WHOLESALE CENTRAL BANK DIGITAL CURRENCY EXPERIMENTS WITH THE BANQUE DE FRANCE

New insights and key takeaways

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BANQUE DE FRANCE

EUROSYSTÈME

Key policy takeaways

1. Issuing a wCBDC, as a complement to a rCBDC, would contribute to the singleness of money by ensuring the anchoring value of CeBM for both retail and wholesale payments, and convertibility between the different forms of private money.

2. International cooperation and public-private partnerships remain a priority to converge towards a more globally inclusive and interoperable wCBDC framework.

3. Interoperability should be prioritised to ensure seamless data and transaction exchange between DLT-based and conventional infrastructures.

4. Climate-related concerns highlight the need to develop energy-efficient solutions in the design of wCBDCs.

Key technical takeaways

5. Technological advancements related to DLT offer various means for central banks to maintain control over their wCBDC.

6. Central banks should remain technologically neutral while actively contributing to the adoption of common standards.

7. DLT could enhance the straight-through processing of trade and post-trade activities and contribute to overall financial stability.

8. Continued experiments at domestic and international level are essential to advance our analysis and our efforts to develop an operational framework through a learning-by-doing approach.

Executive summary

Distributed ledger technology (DLT) is garnering increased attention from financial institutions, technology companies and end-users, due to its potential to enhance the efficiency and effectiveness of the monetary and financial system. This is leading to a rise in the number of projects in this field.

Central banks play a crucial role in supporting this development by exploring a new form of central bank money (CeBM), called central bank digital currency (CBDC). The development of CBDC is a key challenge for central banks to maintain the anchoring value of CeBM in a digital economy. Although the underlying technologies may be different, this need applies to both retail payments – through the issuance of a retail CBDC (rCBDC) – and wholesale payments – through the issuance of a wholesale CBDC (wCBDC). Both would contribute to preserving the singleness of money by ensuring the convertibility at par between CeBM and commercial bank money (CoBM), at a time when other assumed settlement assets are being developed on DLT, notably stablecoins and tokenised deposits. CeBM can to help mitigate the risks of liquidity fragmentation that could arise from the widespread adoption of private settlement assets. As regards new markets on DLT and the so-called emergence of tokenisation of finance, the ultimate goal of central banks is to ensure that these markets can benefit from the safety of settlement in CeBM, should they develop further and become systemic.

Considering their threefold role (i.e. CeBM issuer, supervisor and market infrastructure operator), central banks are instrumental to contribute to the definition of appropriate rules and regulatory frameworks with regards to DLT ecosystems. The learning-by-doing approach developed so far by the Banque de France should help in order to best assess the requirements for refining regulatory and oversight frameworks and to best appraise the impact of DLT on their mandates.

The Banque de France's significant track record provides valuable insight and perspectives on financial asset and CeBM tokenisation, financial tokens' settlement and the use of CBDC for wholesale cross-currency and cross-border payments. For over three years, the Banque de France has conducted twelve experiments on wCBDC to test the effectiveness and efficiency of wCBDC – defined as tokens of CeBM issued on DLT – in different use cases (wholesale payment and delivery versus payment (DvP) in both domestic and cross-border contexts involving cross-currency exchanges. In order to do so, the Banque de France worked with a range of stakeholders to better understand their needs and challenges, and tested multiple DLT platforms, including multiple blockchains – assuming that central banks should remain neutral regarding underlying technologies. These experiments have been conducted in order to assess how central banks can retain control of CeBM in a DLT environment, regardless of the distribution model and underlying technology.

A number of conclusions can already be drawn on the two major use cases. Regarding the tokenisation of finance, our experiments demonstrate that wCBDC can reduce trade-to-settlement delays by reducing reconciliation flows for transactions carried out on DLT platforms. DLT has also proved its ability to optimise post-trade functions. The second main use case for DLT concerns cross-border payments. Interoperable wCBDCs have been identified as offering strong potential for facilitating cross-currency payments. Multi-wCBDC arrangements could also facilitate cross-border transactions, including remittances, by optimising current correspondent banking models.

The Banque de France's pioneering role in exploring wCBDCs has established a solid base of expertise that is today underpinned by a number of developed assets, including a DLT (called DL3S[1]) and an

1 DL3S stands for Distributed Ledger for Securities Settlement System, refer to **Appendix 3** for a complete description.

automated market maker (AMM), as well as by explorations of other technologies such as Ethereum Virtual Machine (EVM).

The technological assets developed in the course of the Banque de France's experiments have been supplemented by theoretical considerations leading to the conceptualisation of three models for the provision of CeBM: the **INTEROPERABILITY MODEL**, the **INTEGRATION MODEL** and the **DISTRIBUTION MODEL**, all based on DLTs. These models could address several challenges, including offering public solutions for atomic settlement or to enhance cross-border payments. These models are not mutually exclusive, but complement each other and respond to different use cases. Their respective merits are studied in this report, drawing on concrete experience, to contribute to advancing knowledge in the field of wCBDC implementation.

Work on wCBDC will naturally intensify in the coming years, and the report proposes a first set of principles to guide future endeavours, and help wCBDC address adequately the objectives of enhancing efficiency and security of financial transactions, minimising fragmentation concerns and climate-related issues, and offering further room for international cooperation.

This report highlights the following takeaways:

Key policy takeaways

1. Issuing a wCBDC, as a complement to a rCBDC, would contribute to the singleness of money by ensuring the anchoring value of CeBM for both retail and wholesale payments, and convertibility between the different forms of private money.

2. International cooperation and public-private partnerships remain a priority to converge towards a more globally inclusive and interoperable wCBDC framework.

3. Interoperability should be prioritised to ensure seamless data and transaction exchange between DLT-based and conventional infrastructures.

