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Iberpay

Experimentation Program in Wholesale Digital Currency (wCBDC)

A BME White Paper

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1 Executive Summary

In an innovative experiment conducted by BME and Iberpay, alongside major custodians from the Spanish market (including Banco Cooperativo Español, BNP Paribas, CACEIS Bank Spain, CaixaBank, Cecabank, Kutxabank Investment, Banco Sabadell, Renta 4 Banco, Société Générale, and Unicaja), in collaboration with the Eurosystem, the transformative potential of Distributed Ledger Technology (DLT) has been assessed. This technology is pivotal in revolutionizing the settlement of tokenized financial assets using wholesale Central Bank Digital Currencies (wCBDC). This project is part of the ECB's 2024 experimentation program, which aims to deepen understanding of these technologies, receive valuable feedback from various market participants, and foster financial innovation.

Deloitte collaborated with BME and Iberpay in the analysis and interpretation of the results based on their experience in Digital Assets and Post-Trade, providing insights on the impact of using a wCBDC for the Spanish market. These insights have been analyzed and adapted by BME and Iberpay for inclusion in this publication.

The Spanish initiative has validated the feasibility of issuing, distributing, and settling digital bonds under the Delivery versus Payment (DvP) principle, by connecting two DLT-based platforms: the Digital Bond Platform (DBP) developed by BME for managing tokenized securities, and the Distributed Ledger for Securities Settlement System (DL3S) from Banque de France, responsible for managing digital cash through Exploratory Cash Tokens (ECT).

The experiment involved four key use cases in the lifecycle of a digital bond: issuance, over-the-counter (OTC) settlement, coupon payments, and final redemption. Altogether, 210 operations were executed, mobilizing approximately €29.6 million in digital cash.

The findings demonstrate the Spanish market's technical capability to implement solutions that are interoperable with both emerging and traditional infrastructures like TARGET. The experiment also highlights the possibility for entities not participating in T2S to access DLT platforms, thus broadening the access for a wider range of actors within the financial ecosystem.

Next steps include advancing the technological and operational integration between DLT platforms and traditional settlement infrastructures, improving technological architecture to ensure scalability and continuous availability, and establishing a robust regulatory framework. Effective adoption of wCBDC will require seamless collaboration between the public and private sectors. It will be critical to define clear standards and ensure their alignment and integration with the existing financial infrastructure.

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2 Introduction

New Settlement Models in the Digital Asset Ecosystem

Tokenization is indeed transforming traditional financial markets by enhancing efficiency in asset management and financial transactions. Initially applied in crypto-asset markets, this technology has evolved to operate within regulated financial environments, where its potential to address existing frictions and generate innovative use cases is being explored.

This drive towards tokenizing traditional assets is creating increasing demand for financial infrastructures based on DLT networks that can operate efficiently and reliably in this new ecosystem. This requires a digital payment instrument denominated in a reference monetary unit, facilitating transaction denomination and ensuring settlement. Particularly, Delivery versus Payment (DvP) and Payment versus Payment (PvP) mechanisms, based on DLT, highlight the potential transition toward tokenized forms of money. Without this form of money, key transactions like the sale of tokenized bonds or shares could not fully leverage the benefits of tokenization for financial markets.

Delivery versus Payment - DvP

DvP transactions enhance the stability and efficiency of global financial markets by ensuring that securities transfers occur only when corresponding payments have been made, significantly mitigating counterparty risk. In 2023, DvP and Free of Payment (FOP) transactions constituted a significant portion of the traffic processed in T2S (European Central Bank, 2023). According to the Bank of Spain, an average of 675,000 transactions were settled daily in April 2023, with 472,000 being DvP operations, achieving a settlement efficiency of 93.72%, highlighting its role in process optimization and risk mitigation (Banco de España, 2023).

The high volume of transactions and the need to enhance settlement efficiency highlight the necessity of exploring advanced technological solutions, such as DLT-based settlement, to overcome the inherent limitations and operational risks of the current system. Today's settlement process involves numerous market participants, such as brokers, custodians, central securities depositories, and clearinghouses. This requires executing numerous messaging instructions, payments, and reconciliation procedures. Opportunities exist to improve process efficiency, reduce costs, and minimize operational risks by evolving towards more optimized systems. By incorporating a tokenized settlement model and a tokenized securities platform, many operational risks can be reduced by shortening settlement timelines and reducing the number of actors involved in the process. Additionally, simultaneous settlement of securities and cash could reduce the counterparty risks to which entities are currently exposed.

This is one of the reasons why the European Commission approved a pilot regime for market infrastructures based on distributed ledger technology (Regulation 2022/858, commonly known as the DLT Pilot Regime). This regime permits the issuance, trading, and settlement of financial instruments using blockchain technology. It mandates that for the settlement of DLT-based securities transactions, the Multilateral Trading Facility (MTF) must ensure that the buyer's payment is made simultaneously with the seller's delivery of securities, adhering to the delivery versus payment principle. To foster this immediacy, implementing a tokenized settlement model capable of integrating with trading and settlement systems—or at the very least, ensure interoperability—is essential.

Payment versus Payment - PvP

Cross-border transactions are also critical to the global economy, with daily transaction volumes reaching trillions of euros. In 2023, according to the World Trade Organization, global trade services traffic grew by 9%, fueled by the recovery of international travel and the surge in digital services, underscoring the growing global economic interconnectedness (World Economic Forum, 2024). Additionally, the total value of cross-border transactions—which include wholesale payments between financial institutions, retail transfers, and remittances—is expected to reach $250 trillion by 2027, up from $150 trillion in 2017 (Financial Times, 2024).

However, these transactions are not without challenges. Payment versus Payment (PvP) models, primarily used in cross-border contexts, involve the exchange of assets

or currencies between financial institutions located in different jurisdictions. These settlements often rely on other entities with international agreements (such as CLS for FX transaction settlements or International Central Securities Depositories (ICSD) for cross-border securities settlements) or networks of intermediaries leveraging national arrangements (e.g., correspondent banking). Although these mechanisms facilitate transactions, their scope is limited, covering only certain currencies, assets, and financial entities capable of conducting such movements, causing cross-border settlements to be slow, opaque, and costly processes that entail significant risks.

Consequently, within the PvP transaction domain, substantial improvements can be achieved by applying distributed ledger technology (DLT). Currency exchanges or commercial transactions could be conducted instantaneously, significantly lowering counterparty risk while improving transaction efficiency and security.

In conclusion, given the current scale of operations, the inefficiencies in certain processes, and the proliferation of projects aimed at improving these through DLT technology in PvP and DvP processes, it is vital for both public and private entities to explore various methods to establish reliable tokenized cash settlement mechanisms, both from regulatory and technical perspectives. This will provide a solid foundation for emerging use cases in the capital markets industry, enhancing efficiency, security, and transparency in financial transactions.

3 Theoretical Framework of wCBDC

While they share similar functions as settlement systems and means of payment, there are different digital money solutions designed to offer stable and liquid value in digital environments, each differing in terms of asset backing, regulation, and design[1]. Notable among these are:

- **Tokenized deposits:** These are digital representations of traditional bank deposits issued through DLT-based networks. They are liabilities of commercial banks used for commercial transactions, intra and interbank payments, as well as internal bookkeeping.

- **E-money tokens:** These digital assets are issued by regulated entities, fully backed by fiat currency, and designed for use as a means of payment. In the European context, these assets are defined and regulated under the MiCA Regulation, requiring 1:1 convertibility with the reference currency and issuance by authorized entities subject to regulatory requirements akin to those for traditional electronic money.

- **Wholesale Central Bank Digital Currency (wCBDC):** This is a digital version of money issued by a central bank, specifically designed for use by regulated financial institutions, such as commercial banks and other authorized entities participating in wholesale payment systems. Its use is restricted to the financial sector, for transactions among regulated entities and wholesale institutions.

Due to their characteristics, wCBDCs are especially advantageous for interbank payments and the settlement of tokenized asset transactions globally. This is because wCBDCs can provide a safe and efficient settlement asset, with negligible credit and liquidity risk.

In contrast, tokenized deposits and e-money tokens, issued by private entities, allow redemption at nominal value in sovereign currency. However, these instruments differ in terms of transferability and role within the financial system, which may affect their interoperability with CBDC frameworks.

Over the years, numerous initiatives exploring the benefits that distributed ledger technologies offer to current ecosystems have emerged[2]. However, the significant role of wCBDCs in the industry requires the development of initiatives that integrate the management of wholesale digital cash.

The Importance of wCBDC

Financial Market Infrastructures (FMIs) are fundamental to financial stability, as their operations are closely tied to settlement assets. According to the Principles for Financial Market Infrastructures (PFMI) by the Bank for International Settlements (BIS, 2012), central bank money (CeBM) is preferred due to its elimination of credit and liquidity risks, ensures irrevocable transactions, and reinforces financial stability as a highly secure and trusted settlement asset.

However, the availability of central bank money is not always guaranteed, as some accounts or services may be inaccessible or not operate during required hours. Consequently, FMIs may resort to commercial bank money (CoBM), which, although more accessible, carries credit and liquidity risks, such as loss of access to funds in the event of insolvency. To mitigate these risks, FMIs enforce stringent controls on solvency, capitalization, and regulation of commercial banks.

The shift towards tokenization demands the integration of central bank public money into DLT ecosystems to improve operational efficiency and enable automation. wCBDCs stand out as an option to bolster security in settlements, reduce counterparty risks, and serve as a benchmark asset within systemic infrastructures, incorporating advanced tokenization functionalities (BIS, 2023).

Furthermore, a wCBDC should be integrated with DLT platforms and traditional settlement systems like TARGET through innovative mechanisms such as on-ledger issuance or interoperability bridges that facilitate the connection between both infrastructures. The Eurosystem explores interoperability, crucial in light of the emergence of DLT platforms without standardized settlement systems, where a wCBDC could play a central role.

1 Annex 1 includes a diagram detailing the characteristics of tokenized deposits, e-money tokens, and wCBDC, analyzing aspects such as issuer, regulation, use cases, and other relevant considerations.

2 See Annex 2 for specific examples.

4 Introduction to the Experimentation Program

Objective of the Experiment

For some time, the industry has expressed the need for enhanced engagement with the Eurosystem to continue exploring new technologies for central bank money settlement. Therefore, on December 13, 2023, the European Central Bank (ECB) issued a call for expressions of interest to participate in experimentation on the settlement of tokenized financial assets in wCBDC, to be developed throughout 2024.

Previously, in 2022, the Eurosystem launched the NTW-CG (*New Technologies for Wholesale settlement Contact Group*) to analyze the impact of new technologies on financial asset settlement. Within this framework, a program was established to assess various models for integrating central bank money within DLT environments.

