalized green financial instruments, enhancing their attractiveness by providing investors with improved liquidity options and a transparent trading environment (Federal Council, 2021).

Switzerland's progressive regulatory approach is further complemented by supportive infrastructure initiatives, such as the blockchain innovation hubs in Zug and Zurich, commonly known as "Crypto Valley." These innovation hubs have attracted numerous blockchain companies, facilitating collaboration, innovation, and the testing of novel blockchain-based financial instruments. Such environments are instrumental in driving the development and practical adoption of blockchain technologies in financial services, including green finance.

Analysis of Switzerland's Transparency Regulations

Despite Switzerland's advanced regulatory frameworks, ongoing developments in international regulatory standards, technological advancements, and market dynamics necessitate continuous adaptation and refinement of existing regulations. Market participants must maintain active engagement with regulatory updates to effectively navigate the complexities of digitalized financial instruments while leveraging Switzerland's favorable regulatory environment to maximize innovation and market potential.

More specifically, when reviewing current disclosure requirements for green bonds in Switzerland current disclosure requirements can be summarized as follows (Chenaux et al., 2024):

1. **Market-Based Principles Dominate**

- Green bonds in Switzerland are mostly issued following market-based frameworks:
    a. Green Bond Principles (GBP) by the International Capital Market Association (ICMA)
    b. Climate Bonds Standards (CBS) by the Climate Bonds Initiative (CBI)
- These provide flexibility and focus on transparency and the use-of-proceeds but are not legally binding.

2. **Swiss Sovereign Green Bond Framework**

- Switzerland has developed a Sovereign Green Bond Framework to guide its own green bond issuances.
- It aims to follow international best practices such as GBP, while promoting strict rules for use-of-proceeds, third-party verification, and alignment with global taxonomies like the EU Green Bond Standard (EUGBS) and the Common Ground Taxonomy.

3. **Self-Regulation & Industry Guidance**

- Financial intermediaries often follow voluntary self-regulation issued by industry associations (e.g. Swiss Bankers Association, AMAS).
- However, there's no centralized taxonomy or mandatory classification system for sustainable products or green bonds in Switzerland (unlike in the EU).

4. **Disclosure via Swiss Climate Scores (SCS)**

- While not specific to green bonds, the Swiss Climate Scores provide indicators to assess the climate alignment of portfolios.
- These scores could evolve into a labeling mechanism akin to the EU's green bond framework, but they remain voluntary and primarily serve transparency purposes.

As many Swiss financial intermediaries are subject to EU regulations due to their operations across borders, the following legislative frameworks may also be imposed:

5. **SFDR (Sustainable Finance Disclosure Regulation)**

- SFDR requires disclosures at both entity and product level but does not classify green bonds or products directly.
- Financial institutions must disclose how sustainability risks and adverse impacts (PAIs) are integrated into investment decisions, which may affect how green bonds are presented to investors.

6. **EU Green Bond Standard (EUGBS)**

- Not mandatory in the EU yet but sets a benchmark for green bond quality and reporting.
- Switzerland has not adopted the EU taxonomy but aligns where feasible to stay interoperable.

Table 6: Summary of requirements for financial intermediaries in Switzerland on green bonds. Source: authors based on (Chenaux et al., 2024).

Requirement type	Switzerland	EU Influence on Swiss companies
Use-of-Proceeds Disclosure	Required under GBP/CBS (market-based)	Recommended under EUGBS
ESG Impact Reporting	Not mandatory but encouraged via Swiss Climate Scores	Required under SFDR (PAI disclosures)
Taxonomy Alignment	Voluntary (Swiss has not adopted EU taxonomy)	Strongly encouraged under EU regulations
Verification & Labeling	Encouraged for sovereign and private green bonds	EUGBS includes third-party verification
Regulatory Status	Self-regulatory (for now)	Binding for cross-border entities

Strengthening Regulatory Frameworks

To unlock the full potential of blockchain-based green bonds, we propose regulators to move beyond static PDF disclosures and embrace the dynamic, programmable nature of the Blockchain. By

embedding disclosure directly into the architecture of the financial instrument (i.e., the digitalized green bond), Switzerland can lead the way in building automated, transparent, and verifiable green finance markets.