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Acronyms and terms

ACL: Access Control List

AFT: Agence France Trésor

AML/CFT: Anti-Money Laundering and Countering the Financing of Terrorism

API: Application Programming Interface

BIS: Bank for International Settlements

CBDC: Central Bank Digital Currency

CeBM: Central Bank Money

CLM: Central Liquidity Management component in T2 RTGS

CoBM: Commercial Bank Money

CPMI: Committee on Payments and Market Infrastructures

CSD: Central Securities Depository

DeFi: Decentralised Finance

DLT: Distributed Ledger Technology

DL3S: Distributed Ledger for Securities Settlement System

DvP: Delivery versus Payment

DvP: Delivery versus Payment

DwP: Delivery with Payment

ECB: European Central Bank

Eurosystem DLT: Hypothetical name of the DLT owned by the Eurosystem

EVM: Ethereum Virtual Machine

FoP: Free of Payment

FX: Foreign Exchange

HS2LP: Hashed State Lock Private Protocol

HTLC: Hashed Time Lock Contract

iCSD: International Central Securities Depository

Idemix: Identity Mixer

LP: Liquidity Provider

LSM: Liquidity Saving Mechanism

LT: Liquidity Taker

Market DLT: DLT operated by a market participant

NCB: National Central Bank

OTC: Over-The-Counter

PFMIs: Principles for Financial Market Infrastructures

PFoD: Payment Free of Delivery

PoA: Proof of Authority

PoC: Proof of Concept

PoS: Proof of Stake

PoW: Proof of Work

PvP: Payment versus Payment

RBAC: Role-Based Access Control

rCBDC: Retail Central Bank Digital Currency

RTGS: Real-Time Gross Settlement

Side DB: Side Database

SFC: Smart Fabric Client

T2: Eurosystem RTGS

T2S: Eurosystem DvP platform

TTP: Trusted Third Party

wCBDC: Wholesale Central Bank Digital Currency

ZKAT: Zero-Knowledge Asset Transfer

1. wCBDC use cases – two confirmed driving factors

The digitalisation of financial markets has long since enabled the dematerialisation of financial instruments, such as the disappearance of paper medium for representing securities. This has improved not only the efficiency of the processes involved, but also the overall efficiency of resource allocation between the various stakeholders.

With the goals of both efficiency and security in mind, the Eurosystem has, for the past two decades, focused on harmonising the operations of European financial markets, alongside its financial stability mandate and its role in ensuring the smooth functioning of market infrastructures. The implementation of the TARGET2-Securities (T2S) platform in 2015 played a significant role in standardising settlement and securities transactions. More recently, the TARGET2-TARGET2-Securities consolidation project, which went live on March 20, 2023, has effectively reduced liquidity fragmentation by introducing a central liquidity management (CLM) module.

However, the remaining presence of fragmentation in market infrastructures also signifies that there is room for further progress towards greater integration. Indeed, the various stages in a financial transaction are carried out in sometimes heterogeneous regulatory contexts, and involve multiple platforms, each specialised in the trading, clearing or settlement of financial instruments. This multiplicity of platforms necessitates complex management of the interfaces between them, requires consolidation of the information they process for a given transaction to ensure the overall consistency of processing, and is a source of hardware, software and operational costs.

In a cross-border context, payments currently face significant challenges related to their high costs, slow speed, limited accessibility and insufficient transparency. These challenges are directly linked to the existence of a number of frictions. They include fragmented data standards, lack of interoperability, complexities in meeting compliance requirements, including for AML/CFT and data protection purposes, different operating hours across different time zones, and outdated legacy technology platforms[2].

In recent years, DLT has attracted interest from public authorities and the financial industry as it could pave the way for better integration of the various market and post-trade processes. As part of its roadmap for improving cross-border payments, the G20 has also identified the issuance of a CBDC – both retail (rCBDC) and wholesale (wCBDC) CBDCs – and of multi-wCBDC arrangements as a way of facilitating cross-border payments. These two use cases position wCBDC as a safe settlement asset solution on DLT and as a potential factor for improving cross-border payments.

wCBDC would be a new form of CeBM made available to central banks' eligible market participants for settling wholesale transactions through the use of new technologies such as DLT. Providing a wCBDC service would thus extend the benefits of using CeBM on DLT platforms, particularly in terms of settlement finality and for the management of credit and settlement risk following the Principles for Market Infrastructures (PFMIs), established under the aegis of the Bank for International Settlements (BIS)[3]. The work on a wCBDC goes hand in hand with the development of a rCBDC – the digital euro – as both would contribute to the singleness of money and the anchoring value of CeBM for both retail and wholesale payments in the digital era.

On a technical side, DLT provides robust platforms for information circulation and seamless integration of diverse ecosystems. Recognising such benefits, financial institutions and markets are currently embracing

2 Enhancing Cross-border Payments: Stage 1 report to the G20, FSB, 2020.

3 As set in the Principles for Market Infrastructures (PFMIs), a financial market infrastructure should provide clear and certain final settlement and use CeBM when practical and where available (refer to principles 8 and 9, in Principles for financial market infrastructures, BIS, 2012).

this innovative exchange system technology, and multiplying initiatives and experiments aimed at streamlining transactions on-chain. This transformative approach to asset management and transactional capabilities is driving financial institutions to incorporate DLT into their operational strategies.

Large-scale adoption of DLT poses complex challenges at various levels – national, regional, and international. At cross-border level, implementing multi-wCBDC arrangements requires strong international coordination. Interoperability and standardisation are therefore crucial aspects for ensuring seamless integration and collaboration across different DLT platforms and jurisdictions. Establishing protocols and frameworks that enable efficient cooperation among financial institutions, regulatory bodies and industry stakeholders is vital to unlocking the true potential of DLT.

In this context, public authorities and central banks can make a vital contribution to the framework for these two use cases by (i) providing a safe settlement asset on DLT and (ii) addressing the various issues that could allow wCBDC to improve cross-border payments.

1.1 Providing a safe settlement asset on DLT in a tokenised world

1.1.1 Expected benefits of DLT for the financial industry

Towards the end of the 2010s, the financial industry started to show significant interest in DLT and tokenisation due to the numerous promises it holds. Tokenisation involves the conversion of existing financial assets into digital tokens that can be exchanged on distributed ledgers, or the direct issuance of financial assets in tokenised form – so-called "native tokens".

The first report on wCBDC published by the Banque de France in November 2021[4] highlighted the main benefits of DLT, which include: (i) enhancing transparency through better tracking of transactions and ownership; (ii) automating certain market segments that do not currently benefit from automated DvP processes; and (iii) improving cost-efficiency by integrating trade and post-trade activities.