According to the document "Introduction to NTW-CG" by the European Central Bank, the Eurosystem's work has three main objectives, while reinforcing central bank money as a cornerstone of stability, integration, and efficiency in the European financial and payment system (European Central Bank, 2023):

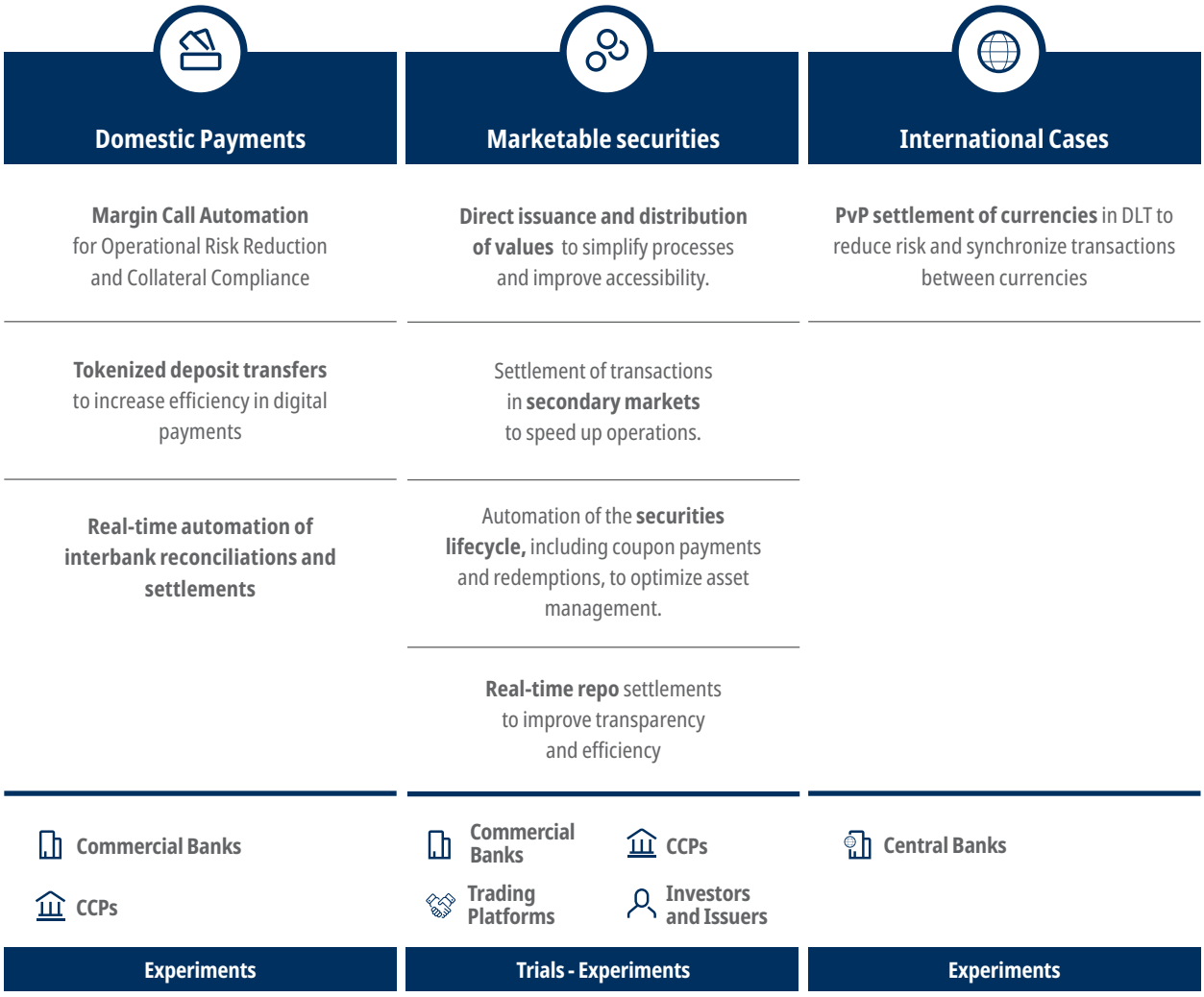
- Enhance the Eurosystem's knowledge and understanding of different solutions.
- Consistently and coherently obtain market feedback on potential solutions.
- Demonstrate the Eurosystem's interest and willingness to support innovation.

To achieve these objectives, the experimentation work was structured around nine key areas, mainly related to DvP, grouped into two distinct approaches (European Central Bank, 2023):

- Valued objectives for analyzing the behavior of distributed environment technologies in various proposed initiatives, covering both trials (real settlement using central bank money within a limited timeframe) and experiments (simulated settlement in controlled environments):
  - **Performance and efficiency in settlements:** evaluate DvP based on latency, scalability, and instant and "atomic" settlement.
  - **Reliability and security**: assess the resilience and security of DLT infrastructure in asset settlement.
  - **Information management**: assess privacy, transparency, and reconciliation mechanisms within DLT platforms.
  - **Automation features**: evaluate automation capabilities in DvP processes, including coupon payments and programmable cash leg functionalities.
  - **Integration of interoperability solutions with new environments (market DLT)**: validate technical and operational connectivity with market DLT.
  - **Energy consumption**: assess resource efficiency and explore energy-optimization strategies.
- Additional objectives reviewed in depth:
  - **Integration of interoperability solutions with existing environments (TARGET Services)**: understand how different solutions could integrate with TARGET Services and its potential product design under stable operational conditions, supported by feedback from DLT market operators.
  - **Liquidity management and settlement finalization**: implement liquidity management mechanisms and explore the technical and operational implications of a potential 24/7 operating model.
  - **Preliminary and qualitative cost analysis**: conduct a high-level estimation of the costs and complexities involved in integrating interoperability solutions to multiple DLT platforms.

Regarding the topics reviewed through trials and experiments, the Eurosystem focused on three key areas: domestic payments, securities operations, and cross-border currency settlements. Each area addresses specific challenges of the financial system through the integration of innovative technologies like DLT.

Figure 1. Eurosystem Trials and Experiments.



To investigate and test all the topics and use cases mentioned, three solutions based on interoperability between market DLT platforms and central bank infrastructures for wCBDC settlement were employed. Further information on these solutions is provided in Annex 3.

5 Definition of the Initiative Proposed by the Spanish Market

5.1 Vision of the Use Case

The main objective of the proposed Spanish use case is to explore a solution for the issuance and settlement of digital bonds leveraging blockchain technology. Specifically, the initiative focuses on simulating the settlement of tokenized bonds using central bank money, following the delivery versus payment (DvP) principle. The DvP settlement was conducted through the interconnection of two networks based on different DLT technologies: one operated by BME, which hosts the tokenized securities, and another managed by the Banque de France, where the digital cash or Exploratory Cash Tokens (ECT) are located, with the latter being one of the three solutions included in the experimental setup. This process was designed to ensure atomic settlement, meaning that the exchange of assets occurs instantly and based on an all-or-nothing principle, even with two synchronized platforms.

For the proposed idea, BME's 2022 initiative, BME Digital Bond (BME, 2023)[1] [2] , was leveraged. This initiative implemented a DLT platform to execute the lifecycle of a bond in a regulated productive environment. Thus, through experimentation, the behavior of a bond's lifecycle could be studied, simulating processes such as operations between both DLT platforms, ECT issuance, and the simulation of tokenized bond settlement without requiring deployment in a live environment. Choosing to perform an experiment aligns with the need to assess the solution's feasibility, scalability, and efficiency, avoiding the potential operational complexity associated with a trial under real conditions. Moreover, this initiative achieved higher participation from the Spanish market, driven by objectives of learning and harmonization.

The experiment was organized with the collaboration of BME and Iberpay alongside participation from major custodians of the Spanish market, such as Banco Cooperativo Español, BNP Paribas, CACEIS Bank Spain, CaixaBank, Cecabank, Kutxabank Investment, Banco Sabadell, Renta 4 Banco, Société Générale, and Unicaja. These entities, committed to innovation, decided to become part of the project to explore the possibilities offered by DLT technology in the issuance and settlement of digital securities, ensuring that the solutions developed meet the real needs of the financial sector. BME contributed its expertise as a market infrastructure operator and its prior experience with projects like BME Digital Bond, ensuring proper management of tokenization and securities settlement by connecting traditional and emerging technologies. Iberpay, as a critical payment infrastructure and leader in the field of digital payments, brought its experience from initiatives like Smart Money[3], focusing its efforts on exploring the distribution of wCBDC and its practical applications. Additionally, Deloitte has concentrated on drafting the whitepaper, contributing experience in ECB regulatory projects and specific knowledge in market infrastructures.

This joint effort combines technical know-how, practical experience, and regulatory perspectives, resulting in a complex initiative due to the number of actors involved. Throughout the process, various reconsiderations of the initial idea were required, such as segmenting participants into custodial groups and issuing more bonds than originally planned, to support the anticipated transaction volume. However, these adjustments have provided diverse perspectives to the experimentation, contributing to the successfully execution of the initiative.

Thus, the proposed initiative contributes to the initial objective of experimenting with the issuance of wholesale digital money proposed by the Eurosystem, offering a distinctive contribution to the collective experimentation efforts of the financial community. This also supports the European Central Bank in exploring potential paradigm shifts in managing digital assets in wholesale financial transactions.

1 BME successfully completes its participation in the ECB's experimentation program for the settlement of payment transactions using digital tokens | BME Spanish Exchanges and Markets.

2 Paper-Digital-Bond-20july.pdf

3 SMART MONEY Initiative – Iberpay - Sector Preparation for the Potential Launch of the Digital Euro or Digital Bank Money

Infrastructures and Key Roles

The technical design of the use case is based on the interoperability between two main infrastructures:

1. Digital Bond Platform, DBP (BME):
A platform designed to handle the settlement of digital and tokenized securities. Its main function is to handle settlement orders, ensuring efficient and secure transfers of digital bonds between participant accounts. It also allows for settlement against payment through interconnection with tokenized cash management platforms, as demonstrated in this experimentation.

2. Distributed Ledger for Securities Settlement System, DL3S (Banque de France):
This platform is responsible for managing the issuance and distribution of Exploratory Cash Tokens (ECT). It simulates the creation of digital money within the experimental scope, issuing it into participants' wallets, providing a controlled environment to simulate its issuance, circulation, and use within an experimental financial system.

To ensure the effectiveness of this solution, the following key roles have been defined:

Figure 2. Roles and Functions.

Role		Functions
1	CSD	Orchestrator of the DBP-Network, responsible for generating positions and managing the issuance of digital bonds.
2	Central bank	Orchestrator of the DL3S Network responsible for generating the positions and managing the emission of ECT.
3	Cash Manager	Responsible for wallets and cash, operating as an intermediary between investors, who participate through custodians, and the Banque de France. In addition, it manages and facilitates requests for the issuance of ECTs.
4	Agent entity	It represents the issuer in the management of digital money operations, notifies the CSD of the characteristics of the issuance, and manages corporate events.
5	Custodians	It acts on behalf of investors, managing their securities and cash wallets.
6	Investors	It carries out the operations related to the acquisition of the bonds.

5.2 Technical Definition of the Initiative

For the implementation of the proposed initiative, the three cash management platforms presented by the Eurosystem within the experimentation program have been evaluated.

BME's Digital Bond Platform (DBP) focuses exclusively on managing the lifecycle of tokenized securities. This platform enables the generation of instructions for either payment or cash management but does not manage the associated cash flow, which is managed externally by a dedicated cash platform. The initiative was designed leveraging the traditional two-tiered securities registration structure in Spain[4].