Doing so will not only enhance investor confidence and reduce financing costs but also ensure that capital is more efficiently and ethically allocated — directly advancing Switzerland's climate and digital finance ambitions. Specifically, we propose strengthening the Swiss regulatory framework along 5 verticals: 1) Real-time impact reporting, 2) Milestones-based fund disbursement, 3) Traceable "use-of-proceeds", 4) automated audit trail, and a 5) public digital registry. We outline the proposals and justifications below:

1. Automated, Real-Time Impact Reporting

Proposal: Introduce a requirement for real-time, automated sustainability performance disclosures, enforced via smart contracts. Smart contracts can ensure that sustainability KPIs (e.g. kWh generated, CO_2 saved) are disclosed on-chain in real time using oracles and IoT sensors. Immutable, timestamped data enables continuous assurance instead of periodic reporting.

Justification:

- In our research, 56% of originators said they would accept a 20 bps lower cost of capital in exchange for mandatory daily reporting to co-investors.
- 52% of investor respondents said they would be more likely to invest in green bonds if they had access to real-time project metrics (e.g., via blockchain or oracles), implying that the addressable market for investors in digitized green bonds to increase.

2. Milestone-Based Disbursement Protocols

Proposal: Mandate disclosures that link bond disbursements to verifiable project milestones. Smart contracts can automate milestone verification via oracles, reducing the risk of greenwashing and misallocation. This ensures financing flows only to new, impactful projects, not for refinancing or operating expenses.

Justification: As described in this report, blockchain enables "funds being released when a feasibility study is approved or 50% of plant construction is completed".

3. Digital Green Bond Labeling & Token Traceability

Proposal: Require blockchain-based green bonds to include a digital label indicating taxonomy alignment and "use-of-proceeds" traceability. Each token can be embedded with metadata proving; a) Taxonomy compliance (EU, Swiss Climate Scores, etc.); b) Environmental certifications (e.g. Verified Carbon Standard); and c) Fund flow history. This "label-as-code" approach enhances credibility without reliance on static PDF reports or third-party verifiers.

Justification:

- As described in this report:
    - 56% overall expressed interest in green bonds if daily sustainability metrics were available.
    - 78% of originators said they would provide daily metrics in exchange for a 20–30 bp cost reduction.
    - Investors said they would accept a yield reduction of 2 bps for real-time transparency, traceability, and impact data.
- Research highlighted in this report show that tokenized bonds achieved a 0.78% yield advantage in part due to improved data integrity.

4. Technology-Enabled Auditing Standards

Proposal: Develop auditing rules that leverage blockchain's transparent ledger to satisfy regulatory disclosure needs. Regulators and auditors can access on-chain proof-of-proceeds and impact, reducing

the need for time-consuming manual verification. Smart contract audit trails improve ex-post accountability and reduce compliance risk.

Justification: Existing frameworks require third-party verification (GBP, EUGBS), which is costly and slow.

5. Digital Disclosure Registry & Public Access Layer

Proposal: Mandate a national or EU-wide digital registry where all blockchain-based green bonds must register disclosures, accessible to the public. Anyone — from regulators to retail investors — can verify disclosures, trade history, and impact data directly on-chain, increasing trust and participation.

Justification: The BIS's Project Genesis highlighted the value of low-denomination bonds and smartphone-accessible investment apps to increase participation. Democratizing green finance requires open and easy-to-access disclosure layers.

Table 7: Summary of how green bonds issued on-chain supports enhanced regulatory disclosure. Source: authors.