Transparency

In contrast to centralised ledgers, DLT provides easy access to data and transaction records as it is not necessary to request access from a third-party record keeper. This facilitated access is available to all participants, including supervisors who could use it for supervision or oversight purposes, provided that the data is appropriately mapped to ensure the identification of the participants. This greater transparency could ultimately contribute to enhanced financial stability.

Beyond facilitating regulatory reporting, this enhanced information management and data tracking could also support governance by facilitating the monitoring and assessment of certain objectives. For instance, it could be easier to implement conditionality in payments through the programmability of tokens in order to meet criteria such as Environmental, Social, and Governance (ESG) principles[5]. In that sense, DLT could be a vector for improving performance and compliance.

Automation

DLT could be particularly useful for complex transaction processes that are still not sufficiently standardised. DLT opens up the possibility of implementing DvP mechanisms and therefore automating market operations which, until now, have only been processed manually or have required the intervention of a trusted third

4 Wholesale CBDC experiments with the Banque de France, Banque de France, 2021.

5 Blockchain technologies as a digital enabler for sustainable infrastructure, OECD, 2019.

party (e.g. small cap bonds, structured finance and over-the-counter (OTC) traded products). The use of DLT in these market segments, which are particularly exposed to operational and counterparty risks, could help to mitigate these risks. The programmability feature of smart contracts could also be used to optimise liquidity management or enable central banks to issue wCBDCs on DLT with functions specific to central bank operations (refer to Box 1), similar to those allowed on current market infrastructures. Composability features could also be used to manage complex financial products. Automation could help eliminate certain frictional costs that currently impact transactions executed via traditional channels. Lower costs could enable new types of transactions to be carried out, such as transactions on fractional shares of an asset, which could democratise investment.

BOX 1 PROGRAMMABILITY AT A GLANCE

Smart contract programmability opens up new possibilities for automating transaction processes, reducing operational costs and enhancing overall efficiency, including in central bank operations. With programmability, wCBDCs could have smart contract capabilities, enabling the automated execution of predefined conditions and actions. This could include features such as programmable payment schedules, conditional transfers and automated governance mechanisms. The added value of these developments lies in the ability to concentrate on a single platform various types of transactions which are currently split between different dedicated infrastructures (e.g. at Eurosystem level, DvP on T2S, payments in T2 and TIPS).

It is important to stress, however, that while programmability enhances functionality, the core principle of fungibility must be maintained. Fungibility ensures that each unit of CeBM is interchangeable and indistinguishable from another. Programmability should be distinguished from the concept of programmable money, as the latter could imply modifying the fundamental fungibility of money. Striking the right balance between programmability and preserving fungibility is key to harnessing the potential of DLT while upholding the integrity and usability of wCBDCs.

Cost-efficiency

DLT would offer the possibility of facilitating the straight-through processing of trade and post-trade activities, with the aim of significantly reducing settlement times, operational risks and liquidity fragmentation. The current operational processes of a market transaction – the negotiation and agreement on the terms of a transaction – as well as the related post-trade processes – the clearing, settlement and delivery of the securities – are managed separately, which often leads to complex and costly reconciliations. By getting the whole ecosystem for a given market segment – including investors, issuers and custodians – on the same DLT platform, there would be less need for reconciliation and a leaner straight-through processing. The Banque de France's experiments in 2020 and 2021 supported this observation, in particular that conducted with Euroclear which tokenised the wCBDC settlement of post-trade OAT settlement operations (refer to Box 2 and to Appendix 2 for an overview of the Banque de France's experiments).

BOX 2 THE EUROCLEAR EXPERIMENT

Overview of the experiment

Conducted in 2021 in collaboration with the Banque de France, Euroclear France, Agence France Trésor (AFT), primary dealers (BNP Paribas, Société Générale, Crédit Agricole CIB, HSBC Continental Europe) and custodians of the French market, the experiment aimed to evaluate the potential of wCBDC in post-trade OAT settlement operations.

The experiment was conducted in a test environment, with both wCBDC tokens and OAT securities natively issued on the blockchain ledger. It covered the issuance, distribution and redemption of wCBDC, the issuance and distribution of government bonds, operations on the secondary market involving the exchange of these bonds and the payment of a coupon. Participating banks acted as OAT market players and custodians, simulating securities trades.

…/…

Lessons learned

This experiment provided evidence that atomic settlement of a DvP transaction can be executed without the need for a trusted third party, while maintaining the expected levels of anonymity and confidentiality within a market infrastructure. It demonstrated that blockchain technology and DLT can support the implementation of complex business features like REPO management and liquidity-saving mechanisms such as recycling and auto-collateralisation.

By utilising a permissioned DLT such as DL3S[1], central banks have full control over their wCBDC and can adapt their roles in securities management while ensuring that the central securities depository (CSD) fulfils its responsibilities. In this experiment, the issuer of the bond (AFT) was granted the ability to issue securities tokens, and custodian banks could manage securities wallets for their customers. However, the CSD maintained a comprehensive view of all securities exchanges conducted on the platform and participated in validating the securities leg of transactions through its node.

The experiment also showcased the potential to link DLT operations to settlements in the T2S system, paving the way for cross-system use cases. It demonstrated that leveraging the distributed features of blockchain is possible without compromising the supervisory capacity of competent authorities.

1 DL3S stands for Distributed Ledger for Securities Settlement System, refer to **Appendix 3** for a complete description.

1.1.2 Preserving the pivotal role of CeBM for the safe development of tokenised financial markets

As public authorities, central banks must be prepared to accompany tokenisation, maximising the benefits of DLT while minimising the associated risks to ensure market integrity and confidence. The use of wCBDC as a settlement asset on DLT could help addressing these risks.

Market integrity

The adoption of DLT could bring new players to financial markets, who would coexist alongside traditional financial stakeholders. This coexistence could lead to a gradual change in the competitive structure of financial markets, creating a potential need to adapt the role of traditional actors within the transaction chain. Increased competitive pressure from tokenised finance on traditional finance could pose a risk to the integrity of financial markets.

One of the factors that can accentuate this risk is fragmentation, which can be twofold – in terms of both liquidity and technology. On one hand there will be legacy systems, and on the other several types of DLTs, each of them requiring its own liquidity provision. As these different systems and platforms might not at first be interoperable, the result will be fragmented liquidity, the coexistence of multiple standards and the emergence of technological silos. The potential rise of such a silo situation and subsequent fragmentation poses a significant challenge to financial market integrity.