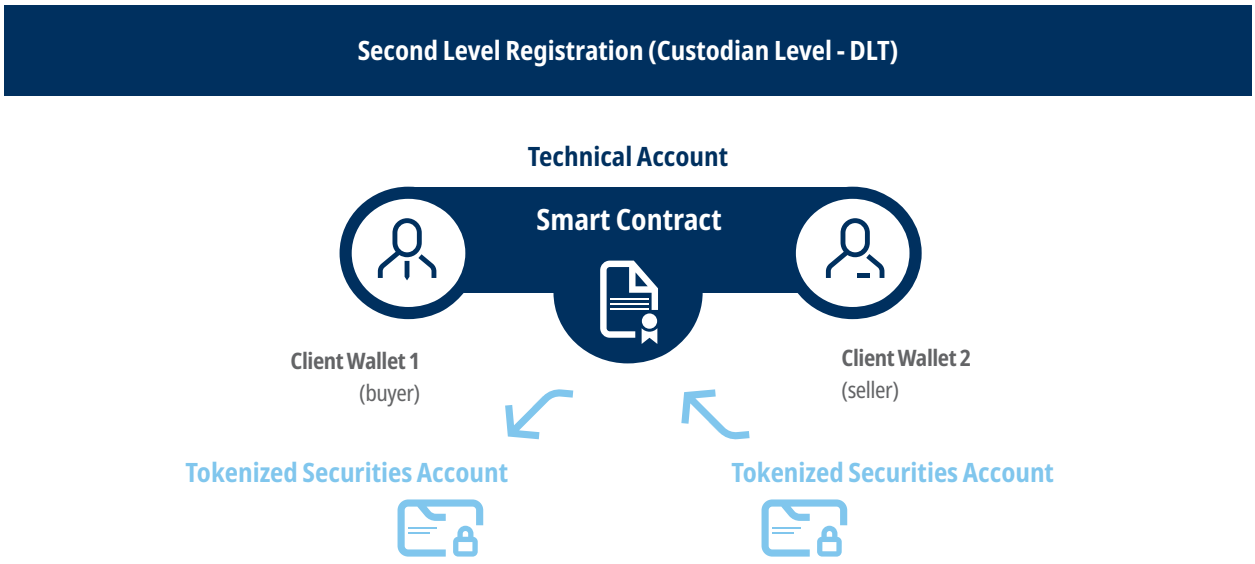
The BME-DBP platform was developed as a blockchain-based system, utilizing a private, permissioned network built on Hyperledger Besu, an Ethereum implementation optimized for enterprise applications. A key feature of this network is its private and permissioned nature, which restricts access to designated accounts. This approach enhances security measures by ensuring that only authorized parties can participate in transactions within the network. Additionally, the network is designed with a limited number of nodes to optimize transaction processing times.

Another key advantage of the network is its "gas"-free design, allowing any DLT address to send transactions without requiring a balance or additional constraints. This facilitates accessibility and ensures an efficient settlement process. The implementation of the QBFT consensus algorithm, based on proof of authority, was chosen for its ability to provide high levels of security and integrity without compromising operational efficiency.

The solution proposed by Banque de France, DL3S (Distributed Ledger for Securities Settlement System), implements a private DLT platform based on Hyperledger Fabric. In this environment, Exploratory Cash Tokens (ECT) are issued to simulate and evaluate their functionality in bond settlement operations. Specifically, all operations involving ECT (mint, burn, settlement) are carried out exclusively on Banque de France's DL3S network, while digital bond operations are managed on the corresponding securities platform.

Within the framework of the Spanish community's experimentation, it was determined that DL3S provides the necessary functionalities for BME's DBP network to synchronize and execute cash management using HTLC protocols, while avoiding unnecessary operational overhead.

Figure 3. Source: BME



4 Given that this is an experimentation, the interaction with the General Register of Iberclear-T2S has been removed, along with all associated reporting and regulatory requirements, allowing for a more efficient and simplified MVP. Consequently, the presented scheme reflects only the level of record-keeping at the custodian level on the DLT, in accordance with the operations implemented in this experimental environment.

Architecture

Regarding the architecture of the platform, BME-DBP was developed by adopting modern architectural best practices, adopting approaches such as Domain Driven Design (DDD), Command Query Responsibility Segregation (CQRS), and Event-Driven Architecture (EDA).

The BME Platform was designed by deploying a series of smart contracts. These contracts serve a dual purpose: they manage various bond issuances and implemented functionalities that cover the entire bond lifecycle, incorporating elements from both primary and secondary markets, as well as corporate events. As a result, this approach allowed for complete traceability of all bond-related activities.

The integration between the platforms of Banque de France and BME was executed through the HTLC (Hashed Time-Locked Contracts) protocol, supported by a communication layer based on REST API over HTTP. This HTLC

Figure 4. Source: Banque de France

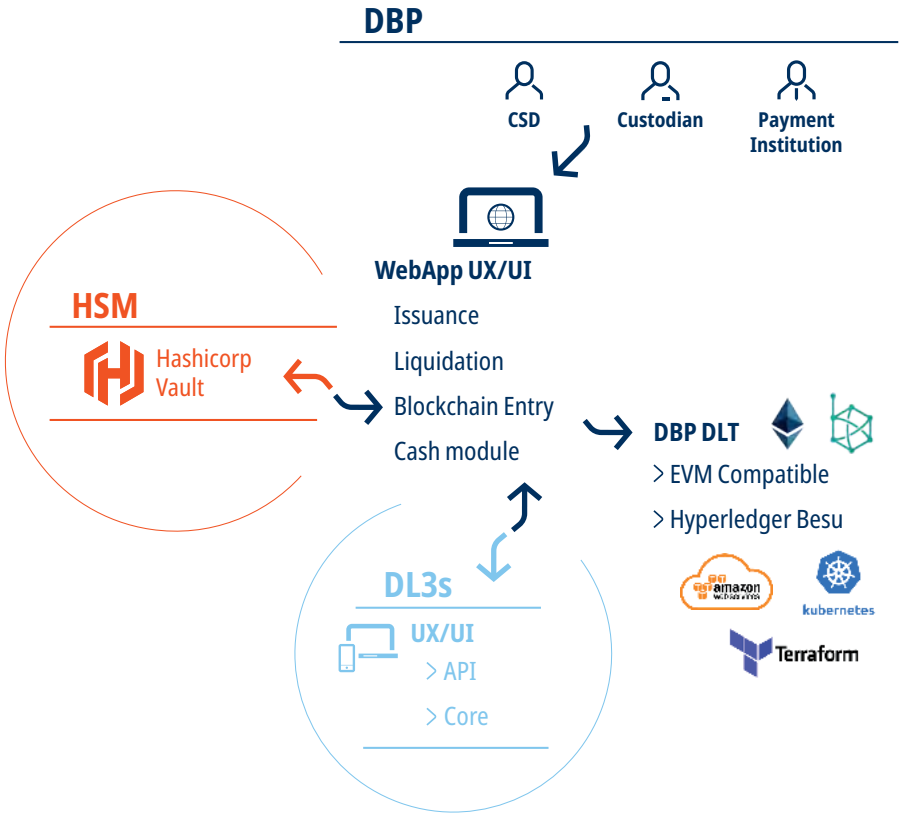
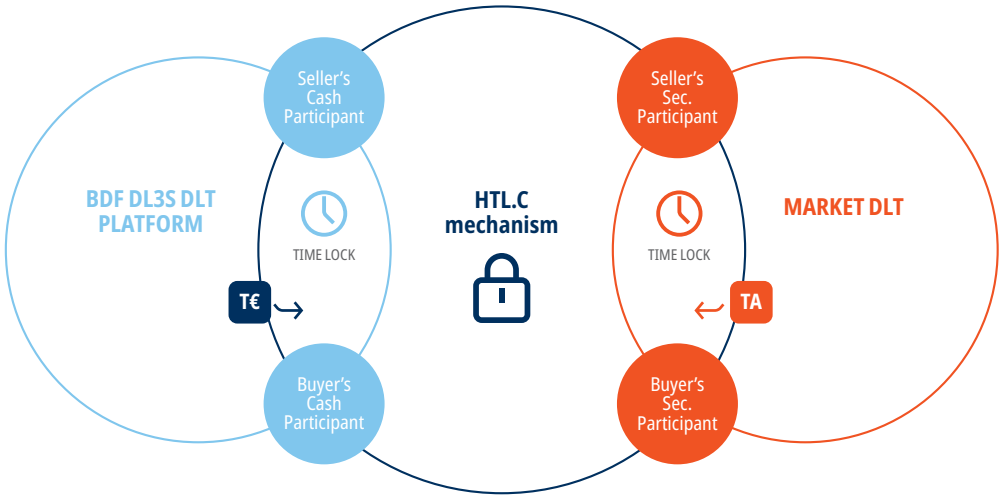


Figure 5. Full-DLT Interoperability Model (Banque de France)



mechanism enables time-bound conditional payments, eliminating the need for a trusted intermediary entity. In this framework, the entities involved in the movements of securities and digital cash (in the form of ECT) interact synchronously to ensure delivery versus payment (DvP) settlement based on the "all or nothing" principle. The process operates under the following key conditions:

1. Securities are delivered and cash is transferred only if both parties meet the conditions set in the contract within the allotted time.

2. If any part of the exchange fails, either due to non-payment or non-delivery of securities, the entire transaction does not settle.

3. In case of failure due to other causes, a pre-agreed contingency procedure is activated to mitigate risks.

5.3 Playbook

The playbook covers the execution of a range of previously identified use cases, covering the entire lifecycle of a digital bond. Its objective is to ensure that at each stage, the integrity of both the digital money and financial securities is preserved: issuance and distribution of the bond, OTC settlement, coupon payment, and final redemption.

These cases were carried out on consecutive days, following the logical order of the bond's lifecycle. The initial goal of the proposed initiative was to demonstrate the technical feasibility of issuing and managing a digital bond in a distributed environment, using a single ISIN across all operations. This approach aimed to simplify coordination among the custodians participating in the initiative, allowing for testing interoperability and efficiency in a controlled context. However, due to the high volume of transactions that needed to be managed concurrently—combined with the additional load from other initiatives running on the DL3S network during the experimentation phase—the program's management recommended adjusting the approach by reducing simultaneous transaction volumes. As a result, five different ISINs, corresponding to five bonds, were issued. The participating custodians were grouped to receive rights and execute OTC transactions. In the following subsections, the processes for these use cases will be elaborated without disclosing specific participants.

In this experiment, two main processes have been defined to manage the interaction between bonds and cash: Delivery-versus-Payment (DvP) and Payment Free of Delivery (PFoD). DvP ensures that the transfer of digital securities (bonds) and cash tokens (ECT) is performed simultaneously, preserving the integrity of both assets and counterparties. The HTLC protocol is used for this purpose, synchronizing the movements of cash and securities, eliminating counterparty risks and ensuring settlement under the "all or nothing" principle.