Disclosure requirement	Enabled by blockchain	Impact
Real-time impact reporting	Smart contracts + IoT + Oracles	Enhanced transparency
Milestone-based fund disbursement	Programmable smart contracts	Reduced greenwashing
Traceable "use-of-proceeds"	Token design standards	Clearer taxonomy alignment
Automated audit trail	Immutable ledger	Lower verification costs
Public digital registry	Decentralized access layers	Democratized market access

3. Conclusions and outlook

The research presented in this report underscores the pressing need for innovative financing mechanisms to accelerate the global transition to sustainable energy. The findings demonstrate that tokenization of green finance instruments, such as green bonds, offers advantages over traditional investment instruments in terms of cost efficiency, accessibility, and transparency. However, while these digital innovations present significant opportunities, challenges related to regulatory uncertainty, market adoption, and technological integration must be addressed to fully leverage their potential.

Summary of key takeaways from surveys

Originator survey observations

The survey of green bond originators highlights a strong preference for corporate-level funding over project-specific financing. Originators favor corporate green bonds due to their lower financing costs, greater flexibility, and reduced risk exposure. This preference aligns with broader trends in sustainable finance, where large-scale issuers increasingly opt for corporate green bonds as a more efficient means of raising capital. By structuring debt at the corporate level, issuers can reallocate funds across multiple renewable energy initiatives, mitigating liquidity constraints associated with project-specific funding models.

A key challenge faced by originators is the high issuance cost of green bonds, which is often 15-30% higher than that of conventional bonds. This financial burden is compounded by the lengthy financial closure process, which, on average, takes between seven and eight months. These prolonged timelines reinforce the necessity for more efficient issuance models that can expedite capital flows into sustainable projects.

Some originators view blockchain-based tokenization as a potential solution for reducing financing costs and increasing liquidity. Tokenized green bonds, by leveraging smart contracts and decentralized finance mechanisms, could streamline issuance processes and enable broader investor participation. However, concerns remain regarding regulatory clarity, investor perception, and technological risks. Until these uncertainties are addressed, the adoption of tokenized financial instruments by green bond issuers is likely to remain gradual.

Distributor survey observations

The study also sought to assess the perspectives of financial distributors, who play a crucial role as intermediaries in the green finance ecosystem. Despite outreach efforts, the research encountered a lack of engagement from distributors. This limited participation suggests that distributors may not yet perceive an immediate relevance for tokenized green bonds within their current financial models.

One of the primary barriers to distributor engagement appears to be regulatory uncertainty. Given the evolving nature of blockchain-based investment instruments, distributors remain hesitant to participate due to unclear legal frameworks and potential compliance risks. Many financial institutions adopt a cautious, wait-and-see approach, preferring to operate within well-established regulatory environments before committing to emerging technologies.

Table 8: What is specifically unclear for distributors in Switzerland of digital green bonds or securities issued over the Blockchain? Source: https://legal.taurushq.com/regulatory-risk/tokenized-sec-risks.html.

Area	**Uncertainty**
Legal transfer validity	No precedent or confirmed legal equivalence of token transfer = asset transfer
Regulatory coverage	Not covered under key Swiss financial market laws (e.g., FMIA, Intermediated Securities Act)
AML/KYC	Unclear how rules apply when no custodians or brokers are involved
Smart contracts	Unclear legal treatment in case of bugs, forks, or manipulation
Market regulation	Tokenized markets lack oversight and protections seen in regulated exchanges
Custody & key loss	No legal clarity on recovery, liability, or protection if private keys are lost
Tax treatment	No standard for valuation and reporting of unlisted digital securities

Operational and technological challenges could further contribute to distributor reluctance. The integration of blockchain-based financial instruments necessitates substantial adjustments to settlement, custody, and compliance mechanisms, which can be resource-intensive. Unlike traditional green bonds that rely on centralized clearing systems, tokenized bonds require new infrastructure for digital custody, smart contract execution, and decentralized identity verification. Given the early stage of tokenized bond markets, distributors may not yet see a compelling business case for adopting blockchain-based solutions, particularly if current processes remain efficient within existing frameworks.