Potential new barriers

In such a scenario, central banks would strive to prevent the emergence of new barriers, similar to those identified in the 2000s (referred to as Giovannini barriers[6]). However, in the 2000s, market practices were established at national level and diverged from one country to another. Today, with DLTs, the divergences are no longer domestic but have more to do with the coexistence of several platforms and the different market practices that will emerge. The efficiency of financial markets, and therefore of future DLT platforms, is indeed strongly dependent on the achievement of sufficient critical mass in terms of the number of products, the plurality of flow exchanges and the number of participants within the network. Given the variety of uses envisaged for DLT, it is plausible that a number of platforms will emerge, each specialising in a different type of financial product.

6 Cross-Border Clearing and Settlement Arrangements in the European Union, The Giovannini Group, 2001.

The Giovannini barriers did necessitate intervention from Eurosystem central banks to facilitate the settlement of financial securities and foster market efficiency. For example, the go-live of the Eurosystem T2S DvP platform in 2015 played a vital role in standardising information exchange methods through the adoption of the ISO 20022 messaging standard. In the context of tokenisation, the role of central banks would be to proactively help consolidate standards and practices as they emerge to protect market integration and prevent the reoccurrence of barriers. One way of ensuring this is to preserve the anchoring of CeBM in wholesale transactions.

Providing CeBM on DLT to ensure the safety of settlements

As the number of assets being issued as tokens on DLTs increases, the need for a safe settlement asset has become apparent[7], as central banks must persist in safeguarding the essential trust in money in this rapidly changing environment.

Recent history teaches that interbank transactions should be settled using CeBM. In fact, the financial crisis of 2008-2009 highlighted the importance of settling financial transactions in CeBM issued by central banks to reduce counterparty and liquidity risks. Commercial bank money (CoBM) or stablecoins cannot provide such security. The importance of settling in CeBM is now enshrined in the Principles for Market Infrastructures[8] (PFMIs) established under the aegis of the BIS for transactions recorded and settled on systemic market infrastructures. Should the use of DLT to issue financial assets develop to the point of making these markets potentially systemic, the use of CeBM as a settlement asset will have to be favoured in order to ensure the safety of settlements.

Moreover, leveraging CeBM through DLT could help to minimise settlement risk for OTC trade, including for investors who cannot benefit from settlement in CeBM money or DvP. Such trades are currently deposited with custodians or international CSDs (iCSDs), where settlement occurs in CoBM in the books of the investors' or fund managers' banks.

A wCBDC should integrate with both the existing and future money and payments ecosystem and expand the range of payment options available. In retail payments, CoBM plays a dominant role in terms of the value of payments in the euro area. CeBM, in the form of cash, plays an anchoring role, which is essential for the singleness of money, and which could be preserved in the digital age with the issuance of a rCBDC, the digital euro. Regarding wholesale payments, it is essential to prioritise and strengthen the use of CeBM within the DLT ecosystem, for the continued application of the aforementioned PFMIs. This is necessary to maintain its anchoring function for interbank and wholesale payments and to ensure financial market stability. Nevertheless, some investors without access to CeBM may be tempted to rely on crypto-assets such as stablecoins to settle their assets on DLTs, creating new risks for financial stability[9] and the integrity of the financial system[10]. This is why tokenised bank deposits, for example, could also be available in the DLT ecosystem alongside wCBDC, with wCBDC playing a pivotal role in ensuring convertibility between the different forms of private settlement assets. This necessary convertibility between private (i.e. any form of CoBM) and public (i.e. any form of CeBM) money also requires interoperability between legacy systems and DLT platforms. Refer to Box 3 for a comparison between stablecoins and tokenised deposits.

7 For more details, refer to the section **Rationale** of Wholesale CBDC experiments with the Banque de France, Banque de France, 2021.

8 Principles for Financial Market Infrastructures, BIS, 2012.

9 Assessment of Risks to Financial Stability from Crypto-assets, FSB, 2022.

10 Stablecoins versus tokenised deposits: implications for the singleness of money, BIS, 2023.

BOX 3 STABLECOINS VERSUS TOKENISED DEPOSITS

The BIS has worked on the differences between stablecoins and tokenised deposits in terms of circulation, valuation and risks, and has helped to define the concept of tokenised deposits[1, 2]. The BIS describes stablecoins as a "digital bearer instrument model", representing a bearer claim on an issuer backed by a pool of assets. Stablecoin units can circulate between customers identified by the issuer (KYC) and beyond to unidentified users without the need to update the issuer's balance sheet. Stablecoins can be exchanged both at par with the issuer and on the secondary market at a market price determined by the credibility of the issuer to repay this claim: the market price is therefore variable.

In contrast, the BIS describes tokenised deposits as a "non-bearer instrument model". They represent a claim on an issuer and are therefore guaranteed by the entire balance sheet of the credit institution (recorded as liabilities). They are therefore not backed by a reserve that would be recorded as an asset of the credit institution. The circulation of tokenised deposits is limited to customers identified by the issuer (KYC) and not beyond. Therefore, the transfer of tokenised deposits between customers of two different issuers would involve a transfer of CeBM, in the form of CBDC, between the issuers. This replicates the current operation of our two-tier banking model, where a transfer of commercial money between two different institutions implies a transfer in CeBM.

1 Stablecoins versus tokenised deposits: implications for the singleness of money, BIS, 2023
2 Annual Economic Report, Section 3, BIS, 2023

As CeBM is the safest and most liquid asset, central banks should get ready to provide it for settling tokenised assets on DLT platforms. This requires exploring various wCBDC solutions, such as providing tokenised CeBM directly on DLT in the form of tokens – in order to take full advantage of the disruptive features of the wCBDC, which integrates both the payment message and the money movement – or implementing trigger solutions that interface DLTs with existing settlement systems.

1.1.3 The European Pilot Regime: a sandbox to assess DLT applications under real conditions

The introduction of the Pilot Regime on March 23, 2023 marks a significant step towards enabling the EU to fully embrace the digital economy. It will promote innovation and enhance competitiveness to provide the benefits of digital finance to businesses and citizens while protecting consumers and preserving financial stability.