Figure 6. Lifecycle of a digital bond

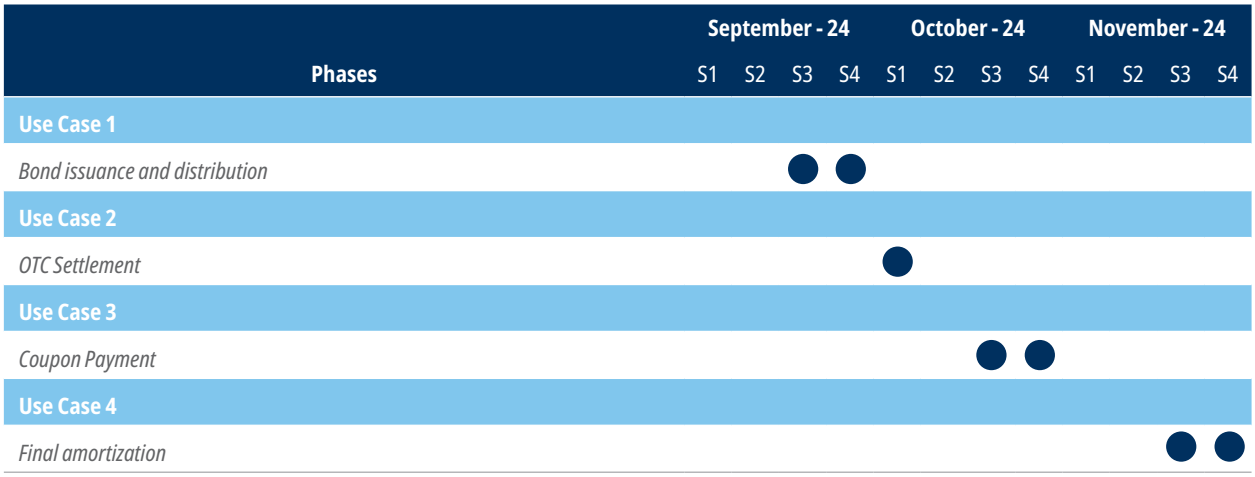
A Bond issuance and distribution	B OTC Settlement	C Coupon Payment	D Final amortization
Bond tokenization	Bilateral settlement instructions between investors from different custodians	Execution of coupon payments according to the deadlines described in the *Smart Contracts*	Simultaneous settlement of cash and securities from both networks
Integrity of securities in distribution to investor accounts	Communication and interoperability between networks		Proper disposal of digital bond securities after completion of redemption
Simultaneous distribution of cash and securities to investors' accounts on each DLT network			Report on wallet holdings and assets for all roles involved
Report on wallet holdings and assets for all roles involved			

On the other hand, PFoD allows for cash transfers without the simultaneous delivery of securities, as in the case of coupon payments. It also simplifies operational workflows in selected scenarios.

In this context, a significant operational peculiarity has been identified: the participation of a custodian lacking direct access to TARGET. As a result, a new settlement model has been explored where cash transfer must occur through an intermediary custodian with access to the cash platform. This division of responsibilities helps highlight operational dynamics and adjustments that could be applied in real-world scenarios.

Lastly, regarding scheduling, the four experimented use cases were executed sequentially across the five issued bonds, following a chronological order over approximately three months.

Figure 7. Phases of Different Use Cases



5.3.1 Wallet configuration in the experimentation

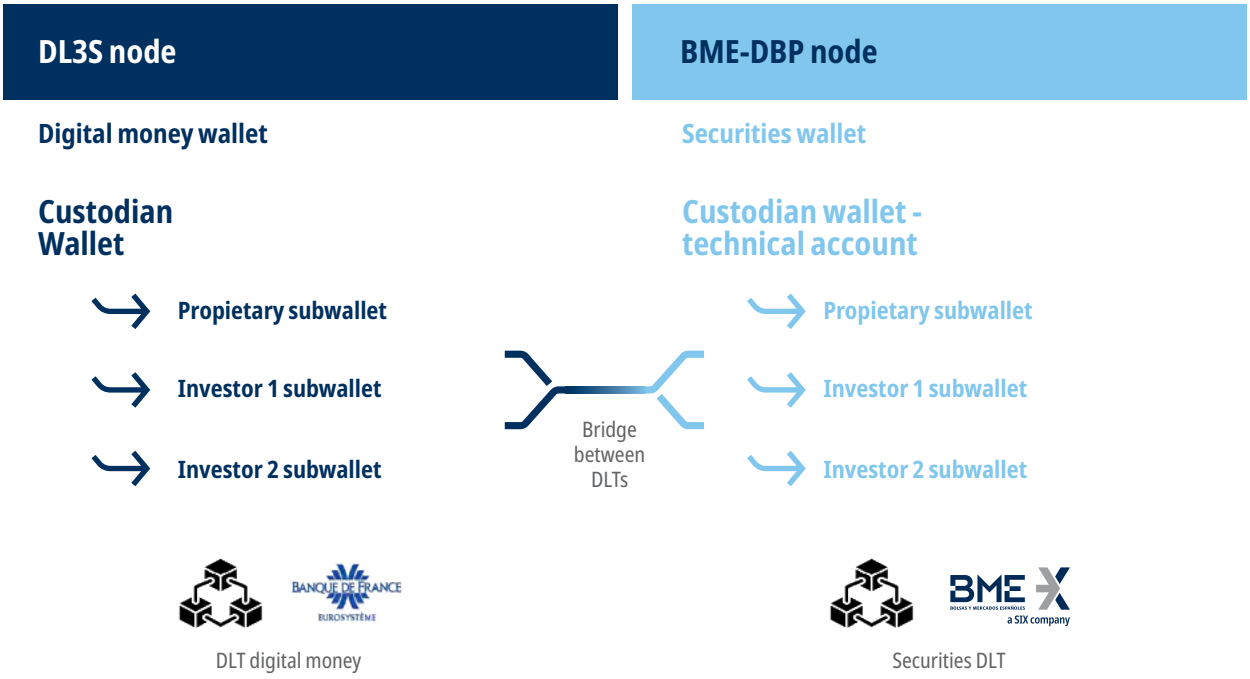
Before detailing the use cases carried out in the experimentation and the movements and instructions executed, it's important to first outline the wallet configuration that was implemented.

Due to the platform settings and with the aim of maintaining one wallet per custodian to replicate the current account setup in settlement systems, the structure of each custodian's wallets was designed as follows:

As shown, for each of the custodians' wallets, three sub-wallets were created to represent the three securities accounts needed for the experimentation (i.e., the sub-wallet representing the custodian's own account and one sub-wallet for each simulated investor). In this way, the custodians' wallets are considered technical wallets used to temporarily hold tokens on the platform, but they do not reflect the custodian's actual asset ownership.

Similarly, and with the intent of simplifying the model, the cash wallets for each custodian were structured considering a sub-wallet for each role represented in the use cases (custodian and investors), thus using each custodian's cash wallet to temporarily manage cash token flows between wallets.

Figure 8. Wallet Configuration. Source: Deloitte



5.3.2 Issuance and Distribution of the Bond

The bond issuance and distribution process is executed using an all-or-nothing model, encompassing the following steps:

Prior to the issuance day, Iberpay, representing the custodians, requests the Banque de France (BdF) to issue ECT for the participants in the DL3S network. The central bank is responsible for allocating the tokens to the respective cash sub-wallets of the custodians and investors participating in the issuance. Iberpay validates that the issuance of ECT has been correctly executed in each sub-wallet.

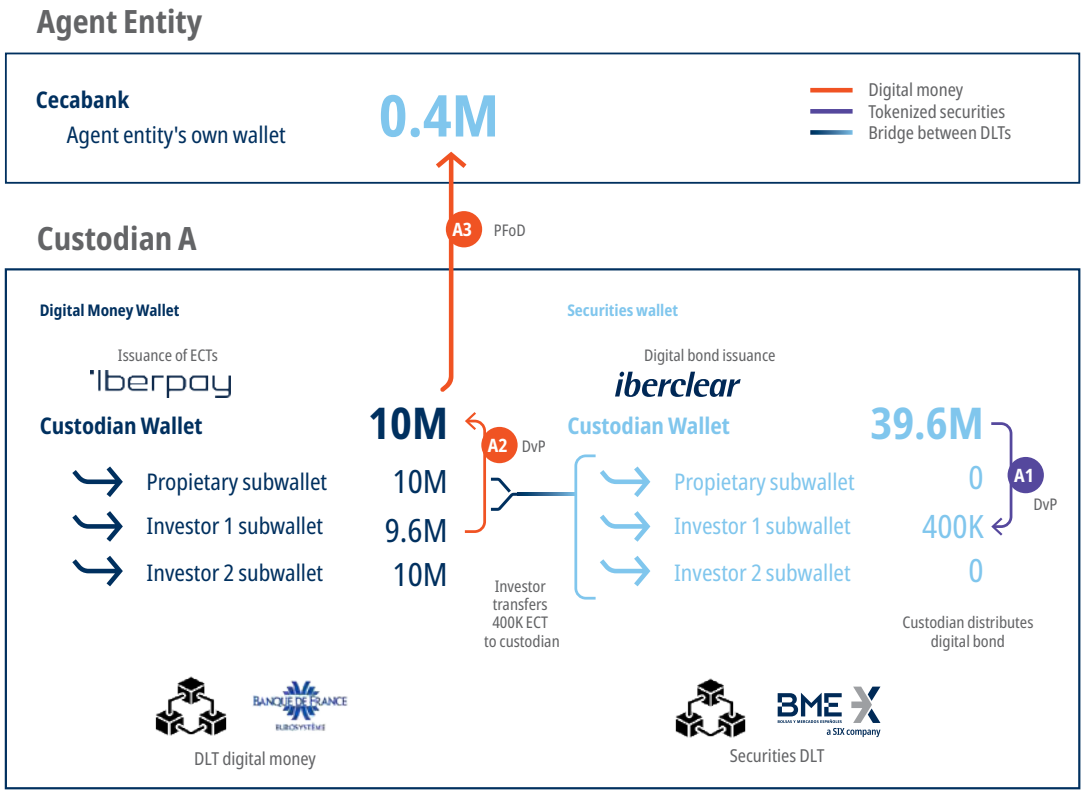
On the other hand, the Agent Entity responsible for managing the initial issuance coordinates with BME to create and allocate the bonds on the BME-DBP platform. Before the issuance day, through the BME-DBP graphical interface, the Agent Entity pre-assigns the bonds to the custodians, who in turn pre-assign them to their clients. The bond cannot be issued unless these pre-assignments have been completed.

On the distribution day, several simultaneous steps occur for the digital bonds to be transferred to the final investors and the cash to reach the agent entity:

- **A-1: Bond distribution**: When the issuance date is reached, the bond tokens are transferred to the sub-wallets of the investors holding a position.
- **A-2: DvP process between investor and custodian**: ECTs are simultaneously transferred from the investors' sub-wallets to the agent entity's wallet, temporarily routed through the custodian's technical wallet of each custodian involved in the process.
- **A-3: ECT transfer to the agent entity (PFoD)**: The bond distribution cannot be successfully completed without the transfer of ECTs to the agent entity through a Payment Free of Delivery (PFoD) process on the DL3S network, instructed from the DBP network, as currently executed in issuance processes.

This process is repeated successively in the different issuances and involved investors.