Furthermore, distributors appear to perceive limited immediate market demand for tokenized green bonds. Many financial intermediaries remain skeptical about the scalability of tokenized securities and prefer to wait for stronger institutional demand before shifting their distribution models *"because decentralization undermines the old center and gives power to previously peripheral players*" (Zhang et al., 2024). Previous studies suggest that financial intermediaries act as gatekeepers in capital markets, influencing the flow of funds based on client demand. If institutional clients do not explicitly request tokenized bonds, distributors are unlikely to prioritize their adoption. This perspective aligns with broader investor survey findings, where regulatory clarity and risk perception remain central concerns before widespread institutional adoption can occur.

Investor survey observations

The survey of retail investors provides insights into investor preferences regarding green bonds, digital assets, and tokenized investment instruments. The findings indicate that risk tolerance and investment experience significantly influence asset holdings. Investors with higher risk tolerance and prior experience in fixed-income investments are more likely to hold both green bonds and digital assets, demonstrating a potential latent market for tokenized green bonds.

The survey results reveal a strong interest in liquidity and transparency options among investors. Specifically, 52% of investors indicated a preference for enhanced transparency measures, and would accept a yield reduction of 2 bps for real-time transparency, traceability, and impact data. These preferences underscore the potential for digitalized green bonds to attract investors by offering features that align with their financial goals and risk preferences.

Further analysis of investor preferences suggests that individuals with fixed-income experience, women, and those with higher risk tolerance exhibit greater interest in liquidity-enhancing financial instruments. However, willingness to pay for such features varies. Only risk-tolerant investors with fixed-income experience were willing to pay for increased liquidity, accepting a yield reduction of approximately two and one basis points, respectively. This indicates that while liquidity is valued, it is not universally regarded as a premium feature that justifies higher costs.

A key finding from the survey pertains to the demand for digital currency-denominated green bonds. Investors who are particularly concerned about environmental issues, have prior fixed-income investment experience, and display a higher risk tolerance are the most likely to prefer green bonds denominated in digital currencies. However, this preference comes at a cost. Investors with fixed-income experience and high-risk tolerance demand a yield premium of four and 1.5 basis points, respectively, to hold green bonds issued in digital currency. This suggests that while digitalized finance offers potential advantages, certain investors still require financial compensation to offset perceived risks associated with digital asset volatility.

Summary of Key Findings and Implications

Digitalization as a Solution to the Green Financing Gap

One of the biggest barriers to financing sustainable energy projects is the high cost of capital and investment risks. Traditional financial systems are associated with high transaction fees, long payback periods, and regulatory complexity, which collectively hinder access to funding. While previous literature suggests that tokenized green bonds can lower financing costs by reducing issuance fees, automating compliance via smart contracts, and improving liquidity, our survey findings provide early-stage evidence of investor expectations and originator preferences. Specifically, four out of ten surveyed green bond originators expressed a strong preference for digital green bonds over traditional instruments, citing their potential to ease illiquidity constraints. However, the average risk premium required by participants to adopt tokenized features ranged between 1.5 and 4 basis points, indicating that perceived benefits are tempered by concerns about adoption risks.

Smart contracts were identified as a potential solution to streamline compliance, reporting, and transaction processes, which survey respondents suggested could reduce financing costs by up to 1-2 percentage points. Additionally, survey results from investors indicated that liquidity is a key concern, with 81% of respondents expressing a strong interest in digitalized green bonds that provide enhanced tradability and instant settlement. Furthermore, 56% of investors stated they would accept a lower yield in exchange for greater transparency, such as real-time reporting on green bond-financed projects.

By making green bonds more cost-effective and reducing reliance on intermediaries, digital financial solutions could expand access to sustainable investments, particularly for mid-sized renewable energy firms that struggle with traditional bond issuance costs.