The aim is to provide a secure derogatory regulatory framework, initially for a period of three years, renewable once, to test all the expected benefits of DLT (transparency, automation and cost-efficiency) presented in section 1.1.1. For example, the introduction of the DLT trading and settlement system, DLT TSS, (refer to Box 4) will make it possible to test the integration of trade and post-trade activities. More generally, this framework will enable the issuance, storage, settlement, and transfer of tokenised securities (e.g. stocks, bonds, shares in collective investment undertakings in securities) on DLT. It will enable market players to test DLT solutions on a large scale, and in particular to develop the secondary market by allowing DLT to be used to establish a multilateral trading facility (MTF) and CSDs.

The Pilot Regime offers a valuable opportunity for private market players as well as public institutions. In this sense, offering settlement solutions in CeBM – for the cash leg of transactions involving tokenised securities – could allow tokenised finance to benefit from the safest and most liquid asset. The ECB has announced[11] the launch of Eurosystem exploratory work on different solutions for settling transactions in CeBM on DLT. It has also created a new market contact group to foster dialogue and information exchange with the financial industry.

In this context, the Banque de France has conceptualised three different models for providing CeBM directly on DLT (refer to section 2).

11 Eurosystem to explore new technologies for wholesale central bank money settlement, ECB, April 2023.

BOX 4 THE EUROPEAN PILOT REGIME PROVIDES A DEROGATORY REGULATORY FRAMEWORK

The Pilot Regime temporarily exempts DLT market infrastructures from certain requirements under European law, including provisions of the MiFID II directive, the CSDR regulation (such as the intermediation obligation) and the SFD directive.

The Pilot Regime introduces three new categories of DLT infrastructures:

1. DLT multilateral trading facility (**DLT MTF**): a multilateral trading system that exclusively allows for the trading of DLT financial instruments, operated by an investment firm or a market operator operating a regulated market, authorised under MiFID II.

2. DLT settlement system (**DLT SS**): a settlement system for transactions involving instruments registered on the blockchain. This system would be operated by a CSD authorised under CSDR.

3. DLT trading and settlement system (**DLT TSS**): a new infrastructure that combines the services of both an MTF and an SS. It is operated either by an investment firm or market operator or by a CSD.

In order to operate market infrastructures under the Pilot Regime, applicants must fulfil certain common obligations. They are required to:

- Apply for a specific authorisation, with the possibility of seeking exemptions from certain provisions of MiFID II and CSDR if necessary.

- Comply with specific general obligations.

- Adhere to any compensatory measures that the competent national authority deems appropriate to request.

The text entrusts the national competent authorities[1] with the power to grant a specific authorisation under the Pilot Regime and, if applicable, to approve requests for exemptions from certain requirements of MiFID II, CSDR, and SFD that would be incompatible with the use of DLT for trading and settlement of financial instruments. However, any exemption request must be proportionate and justified by the use of DLT.

1 The national competent authorities for France are the ACPR, the AMF and the Banque de France.

1.2 Harnessing the potential of DLT for cross-border payments

1.2.1 The potential of DLT to improve interoperability in cross-border payments

The emergence of DLT opens up new opportunities for improving cross-border transactions. Enhancing cross-border payments has been identified as a priority by the G20, which agreed on a roadmap in 2020 containing 19 measures (referred to as building blocks) aimed at improving existing channels, and studying emerging channels based on DLT. Solutions based on the use of a CBDC have been studied using a forward-looking approach as part of a prospective working group, called Future of Payments, under the aegis of the Committee on Payments and Market Infrastructures (CPMI). They have also been studied through experiments conducted by central banks worldwide and the BIS Innovation Hub. Building on this momentum, the IMF has also been considering how DLT could be used to serve public policy objectives, with a particular focus on the design of multi-currency DLT platforms to facilitate cross-border payments and FX transactions, known as *XC platforms*[12, 13]. The BIS has also carried out research on the design of a single platform through the concept of a *unified ledger*[14], which aims to bring together on a single DLT all kinds of tokenised assets, including tokenised deposits and CBDCs. This contributes to a more specific analysis of the role that wCBDCs can play in improving cross-border payments.

12 A multi-currency exchange and contracting platform, IMF, 2022

13 The rise of payment and contracting platforms, IMF, 2023

14 Annual Economic Report, Section 3, BIS, 2023.

DLT indeed has the potential to address a number of frictions impacting cross-border payments in terms of costs, delays and transparency. Banque de France's experiments have shown that multi-wCBDC arrangements could (i) optimise correspondent banking models by reducing the number of intermediaries thanks to multi-currency wallets and processing times, and (ii) enhance the security and flexibility of cross-border settlement by offering transaction traceability and reducing the need for reconciliation.

By offering a wCBDC, central banks would be operating new systems based on DLT, enabling tokenised CeBM to be issued and used as a settlement asset. Central banks are expected to maintain control over their DLT for the issuance of a wCBDC to safeguard their monetary sovereignty. This is likely to result in the coexistence of multiple wCBDC DLTs on a global scale. The question of their interoperability will arise in the short term in order to ensure the exchange of wCBDC tokens. When dealing with this issue, it will be crucial to avoid the difficulties faced by Real-Time Gross Settlement (RTGS) systems which are not interoperable today, other than regionally or indirectly through mainly multilateral platforms, such as CLS, or through links that have been established via the SWIFT messaging system (e.g. correspondent banking arrangements).

One of the key lessons learned from the experience of conventional systems is the difficulty of interoperating RTGS systems due to constraints linked to standardisation, governance and risk management policies. Interoperating wCBDCs would therefore require international cooperation early on in the operational design of each jurisdiction's wCBDC, given that *ex ante* interoperability is easier than *ex post* interoperability. DLT offers flexibility and its decentralised nature can facilitate the emergence of shared governance. However, the governance issues are multiplied when it comes to global platforms. The emergence of DLT platforms is still in the early stages, which means there is scope to develop international standards for wCBDC cross-border functionalities that can be incorporated into their design, enabling domestic wCBDC DLT platforms to interlink at the international level.