Figure 9. Issuance and Distribution of the Bond. Source: Deloitte



5.3.3 OTC settlement

The OTC (Over-the-Counter) settlement use cases in the experiment encompass three key scenarios to analyze the transfer of digital securities and cash, as well as any potential differences between them. The established scenarios are as follows:

1. Between investors with different custodians

2. Directly between two custodians

3. Between investors of the same custodian.

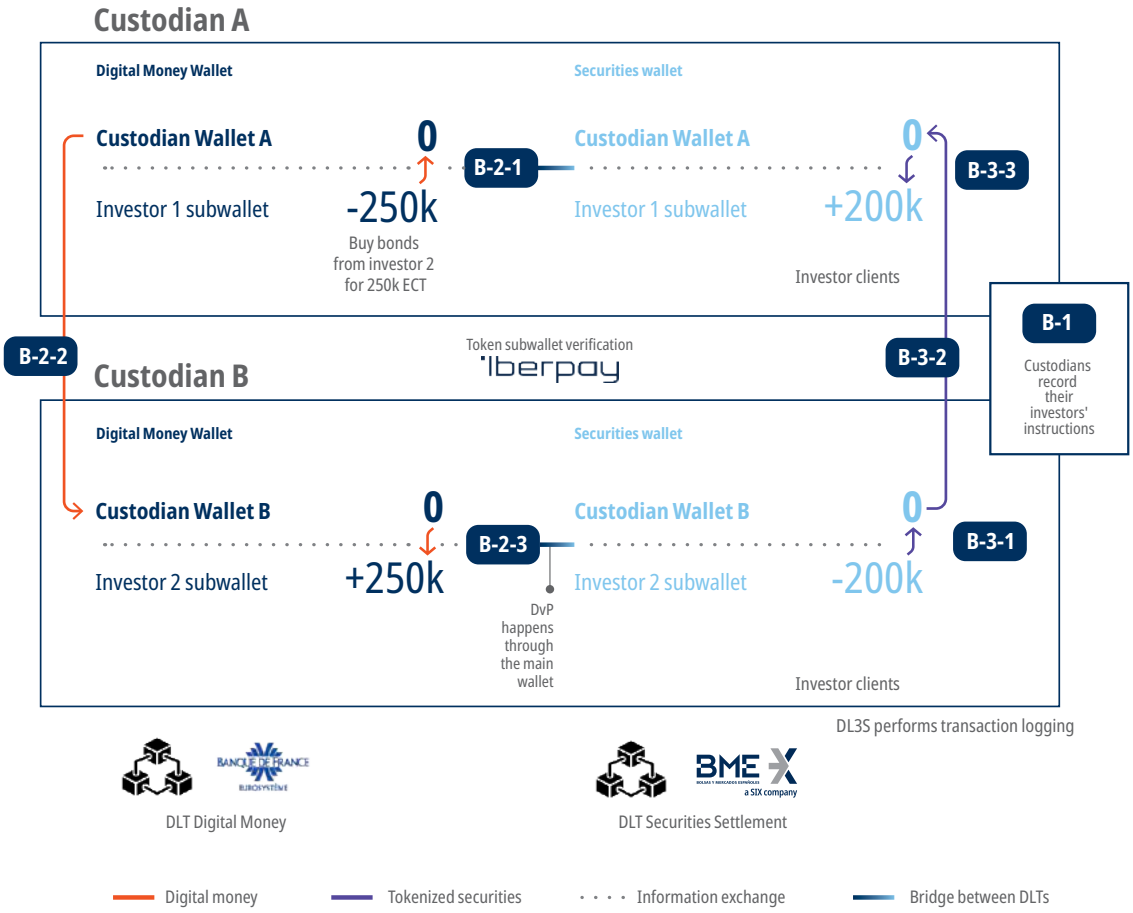
During the execution of the three scenarios, it was found that operationally, cases 1 and 2 show no differences, thanks to the chosen sub-wallet configuration. Below, the operational flows of each case are described:

1. OTC settlement process between two investors represented by two custodians

In OTC operations, the settlement process between investors with different custodians is carried out in several steps, executed as a single atomic operation. As an example, a specific transaction between two custodians is described: Custodian A, acting on behalf of Investor 1 (buyer), and Custodian B, representing Investor 2 (seller).

The process begins with the entry of settlement instructions by both custodians, A and B (**B-1**), on behalf of their respective investors. These instructions specify the transaction details. One of the advantages of DLT is the ability to settle on T+0, so this MVP did not require the definition of different Intended Settlement Date (ISD).

Figure 10. OTC Settlement between Two Investors Represented by Two Custodians. Source: Deloitte



The process continues with a DvP order that coordinates settlement between custodians:

- **RECE settlement (Receive of securities)**: Cash transfer (ECT) from the buyer's custodian (Custodian A) to the seller's custodian (Custodian B).

- **DELI settlement (Delivery of securities)**: Simultaneously, the securities (tokenized bonds) are transferred from the seller's custodian (Custodian B) to the buyer's custodian (Custodian A).

To execute the settlement order, the following simultaneous movements are performed:

- On the DL3S network, ECTs are transferred simultaneously from the buyer's investor sub-wallet to the seller's investor sub-wallet, temporarily routed via technical wallets of the corresponding custodians (**B-2-i**).

- Simultaneously, on the BME-DBP platform, bond tokens are transferred from the seller's investor sub-wallet (Custodian B) to the buyer's investor sub-wallet (Custodian A), also temporarily passing through the technical wallets of the corresponding custodians (**B-3-i**).

Both transfers are executed using the HTLC (Hash Time-Locked Contract) mechanism.

2. OTC settlement process between two custodians

In the secondary market, the settlement between custodians A and B, acting through their sub-wallets, follows the same fundamental processes as the previous one.

First, both custodians enter the settlement instructions, defining the transfer of cash (ECT) and securities (tokenized bonds) (**B-1**). In this case, Custodian A (buyer) enters the Receive instruction (RECE) and Custodian B (seller) enters the Delivery instruction (DELI).

Once both operations are matched, DvP settlement between custodians is executed, involving the following simultaneous movements:

- On the DL3S network, ECTs are transferred simultaneously from the buying custodian's sub-wallet to the selling custodian's sub-wallet, passing temporarily through the technical wallets of the corresponding custodians (**B-2-i**).

- Simultaneously, on the BME-DBP platform, bond tokens are transferred from the selling custodian's sub-wallet (Custodian B) to the buying custodian's sub-wallet (Custodian A), also temporarily passing through the technical wallets of the corresponding custodians (**B-3-i**).

As in the previous scenario, both transfers are executed using the HTLC (Hash Time-Locked Contract) mechanism.

3. OTC settlement process between two investors of the same custodian

In this scenario, the process differs slightly from the previous two scenarios, as only one wallet is involved in each network since the movements are between the investor sub-wallets of the same custodian. However, the process logic is quite similar.

As in the earlier cases, the custodian records the settlement instructions, setting the transfer of cash (ECT) and securities (tokenized bonds) (**C-1**). In this case, the custodian (buyer) instructs the purchase instruction for Investor 1 (RECE) and the sale instruction for Investor 2 (DELI).

As with the previous scenarios, next, the DvP settlement between investors is executed, with the following simultaneous movements occurring in this scenario:

- On the DL3S network, ECTs are transferred simultaneously from the sub-wallet of Investor 2 (buyer) to the sub-wallet of Investor 2 (seller), temporarily routed via technical wallet of the involved custodian (**C-2-i**).

- Simultaneously, on the BME-DBP platform, bond tokens are transferred from the sub-wallet of Investor 2 (seller) to the sub-wallet of Investor 1 (buyer), also temporarily passing through the technical wallet of the involved custodian (**C-3-i**).

As in the previous scenarios, both transfers are executed using the HTLC (Hash Time-Locked Contract) mechanism.

5.3.4 Coupon Payment

In the scenario of a coupon payment, there is no movement of securities, so there are no transfers of bond tokens in the DBP platform wallets.

However, for the coupon payment to occur, the corresponding cash movements required for the custodians and investors holding positions on the record date must be ordered, as would occur in real-world settlement processes, from the securities settlement platform, in this case, DBP.

In this use case, the following steps are followed:

The BME-DBP platform verifies and communicates the total bond positions for each participant as of the record date to the agent entity. The agent entity confirms receipt of this information (**D-1**).

The agent entity requests the necessary amount of ECT from Iberpay to execute the coupon payment (**D-2**). Iberpay coordinates with the central bank to mint the ECTs, and the DL3S network allocates the tokens to the corresponding wallets (**D-3**). Subsequently, both Iberpay, acting on behalf of the custodians, and the agent entity validate that the ECTs are available in their respective sub-wallets.

On the coupon payment date, the corresponding ECTs are transferred within DL3S from the agent entity's sub-wallet to the sub-wallets of the custodians and investors holding positions, passing temporarily through the appropriate wallets (**D-4**).

Figure 11. OTC Settlement Process between Two Investors of the Same Custodian. Source: Deloitte

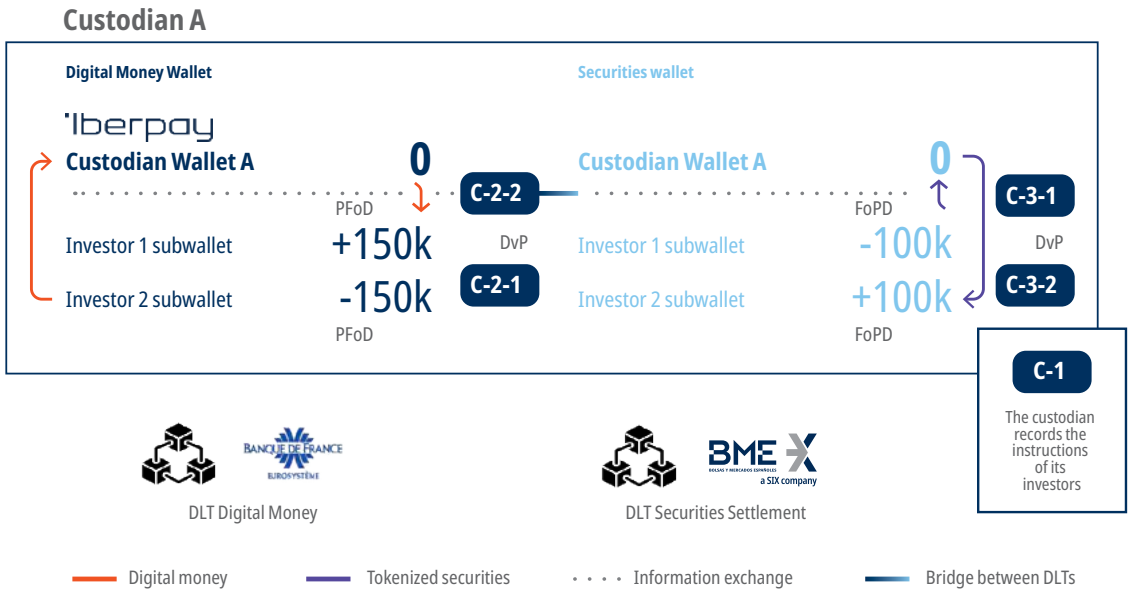
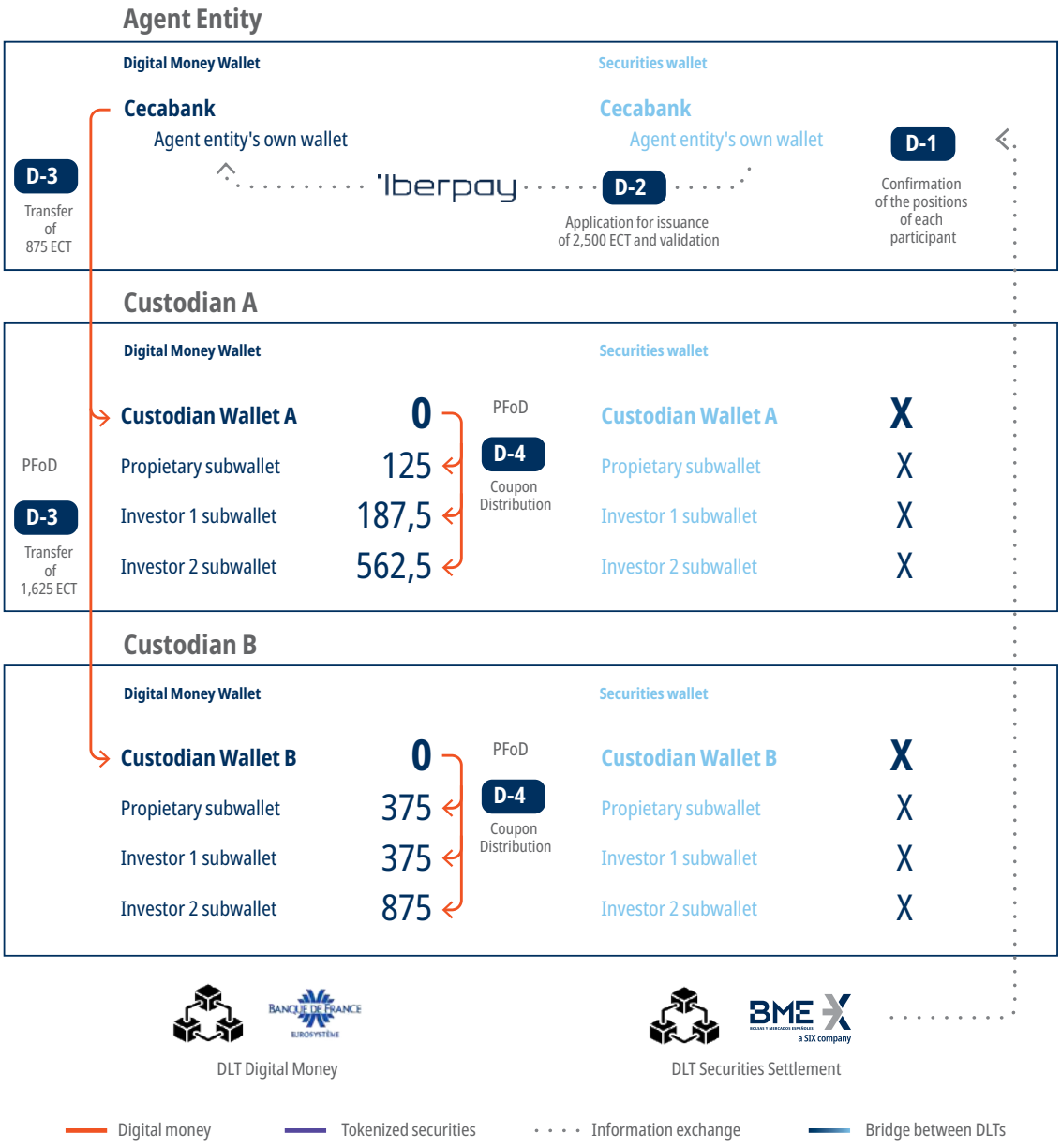