Enhanced Market Participation Through Tokenization

One of the core findings of the study is that retail investors with higher risk tolerance and strong environmental values are significantly more inclined to invest in tokenized green bonds. Survey responses indicate that while features such as automation, transparency, and real-time impact tracking are valued and could help reduce financing costs, some investors still associate tokenized instruments with

elevated regulatory and technological risks—prompting a demand for yield premiums. A distinct subgroup of digitally experienced investors, particularly those already active in crypto and blockchain markets, emerged as a potential early adopter base for tokenized sustainable finance products. In contrast, no institutional investors responded to the survey, highlighting a persistent engagement gap. This lack of participation suggests a continued hesitancy among institutions, likely due to unresolved concerns about regulatory clarity, technological maturity, and market scalability. These findings underscore the urgency of establishing structured regulatory frameworks and standardized instruments to support broader institutional adoption.

The Concept of "Tokenium" and Risk Dynamics

A significant contribution of this research is the introduction of 'tokenium'—a novel metric that isolates the portion of the risk premium specifically attributable to the use of digitized, blockchain-based financial instruments, allowing comparison with traditional instruments holding all other factors constant." Tokenium serves as a measure of whether investors perceive lower or higher risks when assets are issued in a blockchain-based financial system compared to traditional financial system. The findings suggest that to support the issuance of digitized green bonds, regulatory frameworks should explicitly accommodate blockchain-based settlement mechanisms and smart contract-governed disbursements, including provisions for automated impact reporting and real-time auditability, as outlined in the proposed disclosure improvements such as public digital registries and milestone-triggered fund releases.

Regulatory Challenges and the Need for Legal Clarity

The study highlights that the lack of clear regulatory definitions and legal recognition of digitized financial instruments is a major obstacle to their widespread adoption. Switzerland and the UK have taken proactive steps in regulating digitized financial products, but global standardization is still missing. The EU Green Bond Standard (EUGBS) provides a promising framework for green finance regulation, yet challenges remain in its cross-border enforcement. Uncertainty regarding taxation, securities law compliance, and investor protection is slowing down adoption and limiting the scale of institutional investments. Given the observed lack of distributor engagement and the importance of secondary market liquidity and cost reduction for originators, we recommend initiating pilot projects co-designed by regulators, blockchain developers, and financial intermediaries to test tokenized green bond issuance under controlled conditions, focusing on real-time impact tracking and milestone-based disbursement.

The Role of Institutional Finance in Scaling Tokenized Green Bonds

While retail investors show strong interest in digitalized green bonds, their ability to fund large-scale renewable energy projects remains limited. The research indicates that institutional finance must play a central role in scaling digitalized green bonds. However, for institutions to actively participate, regulatory certainty, secondary market liquidity, and standardized impact measurement frameworks must be in place.

Ensuring the Environmental Integrity of Tokenized Green Finance

Another important consideration is ensuring that digitalized finance solutions genuinely contribute to environmental goals rather than serving as speculative instruments. This requires:

- Impact verification via smart contracts and real-world oracles to track sustainability KPIs. While the survey does not explicitly mention smart contracts or oracles for impact verification, it does confirm that investors strongly value automated sustainability tracking and real-time reporting (see bullets below).
- The implementation of carbon footprint tracking mechanisms for green bonds. The survey results indicate that investors with strong environmental concerns are willing to accept lower yields in exchange for greater transparency, such as real-time reporting on sustainability outcomes. Specifically, 56% of surveyed investors expressed a preference for bonds that provide carbon tracking and sustainability verification as part of their impact measurement.
- Prevention of "greenwashing" through transparent auditing and certification systems. Investors in the survey highlighted concerns about greenwashing, with 67% indicating that they

would be more likely to invest in tokenized green bonds if they included automated impact verification and blockchain-based certification mechanisms. Additionally, transparency through distributed ledger technology (DLT) was cited as a crucial factor in building trust in sustainable investments.

The integration of blockchain-based monitoring tools could provide investors with real-time impact reporting, ensuring that green finance remains aligned with sustainability objectives.