The approach must be step-wise and pragmatic, and the public sector must be at the forefront of this endeavour and be in a position to offer cross-border capabilities to wCBDCs currently under development, so as to avoid the recurrence of technical hurdles that previously hampered the interoperability of RTGS systems. As an example, the Banque de France conducted an experiment based on CeBM, in cooperation with Banque Centrale de Tunisie, to facilitate cross-border transfers in CoBM. A CoBM wire transfer was carried out between two individuals, located in France and Tunisia respectively, via the transfer of wCBDC between the Banque de France and Banque Centrale de Tunisie.

1.2.2 Going further: beyond DLT, using tools from DeFi to enhance liquidity for cross-border payments

Moving towards operationalisation also means defining the tools that could eventually, in the most advanced form, enable cross-border transactions to be carried out fully on-chain, without the need for a return leg to traditional systems which could cause frictions impacting speed, costs and transparency. The Banque de France has conducted a number of experiments to explore the potential of liquidity pools in this respect, particularly for PvP transactions involving foreign exchange on DLT. To do this, it has drawn on innovations from the decentralised finance (DeFi) ecosystem, specifically the automated market maker (AMM), which the Banque de France has been testing for some years and which enables decentralised foreign exchange transactions (FX). Testing this specific application (refer to Box 5) is part of the Banque de France's strategy to explore various DeFi applications for different use cases in a secure framework that preserves financial stability in the DLT environment, as well as financial market integrity.

BOX 5 EXPERIMENTS WITH AMMs (AUTOMATED MARKET MAKERS)

Overall description of the AMM

Unlike traditional FX markets where the price is derived from an order book, the automated market maker (AMM) is based on a pool of liquidity.

In traditional finance and for a given currency pair, market makers offer a set of bids and asks (i.e. the order book) either bilaterally or through trading venues. The liquidity mainly stems from those institutions that cross orders from clients, net their liabilities and hold a small portion of the trading flows on their balance sheets. Ultimately, given the high volume of supply and demand, the prices offered for buying and selling are extremely tight, converging towards a reference rate (at the lowest spread between the different prices) as a result of the competitiveness between the market makers.

In contrast, the AMM does not operate on an order book with multiple market makers. The AMM acts as a (single) counterparty for all currency buyers. Liquidity comes from a liquidity pool in which all AMM participants (not just market makers) have the opportunity to provide liquidity. The AMM uses smart contracts and algorithms to automatically set prices that depend on the reserves (i.e. the quantities of CBDC currency tokens in the pool), the size of the transaction and the direction of the exchange by ensuring that the total value of the liquidity pool is the same before and after each transaction. There is no need to find a counterparty for the FX transaction and the liquidity pool operates 24/7.

The Banque de France's experiments with AMMs

The Banque de France has been able to explore the potential of AMMs through different experiments, with:

- The Monetary Authority of Singapore in July 2021;
- The BIS Innovation Hub, the Monetary Authority of Singapore and the Swiss National Bank as part of Project Mariana.

The experiments explored two use cases, namely: (i) payments with FX currency conversion and (ii) PvP between different wCBDCs.

All the operations were carried out on a shared network on which the wCBDCs circulated. This shared network enabled the participating central banks to have a comprehensive view of cross-border payments, while retaining independent control over the issuance and distribution of their own wCBDCs.

To manage FX transactions, an AMM with a liquidity pool was set up, to which participating banks with excess liquidity can contribute in wCBDC.

Experiment with the Monetary Authority of Singapore

The joint experiment with the Monetary Authority of Singapore in 2021 consisted of deploying the AMM smart contract on a single blockchain network based on a private and permissioned version of Ethereum capable of accepting multi-currency wallets. This first version of the AMM was deployed to process a small volume of daily transactions in a PoC.

Project Mariana[1]

Using an AMM, Project Mariana explores joint trading and settlement of wCBDCs, expanding on previous cross-border wCBDC projects that focused on settlement only. The AMM enables decentralised FX trading and settlement using wCBDCs and is hosted on an international network.

The liquidity pool underpinning the AMM is designed as a three-token pool, made up of EUR, SGD and CHF wCBDC. Combining all currencies in one pool increases the potential size of the pool and reduces fragmentation, increasing its chance of providing a reference price.

There are two groups of actors interacting in AMMs: (i) liquidity takers (referred to as LTs or traders and arbitrageurs) and (ii) liquidity providers (referred to as LPs).

.../...

1 Project Mariana: Interim report, BIS, 2023.

In return for their deposit in the liquidity pool, the AMM LPs get a token representing the relative share of their deposit in the pool (so-called liquidity provider tokens, or LP tokens). This share determines the compensation for their deposit, which is paid by liquidity takers through transaction fees[2]. LP tokens also allow participants to track their holdings in the pool over time.

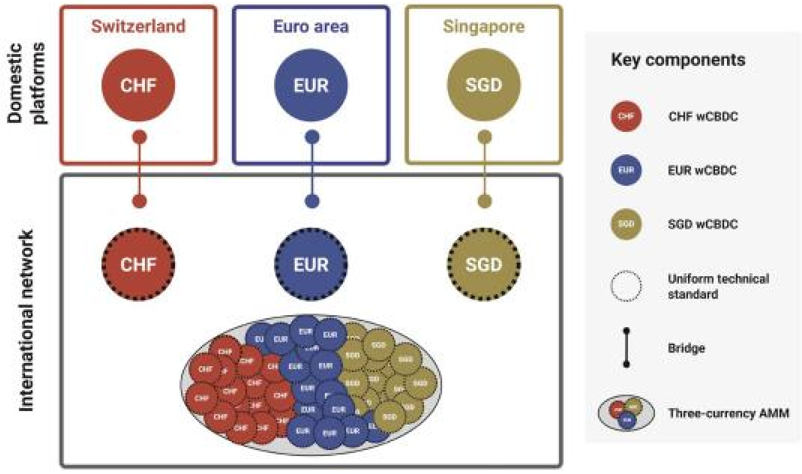

FIGURE 1 – Mariana high level architecture (Source: BIS)

LTs can trade currencies against the pool, subject to transaction fees and slippage. Transaction fees vary depending on how balanced the pool is. Slippage is the difference between the current spot price and the realised price of a trade. The current spot price can be queried using a standard application programming interface (API) for the AMM smart contract, which is a transparency requirement derived from core FX global code principles.