Figure 12. Coupon Payment. Source: Deloitte



5.3.5 Bond Redemption (Coupon Payment + Final Redemption)

The final redemption involves two sequential steps executed in an all-in-one mode:

- A preliminary coupon payment that will involve PFoD-based cash movements, followed by the final redemption itself, which will include DvP operations. The final coupon must be paid, and the bond must be redeemed, which involves transferring tokens to the agent entity to subsequently burn the bond tokens.

This use case can be divided into three blocks:

- The first coupon payment, involving cash-only movements (PFoD), is conducted on the DL3S network from

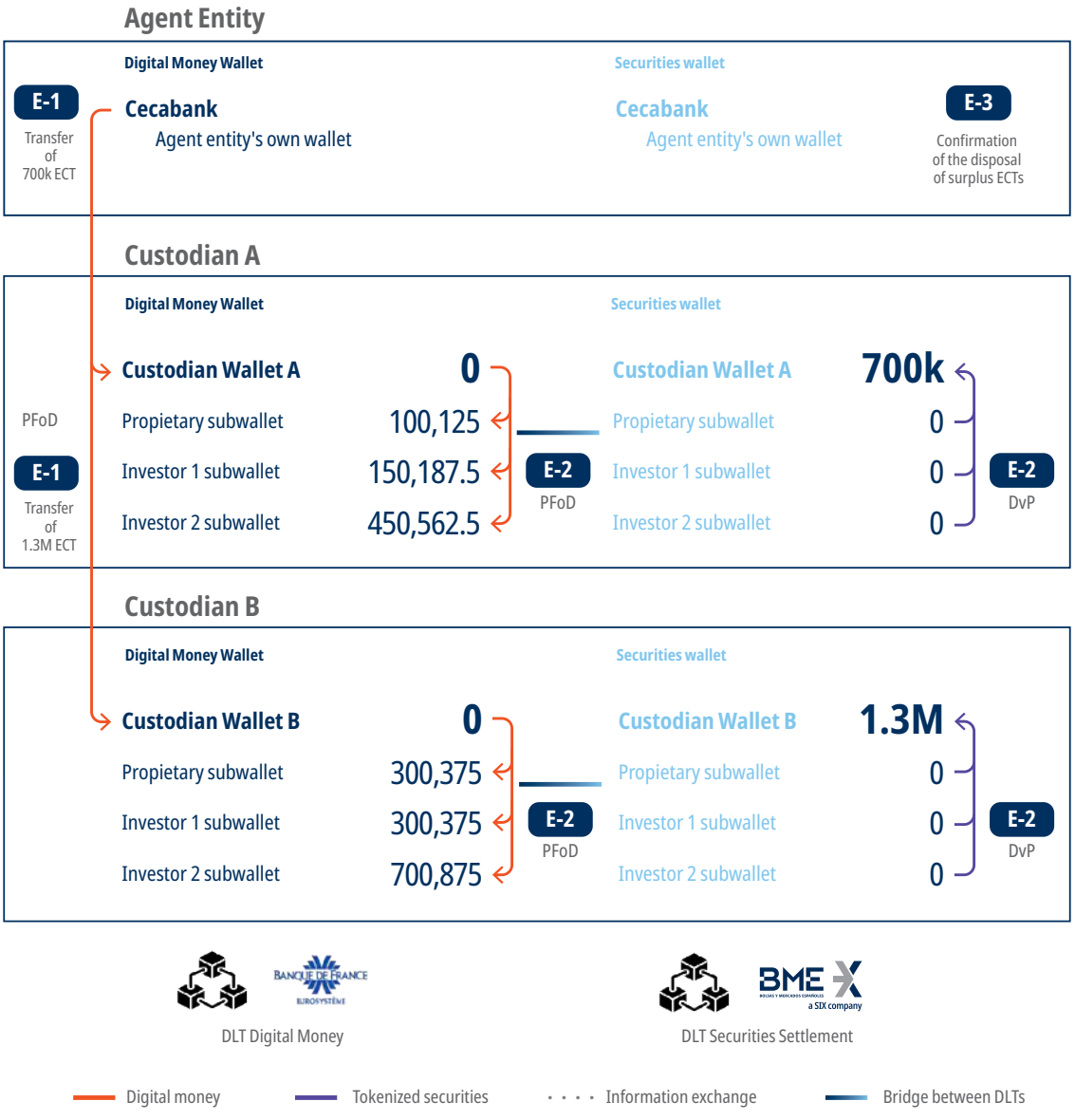
the agent entity's sub-wallet to the sub-wallets of the custodians and investors holding positions, temporarily passing through the relevant technical sub-wallets (**E-1**).

– Next, redemption is executed, involving delivery versus payment (DvP). In this scenario, on the DBP network, movements occur from the sub-wallets of custodians and investors holding positions to the agent entity's sub-wallet, always passing through the relevant technical wallets.

Simultaneously, cash movements on the DL3S network involve transferring the corresponding ECTs from the agent entity's sub-wallet to the sub-wallets of custodians and investors holding positions, also passing through the involved technical wallets (**E-2**).

– Finally, the bond tokens are burned from the agent entity's sub-wallet (**E-3**).

Figure 13. Bond Redemption. Source: Deloitte



6 Experimentation results

This section presents key results on the operational efficiency of the system, evaluated based on the transaction volume and latency analysis of the experimentation led by the Spanish market participants.

It is important to highlight that only volume data and metrics associated with the BME-DBP platform are shown here, as quantitative data from the DL3S platform were provided exclusively by the central bank owner of the platform to the Eurosystem.

Transaction volume and cash flows

The following tables present data on executed operations and the amount of cash mobilized, differentiated by use case: issuance, settlement, coupon payments, and bond redemption.

Figure 14. Source: BME

Total number of operations	210
Issuance	40
OTC Settlement	58
Coupon Payment	32
Redemption and coupon payment	80

Figure 15. Source: BME

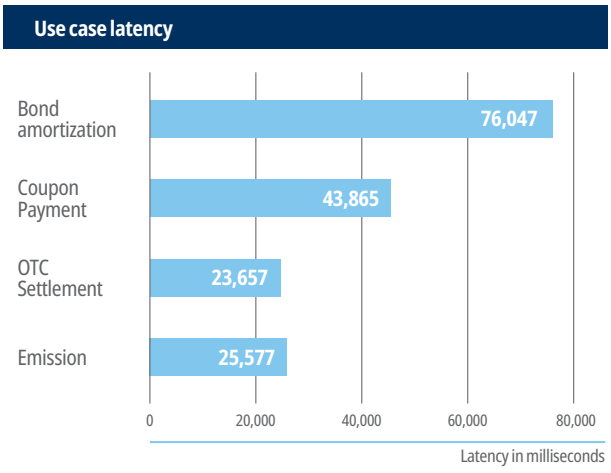
Total cash from operations	29,578,700
Cash issuance	19,000,000
OTC Cash	4,250,000
Cash Coupon	12,500
Cash coupon and redemption	6,316,200

Latency

The following graphs present the analysis of transaction latency, which is the total time elapsed from the initiation to the completion of an operation (end-to-end). Latency is a key performance indicator for assessing the speed and effectiveness of the settlement mechanism, as well as its integration into a digitalized financial environment.

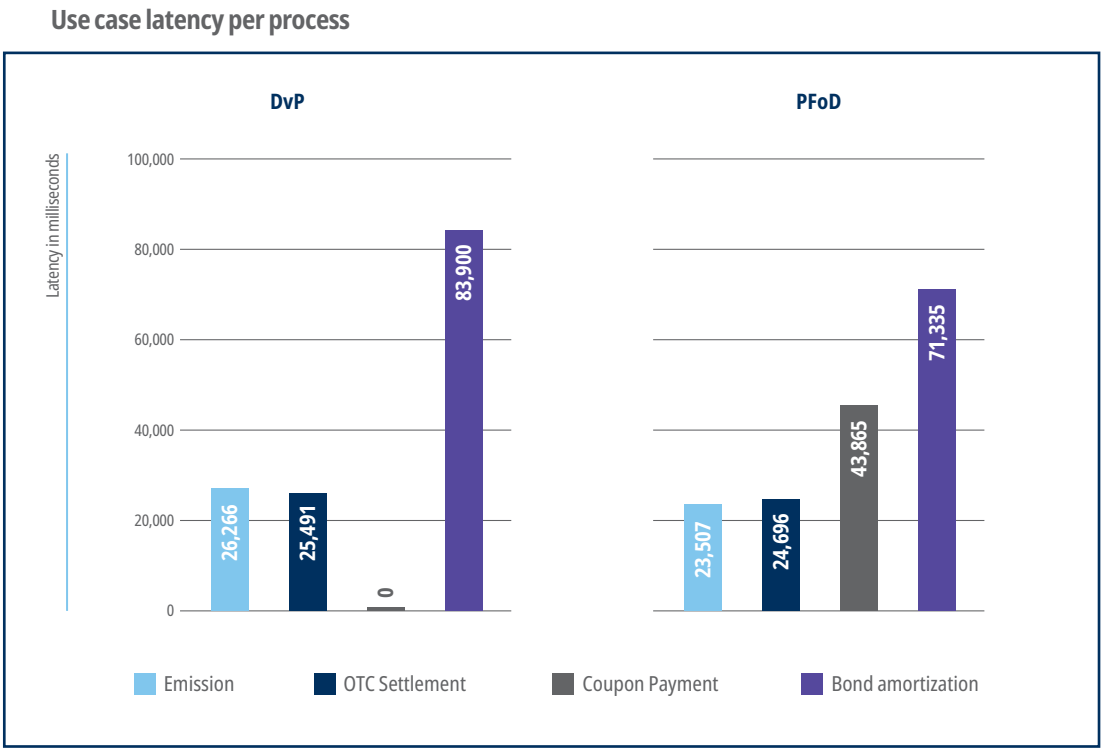
The first figure presents the average latency per use case, considering the five issuances executed in the experimentation by the Spanish community, allowing for a general overview of variability across different scenarios. It is observed that bond redemption transactions record higher latency compared to other types of operations, due to the greater complexity of the process (involving a coupon payment followed by bond redemption) and the additional steps required for execution.