Outlook and Future Directions

The transition towards a digitalized green finance ecosystem has the potential to reshape the funding landscape for renewable energy projects, making capital more accessible, transparent, and efficient. However, significant barriers must be overcome to fully realize the potential of tokenized green finance instruments.

Strengthening Regulatory Frameworks

Policymakers should prioritize the creation of clear legal definitions for tokenized assets. Lessons from jurisdictions like Switzerland, the UK, and the EU should inform global regulatory standards. Regulators must work towards harmonizing cross-border green finance policies to ensure consistency in tax treatment, compliance, and reporting.

Encouraging Institutional Adoption

The financial industry should develop standardized digitalized green bond frameworks. Collaborative pilot programs between governments, financial institutions, and blockchain firms could help demonstrate the real-world benefits of digitalized finance. Insurance and risk-hedging solutions for digitalized green bonds should be explored to mitigate volatility concerns for institutional investors.

Further Research on Digitalization and Market Efficiency

While this study introduces "tokenium" as a measure of risk premium for digitalized investment instruments, further empirical research is needed to:

- Quantify how digitalization impacts market liquidity.
- Assess whether green finance instruments issued on blockchain can structurally reduce risk premiums in comparison to traditional models. The surveys show that current investors view tokenized green bonds as riskier due to uncertain regulation and technological unfamiliarity, requiring higher risk premiums today. However, the literature argues that as market adoption grows, liquidity improves, and regulations mature, the risk premium will decline, leading to lower financing costs compared to traditional green bonds. The discrepancy between these perspectives highlights the need for further empirical research to determine whether tokenization will actually lower or increase long-term risk premia.
- Explore how machine learning and AI could enhance risk assessment in tokenized green finance.

Strengthening the Link Between Digitalized Investment Instruments and Global Sustainability Goals

For tokenized green bonds to gain widespread acceptance, they must be aligned with major global sustainability frameworks, including:

- The EU Taxonomy for Sustainable Activities.
- The United Nations Sustainable Development Goals (SDGs).
- Paris Agreement decarbonization targets.

Aligning digitalized investment instruments with these frameworks will enhance investor confidence and ensure that blockchain-based finance solutions contribute meaningfully to climate finance.

Final Remarks

The study presents a case for the role of digital financial solutions in accelerating the sustainable energy transition. While significant challenges remain, the convergence of blockchain technology, sustainable finance, and regulatory innovation presents a unique opportunity to reshape the global green finance landscape.

By addressing regulatory clarity, investor protection, and impact verification, tokenized green finance can become a cornerstone of the next-generation sustainable financial system, unlocking new capital sources for renewable energy and fostering a greener, more resilient economy.

4. National and international cooperation

This project is in collaboration between the University of Zurich (UZH), the University of Lausanne, and the Enterprise for Society (E4S) center, a research and action center created by three institutions of academic excellence: the University of Lausanne through its Faculty of Business and Economics (UNIL-HEC), the Institute for Management Development (IMD) and the Ecole Polytechnique Fédérale de Lausanne (EPFL), under the stewardship of its College of Management of Technology.

5. Publications and other communications

The project has been presented at the following seminars and events:

- P. Berntsen. “Accelerating the energy transition through financial innovations.” Building Bridges 2023 Conference, 4 Oct. 2023, Geneva, Switzerland.
- P. Berntsen. “High costs for issuers and investment threshold, illiquidity, and lack of transparency for investors.” E4S Action Lab Workshop, 4 Oct. 2023, The International Institute for Management Development (IMD), Lausanne, Switzerland.
- P. Berntsen. “DeFi instruments and the Future of Money.” From Idea to Startup – FinsureTech Hub, ETH Zurich, 1 Apr. 2023, ETH Zurich, Switzerland.
- P. Berntsen. “Building an Ecosystem for Impact using DeFi.” Showcase 2030 Sustainable Innovation Summit, 31 May 2023, SwissTech Convention Center, Lausanne, Switzerland

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