The AMM emerged from DeFi to offer an FX solution on DLT which would complement the conventional FX market, and would not make it necessary to go back through traditional payment systems to carry out a tokenised transaction involving currency exchanges. AMMs could be considered as a tool enabling fully on-chain financial transactions.

Remaining areas for exploration

While the benefits of AMM are promising in some respects, its functioning still raises a number of questions, in particular about (i) pricing, (ii) liquidity costs, (iii) impermanent losses and (iv) the governance of AMM, including legal liability issues:

(i) The determination of the exchange rate relies on an algorithm (implemented by the AMM's smart contract), which could lead to a difference between the rates offered by the AMM and those offered by the traditional markets. If the rate determined by the AMM deviates from those of the market, which converge, the AMM would immediately be arbitrated by the trading participants, as it is the case in traditional markets.

(ii) The liquidity placed in the liquidity pool by participants would be as much immobilised and potentially less productive liquidity in a context of rising interest rates. The opportunity cost to participants of placing wCBDC in the liquidity pool is therefore to be further studied and compared with the remuneration which could be obtained in the market.

(iii) In the event of a sudden change in the price of assets in the AMM, liquidity providers may suffer a potential loss. This is the risk of impermanent loss – a risk specific to liquidity pools. In such a case, the liquidity pool would contain an increased quantity of the asset that has lost value, and a smaller quantity of the asset that has gained value, resulting in a lower total liquidity valuation. The higher the volatility of the assets in the liquidity pool, the greater this risk. Losses only become effective when assets are withdrawn from the liquidity pool. In this case, this loss means that liquidity providers have less return after their withdrawal than if they had their liquidity in their wallet.

(iv) The AMM offers the advantage of requiring little infrastructure and therefore low cost. The opportunity cost associated with the CBDCs' contribution to the liquidity pool is borne by the participants in the liquidity pool, which operates under a common governance accepted by all participants. In the event of a default associated with the AMM's smart contract, the question arises as to which entities are responsible. This issue is not specific to the AMMs as it concerns all smart contracts used in DeFi.

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2 Generally, in decentralised finance, the commission charged also includes an "admin fee", enabling the entity managing the AMM to be remunerated. In the case of the AMM algorithm used in Project Mariana (Curve V2), a portion of this fee is dedicated to adjusting and repositioning concentrated liquidity in order to optimise market efficiency. Ultimately, the algorithm ensures that there is a positive return for the liquidity provider while offering an attractive exchange rate for the taker.

1.3 The three pillars for the successful operationalisation of DLT

In order to move forward with the operationalisation of interoperable DLTs, whatever the use case, three main issues should be further explored: (i) standardisation; (ii) how DLT platforms could fit into the existing ecosystem; and (iii) governance. Ongoing wCBDC experiments are providing central banks with the opportunity to explore diverse standards, use cases and governance arrangements. This should ensure that DLT practices and controls are as effective and secure as those employed in conventional systems.

Standardisation

The major challenge of future work will be to set standards and norms designed to ensure that the operating rules of each DLT have common features that facilitate future interactions. In the absence of international governance to discuss and establish standards at international level, market participants and public actors tend to develop their own standards, in an uncoordinated way, which could be detrimental to the objectives of minimising fragmentation and improving cross-border payments. However, some standards are public and could be leveraged, henceforth contributing to a certain form of convergence. Some standards begin to emerge, such as the ERC20 standard for token formats on Ethereum Virtual Machine (EVM). The Banque de France has been using and developing Ethereum since 2021, in several experiments, notably with the Monetary Authority of Singapore. An improved version of this standard has, for example, been used as part of Project Mariana[15], with the addition of central bank-specific functionalities, made possible thanks to the programmability of smart contracts (refer to Box 7 on whitelisting). The ISO 20022 standard for payment message formats could also be leveraged to ensure interoperability between DLTs and between different DLTs and conventional systems. Financial players are also active in this field, such as SG Forge which proposed the CAST (Compliant Architecture for Security Token) protocol for security tokens, available to the market in open source form[16].

Integration of DLTs into the ecosystem

One of the common features different DLTs could benefit from is the ability to communicate and interoperate in order to satisfy the inherent liquidity needs of their participants and avoid liquidity fragmentation. Standardisation should also help to ensure consistency across ecosystems (i.e. DLT-based or conventional), as some of the possibilities offered by DLT may not be fully replicable in conventional systems, which could otherwise limit the potential benefits of tokenisation. For example, introducing the possibility of fractional ownership of tokens requires real-world systems to also accommodate this possibility[17].

In other words, it is necessary to consider the compatibility and interaction of DLT with existing conventional market infrastructures. These infrastructures, such as RTGS systems, have undergone or are currently undergoing modernisation, which should ensure that they are state-of-the-art and can operate for several years to come – which, in the case of RTGS systems is particularly important in view of its crucial role in monetary policy implementation. The two environments must complement and interact with one another. As yet, DLT cannot replace conventional systems entirely, and in fact needs them in order to function. For example, the process of ramping up tokenised assets necessitates the use of conventional infrastructures. Trading tokenised assets requires the original assets to be locked and unlocked in their conventional systems, which in turn requires seamless interaction across systems[18].

15 Project Mariana: Interim report, BIS, 2023.
16 CAST Framework: White Paper – "Call to Action", SG Forge, 2021.
17 The tokenisation continuum, BIS, 2023.
18 Ramps perform a role similar to that of bridges connecting one DLT to another.

BOX 6 THE SWIFT EXPERIMENT

At the end of 2022, the Banque de France participated in an experiment led by SWIFT[1], alongside fifteen financial institutions including other central banks such as the Bundesbank and the Monetary Authority of Singapore, commercial banks and DTCC.

The objective was to test the interoperability of different CeBM on DLT platforms (based on Quorum and Corda) and conventional payment systems (here RTGS) in simulated environments, as both new and legacy technologies will need to co-exist in the next decade. This was achieved through cash transfers and cross-border payments (i.e. with no underlying DvP or PvP) via simulated wCBDC and RTGS systems, using ISO 2022 messages and an interface built by SWIFT.

1 The Banque de France participates in a new wholesale central bank digital currency experiment with SWIFT, Banque de France, 2022.