Figure 16. Source: BME and Deloitte



For a more detailed analysis, latency results have been broken down by type of operation within each use case. To achieve this, the average latency was calculated considering all issued securities, differentiating between Delivery versus Payment (DvP) and Payment Free of Delivery (PFoD) transactions. This allows for a unique representative value for each type of operation and use case, enabling a more precise assessment of operational performance.

Figure 17. Source: BME and Deloitte

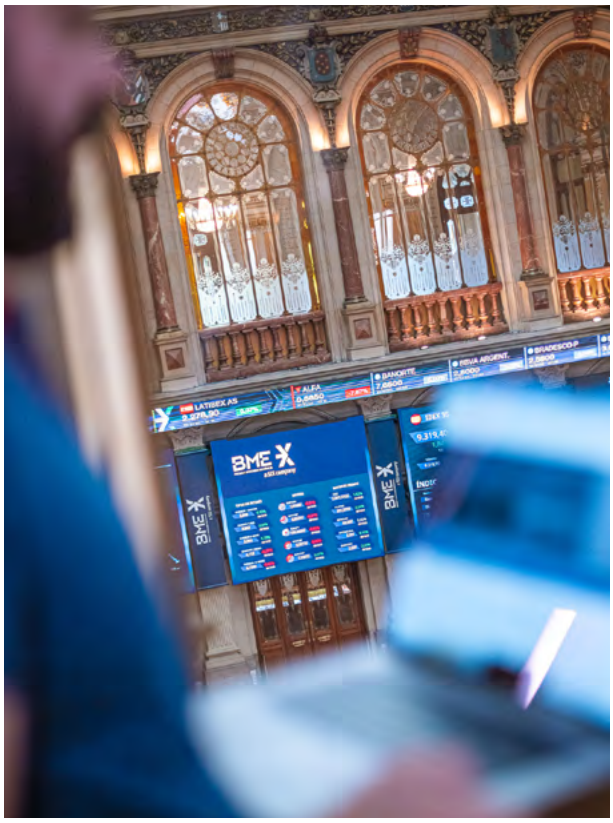


While the analyzed indicators provide a representative view of network interoperability performance, the experimentation was conducted with a specific scope that influences the evaluation of latency compared to consolidated production environments. The observed latency is influenced by both the use case configuration and the network interoperability setup, both tailored to an experimental setup. Therefore, direct comparison with infrastructures like TARGET should be interpreted accordingly within the experimental scope.

Additionally, within the Eurosystem collaboration framework, central banks are collecting data from different initiatives that have participated in the experimentation program, with the aim of publishing findings and development recommendations that will enable more precise benchmarks in future phases. Furthermore, the Eurosystem will continue to provide additional information to facilitate the evaluation of the wCBDC in larger-scale scenarios and its integration with existing infrastructures.

7 Conclusions of the experimentation

The experiment has highlighted the Spanish market's interest in developing solutions based on DLT technology. This interest underscores the need to implement a wholesale central bank money framework that allows the advantages of this technology to materialize, ensuring its integration into the existing financial infrastructure. The experiment results have demonstrated that the market infrastructure and its participants have the technical capability to develop solutions interoperable with the Eurosystem. This interoperability would optimize the settlement of securities and cash in decentralized environments, promoting greater operational efficiency and reducing the risks associated with market fragmentation. This ability is particularly significant in the context of European regulatory initiatives, where interoperability between emerging platforms and traditional payment systems, like TARGET, is a key aspect in the evolution of the financial ecosystem.



Moreover, the experiment validated the full lifecycle of a tokenized bond, from issuance to redemption, verifying the effectiveness of Delivery versus Payment (DvP) and Payment Free of Delivery (PFoD) settlement mechanisms in a decentralized environment. A significant finding is the possibility for non-T2S participants to access trading and settlement platforms on DLT. This suggests a potential broader reach and accessibility of these systems, allowing for greater inclusion of actors in the financial ecosystem and fostering collaboration among various market participants.

However, the development of wCBDCs presents challenges that require further exploration, particularly regarding instant settlement and its impact on legal certainty, as well as efficient liquidity management in a 24/7 operational environment. These challenges, along with the need to advance technological convergence between traditional infrastructures and decentralized networks, shape the next step in the evolution of these models.

In line with this, the Eurosystem has recently announced its intention to expand this initiative to settle operations on DLT-based platforms in central bank money, thereby reinforcing its commitment to innovative market infrastructures (European Central Bank, 2025). This effort is structured around a dual action line: in the short term, an interoperable solution with TARGET services will be implemented, ensuring compatibility with existing infrastructures; while in the long term, an integrated model that allows for DLT-based transaction settlements, including cross-currency settlements on an international scale, will be explored.

This initiative reflects the ECB's commitment to enhancing efficiency and security in European financial markets without compromising system stability. Moreover, it is part of the Eurosystem's efforts to analyze new technologies and foster collaboration with public and private sector actors, ensuring a more harmonized and integrated financial ecosystem (European Central Bank, 2025). These advancements highlight the robustness of the progress achieved so far and underscore the need to continue evolving in the integration of wCBDCs. From these results, the next key development and adoption steps will be identified.

8 Next Steps

The results obtained from the experimentation phase have confirmed the feasibility of wCBDCs and their potential to transform financial market infrastructure. However, their large-scale implementation will require addressing technical, operational, and legal challenges to ensure efficient integration with current systems and maximize the benefits of DLT technology.

In this regard, enhancing collaboration between public and private entities is crucial, strengthening dialogue with market actors through experimentation programs that help identify needs and opportunities. The participation of financial infrastructures and private entities will be key to promoting the adoption of these solutions, relying on the trust that clients place in them as natural intermediaries in asset management.

The transition to a productive environment will require improvements in technological architecture, focusing on optimizing the distribution of Exploratory Cash Tokens (ECT), process automation, and platform programmability. Additionally, ensuring system scalability to manage increasing transaction volumes without compromising operational efficiency or security is essential. Another key aspect will be ensuring continuous operational availability (24/7), enabling participants to access settlement infrastructures uninterruptedly, reducing dependencies on traditional systems. To this end, it will be necessary to evaluate the feasibility of these new models from a regulatory standpoint and guarantee a regulatory framework that provides legal certainty to all parties involved.

In the short and long term, the development of the wCBDC should advance in tandem with the European Central Bank's efforts, ensuring that the proposed solutions address market needs and support the evolution of the European financial ecosystem. The progressive integration of these mechanisms will enable the consolidation of an interoperable and efficient environment, facilitating the adoption of new technologies without compromising the stability and functioning of traditional markets.

Annex 1.
Types of digital assets for settlements

Annex I Table. Source and Preparation: Deloitte

Asset typology	A **Tokenized Deposits (DT)**	B **E-money Tokens (EMT)**	C **Wholesale Central Bank Digital Currency (wCBDC)**
Issuer	- Credit institutions	- EU credit institutions - Electronic Money Institutions Authorized Under the Electronic Money Directive (EMI)	- Central Banks
Collateral asset	- Secured by traditional deposits	- Guaranteed by FIAT 1:1	- N/A
Regulation	- Supervised by the Bank of Spain, which ensures that banks comply with requirements such as: risk diversification, establishment of sufficient reserves, etc.	- Regulation of MiCA in Title IV (electronic money tokens). - The CNMV is the entity designated to supervise the issuance and offering of these assets in Spain.	- Applicable Existing Regulations
Wholesale use cases			
Payment-versus-Payment			
Delivery-versus-Payment	✓	✓	✓
Main Considerations	✓	✓	✓
Technical Considerations	- Part of the need for consortium or interoperable solutions - Technical infrastructure needs to be developed to tokenize cash	- Part of the need for consortium or interoperable solutions - Technical infrastructure needs to be developed to tokenize cash	- Waiting for the ECB to develop the technical infrastructure
Other Considerations	- Guaranteed by the deposit guarantee fund	- MiCA restricts interest payments for e-money tokens and asset referenced tokens. - Part of the need for consortium or interoperable solutions	- The market infrastructure experimentation program developed in 2024 focused on DvP, with a parallel exploration of PvP.
Selected Examples	**Singapore's Project Ubin** Banks like DBS tokenized their deposits on a distributed ledger to enable real-time settlement.	**JP Morgan Coin** A bank-issued digital token representing commercial bank money, used for instant settlement between institutional clients.	**Hong Kong's mBridge Project** A multi-CBDC platform enabling real-time cross-border settlements between central banks of Hong Kong, Thailand, UAE, and China.

Annex 2.
Global initiatives around wCBDC

Helvetia: Led by the Swiss National Bank in collaboration with the BIS Innovation Hub and SIX Digital Exchange, Project Helvetia focuses on integrating a wCBDC with tokenized securities settlement platforms. Its goal is to evaluate how a digital currency can support efficient settlement of tokenized assets in a modern financial market environment.

Agorá: Led by the BIS in collaboration with seven central banks (Banque de France, Bank of Japan, Bank of Korea, Bank of Mexico, Swiss National Bank, Bank of England, and the Federal Reserve Bank of New York), Project Agorá seeks to integrate wholesale money and tokenized deposits on a public-private platform. Beyond being a PoC, it aims to develop a prototype to test current and future use cases, potentially laying the groundwork for a new financial infrastructure designed for cross-border payments.

Jasper-Ubin: This project is a collaboration between the Bank of Canada and the Monetary Authority of Singapore (MAS), exploring the use of a wCBDC for cross-border payments. It stands out for its focus on interoperability between different blockchain platforms, using DLT to facilitate faster and more secure transactions between jurisdictions with different financial systems.

Khokha: Led by the South African Reserve Bank, Project Khokha evaluates the viability of a wCBDC for wholesale payments in a domestic environment. Its main goal is to increase efficiency and reduce costs in interbank settlement infrastructures while ensuring high standards of security and resilience.

Aber: This project is a joint initiative between the Saudi Arabian Monetary Authority (SAMA) and the Central Bank of the United Arab Emirates. Aber focuses on the issuance of a wCBDC to facilitate cross-border payments and improve liquidity management efficiency, testing the viability of a shared solution between two countries with different currencies.

DREX: DREX is an initiative by the Central Bank of Brazil aimed at exploring the issuance of a wCBDC for domestic payments. This project prioritizes the digitization of the Brazilian financial system and improving interoperability among financial institutions.

Dunbar: Project Dunbar, led by the BIS Innovation Hub along with several central banks (Malaysia, South Africa, Singapore, and Australia), investigates the viability of a shared platform for cross-border transactions operating with multiple wCBDCs.

mBridge: The mBridge project is a collaboration between the central banks of Thailand, Hong Kong, the United Arab Emirates, and China. This pilot focuses on multi-currency cross-border payments, testing the use of a DLT platform to increase efficiency and reduce settlement times in international transactions.

Lithium: Lithium is an initiative led by the DTCC in the United States, evaluating how a wCBDC can improve settlement and clearing processes in traditional financial systems.

Annex II Table. Source and Preparation: Deloitte

Projects / Initiaves	Entities Involved	Project Type	Designed scope	Start year	Status
Jasper-Ubin	Bank of Canada, Monetary Authority of Singapore	Pilot project	Cross-border	2018	Completed
Khokha	South African Reserve Bank	Project Proof of Concept	Cross-border	2018	Completed
Aber	Saudi Central Bank, Central Bank of the U.A.E.	Pilot project	Cross-border	2019	Current
Helvetia	Schweizerische Nationalbank, Banque Nationale Suisse, Banca Nazionale Svizzera, Banca Naziunala Svizra, Swiss National Bank	Pilot project	Domestic	2020	Current
DREX	Banco Central do Brasil	Pilot project	Cross-border	2021	Current
Dunbar	Reserve Bank of Australia, Bank Negara Malaysia, South African Reserve Bank, Monetary Authority of Singapore	Pilot project	Cross-border	2021	Current
mBridge	People's Bank of China, Hong Kong Monetary Authority, Bank of Thailand, Central Bank of the U.A.E.	Pilot project	Cross-border	2021	Current
Lithium	DTCC	Pilot project	Cross-border	2022	Current
Agora	Banque de France, Bank of Japan, 한국은행 Bank of Korea, Swissnat, Bank of England, Banco de México	Pilot project	Cross-border	2024	Current
Eurosystem exploratory programme for wCBM	Banco Central Europeo	Pilot project	Cross-border	2024	Current

Project Proof of Concept: Projects at an advanced stage of research that have published a proof of concept.

Pilot project: Advanced projects in development that are being tested in a real environment to evaluate their feasibility.

Cross-border

Domestic

Completed

Current

Annex 3. Different alternatives within the Eurosystem

Full-DLT Interoperability Solution

In this solution developed by the Banque de France, central bank money is issued in the form of tokens managed on a DLT platform (DL3S). This platform is interconnected with different market DLTs, from which transactions with tokenized financial instruments generate payments in central bank money. In summary, the CeBM would be issued as tokenized cash and settled on a Eurosystem DLT platform connected to market DLTs.

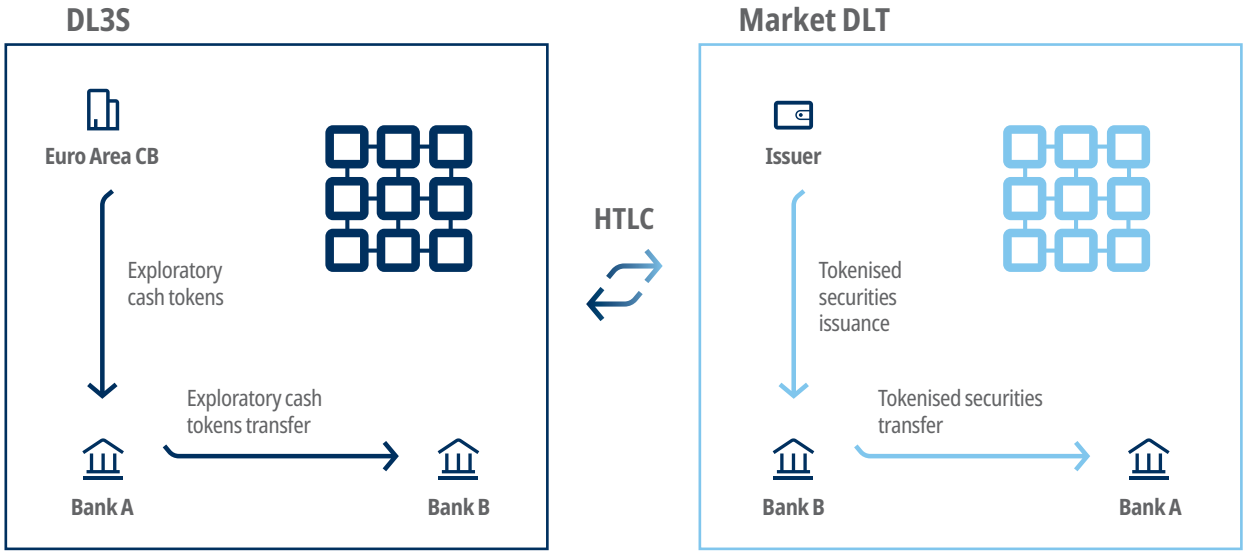
- **Asset leg**: A smart contract on a market DLT locks the asset/payment and sends the payment transaction to the DL3S DLT (Eurosystem's DLT platform for CeBM settlement) through an interoperability mechanism.
- **Cash leg**: The settlement of the cash leg occurs on the DL3S DLT.
- **DvP/PvP**: The interoperability mechanism is responsible for completing the delivery of the cash leg (in the form of tokenized cash) on the DL3S DLT, which releases the asset/payment on the market DLT.

Trigger Solution

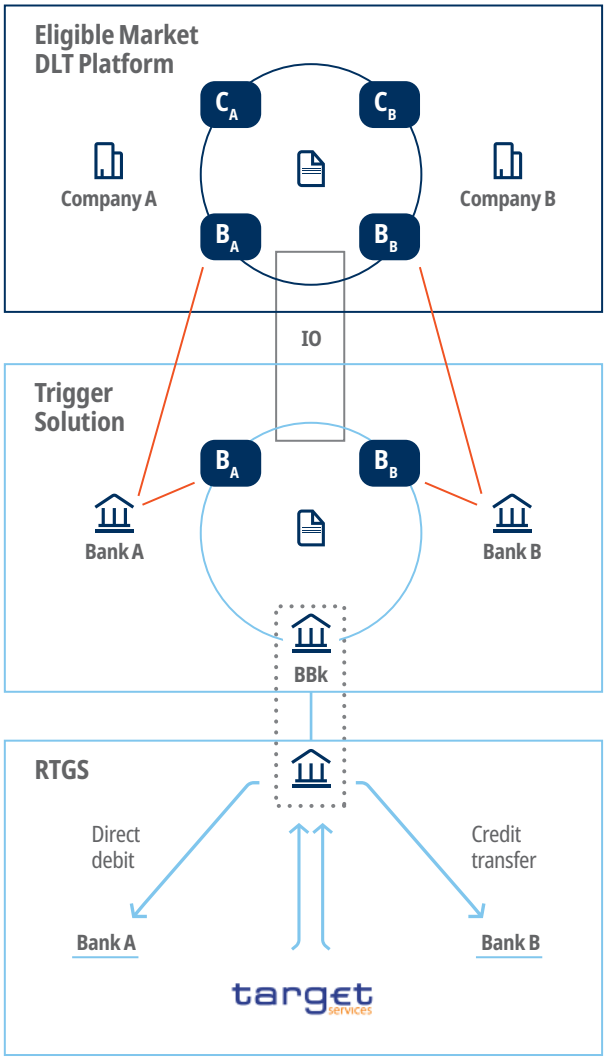
The solution provided by the Bundesbank allows the settlement of wholesale financial transactions based on DLT using central bank money through the current T2 RTGS. The infrastructure, known as Trigger Chain, acts as a "technical bridge" between the T2 RTGS component and market DLT platforms (Asset Chains).

Regarding the designed solution, related experiences have already been conducted. In 2021, the Deutsche Bundesbank, along with the Deutsche Börse Group and Germany's Finance Agency, successfully developed and tested the Trigger solution. A bridge was created between the DLT platform operated by Deutsche Börse and the conventional payment system TARGET2 of the Eurosystem via the DLT platform operated by the Bundesbank (Trigger Chain) to settle DLT-based securities transactions in central bank money, without the need to create tokenized central bank money (Deutsche Bundesbank, 2021).

Annex V. Source: Eurosystem Documentation



Annex III. Source: Eurosystem Documentation



The solution can be categorized and summarized in the following three aspects (European Central Bank, 2023):

- **Asset leg**: A smart contract on the market DLT locks the asset/payment and triggers the payment transaction using the Trigger Chain (Bundesbank's DLT) through an interoperability mechanism.
- **Cash leg**: The payment settlement occurs in TARGET.
- **DvP/PvP**: The confirmation of settlement in TARGET is forwarded to the market DLT to execute the delivery of the asset/payment.

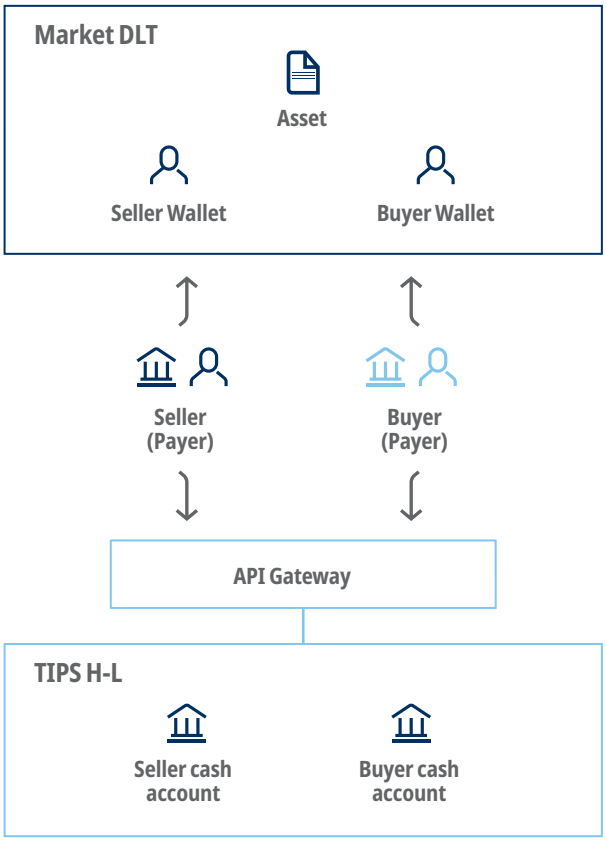
TIPS Hash-Link Solution

The TIPS Hash-Link model provided by Banca d'Italia offers interoperability between a market DLT platform and a payment system (e.g., TARGET) based on the API Gateway design approach. Inspired by the Hash-Time Locked Contracts (HTLC) protocol, TIPS Hash-Link has been adapted to overcome some common failure scenarios of HTLC, using TIPS as a trusted escrow for funds and a smart contract to securely coordinate DvP operations on the DLT.

Regarding its main highlights:

- **Asset leg**: A smart contract on a market DLT locks the asset/payment and forwards the payment transaction via an API and interoperability mechanism (hash link).
- **Cash leg**: Payment settlement is conducted through a platform similar to TIPS.
- **DvP/PvP**: Confirmation of payment in CeBM in TARGET results in the delivery of the asset/payment on the market DLT.
  - TIPS Hash-Link solution provided by Banca d'Italia.

Annex IV. Source: Eurosytem documentation



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