Governance

These developments bring to the forefront issues of governance and the challenges faced by several wCBDCs circulating on interoperated DLTs or on the same shared DLT. These configurations involve defining certain governance features which apply to conventional payment arrangements, but which are also specific to the decentralised nature of DLT. These include the following:

- the nature of the DLT (i.e. public or private and permissioned or permissionless), which holds significant importance since, for example, the choice of a public DLT could expose central banks to the risk of a fork;

- the consensus mechanism and the distribution of nodes, insofar as it identifies the distribution of power of validation within the chain. These choices are also decisive in determining the carbon footprint of a DLT, as some mechanisms can be energy-intensive[19]. The Proof of Work (PoW) used by Bitcoin is an example, as opposed to newer alternatives such as the Proof of Stake (PoS) used in Project Mariana or the Proof of Climate awaReness (PoCR)[20, 21] derived from the Proof of Authority (PoA). In the case of the PoS, validators can be selected to create new blocks and secure the network based on the number of tokens they hold and are willing to "stake" as collateral. This eliminates the need for resource-intensive mining computations and reduces power consumption. Most of our experiments have tested models with lower energy consumption as they are running on permissioned or PoS-based blockchains (e.g. Hyperledger Fabric, DAML on Besu, Corda, Quorum and the new generation of Ethereum[22]). It can therefore be assumed that DLT-based financial infrastructures can be low-carbon and the high energy consumption required to run the Bitcoin blockchain should not conceal the fact that the DLT ecosystem is moving towards technologies that consume less energy;

- the allocation of responsibilities between the parties involved (e.g. responsibility for interoperability mechanisms or bridges, responsibility for tokens in circulation on the DLT);

19 Alternative consensus mechanisms, such as the Proof of Stake (PoS), the Proof of Authority (PoA) or the Proof of Climate awaReness (PoCR) have been developed, aiming for improved energy efficiency. Due to the limited scale of the experiments conducted by the Banque de France, it was not feasible to directly measure the energy efficiency of distributed systems in comparison to conventional systems. Nonetheless, they showed the existence of viable options in terms of consensus mechanisms, which can effectively limit the carbon footprint of a CBDC.

20 Crédit Agricole CIB and SEB launch a sustainable and open digital bond platform built on blockchain technology, Crédit Agricole CIB, 2023.

21 The PoCR consensus intends to make the nodes compete for a better carbon footprint, so that the lower the footprint, the higher the earning, and the lack of progress on the carbon footprint would progressively reduce the earning as others get better. The income will be denominated in the native token of this new public blockchain (the Climate awaReness Coin, CRC) and therefore, like any other shared infrastructure, the tokens will gain a monetary value through their increased use on the blockchain. Thus, a node's income will be higher if it can demonstrate that it is operating with a more efficient setup than other nodes.

22 In September 2022, Ethereum made the transition from Proof of Work (PoW) to Proof of Stake (PoS), which uses far less power and should make the network about 99% more energy-efficient, according to figures from the Ethereum Foundation.

- a model for access to wCBDC that is compatible with the constraints and requirements of the various participating jurisdictions, for instance in terms of confidentiality, KYC and AML/CFT checks;

- the control of the central bank over the issuance and redemption of wCBDC.

These governance features need to be explored further. Through its experiments, the Banque de France has already been able to investigate further the issue of wCBDC access and lifecycle control on DLT. The November 2021 report highlighted that the main challenge in terms of governance would be to ensure that the central bank has direct control over the issuance and redemption of wCBDC, while at the same time allowing wCBDC to be used as a settlement asset in compliance with the regulations, and to avoid any outsourcing of CeBM. Our initial findings have shown that private and permissioned DLTs could be considered to be the most secure venues as they provide the ability to maintain full control over the circulation of and access to wCBDC. However, smart contracts offer possibilities of retaining control over wCBDC that may allow central banks to continue overseeing access to CeBM, including in public DLTs. As part of Project Mariana with the BIS Innovation Hub, the Monetary Authority of Singapore and the Swiss National Bank, the Banque de France has experimented with whitelisting as another means of controlling access to wCBDC, applicable to both permissioned and permissionless DLTs (refer to Box 7 on whitelisting).

BOX 7 WHITELISTING AS A MEANS OF CONTROLLING ACCESS TO WCBDC

The key findings of the November 2021 report mentioned that central banks could retain control over the issuance of a wCBDC on DLT. As mentioned in **Box 1**, programmability can enable automated governance mechanisms. The Banque de France's experiments explored how central banks can exercise similar controls in a DLT environment, without having to be operators of the DLT themselves. In this case, wCBDC tokens are issued through smart contracts (computer programs embedded in the DLT). The experiments tested different mechanisms through which central banks can retain control over their settlement asset when it is circulating on a DLT. This question of control over wCBDC is all the more relevant as a wCBDC could trigger demand from financial actors that do not currently have access to CeBM but want to settle financial instruments in wCBDC.

The controls implemented during the experiments via smart contracts include, for instance:

- making central banks the sole issuers of wCBDC tokens;

- allowing central banks to blacklist entities for AML/CFT reasons and to consequently freeze their wCBDC tokens.

As part of Project Mariana, the Banque de France also explored the possibility of identifying all permitted users of the wCBDC tokens, and checking participants' authorisation for every transaction. One of the solutions that was studied and tested is whitelisting. Whitelisting allows central banks to maintain control over who can access and transact with their wCBDC, making it a possible way of controlling AML/CFT risk and KYC requirements on DLT. On a permissionless blockchain, whitelisting is carried out by means of smart contract features, which ensure that the funds are released only when all pre-defined conditions such as access conditions are met. In the case of a permissioned blockchain, these checks can be verified either by a trusted third party or by a smart contract.

By selectively authorising specific regulated entities, central banks can ensure compliance with regulatory requirements, prevent illicit activities and manage the overall flow and usage of the digital currency.

2. The Banque de France's solutions to address wCBDC use cases and associated challenges

As explained in section 1, wCBDC would be a new form of CeBM made available to central banks' eligible market participants for settling wholesale transactions through the use of new technologies such as DLT.

In line with the identified use cases for wCBDC, namely tokenisation and cross-border payments, the Banque de France has undertaken an experimentation programme since November 2020 (refer to Appendix 2 for details of these twelve experiments and their added value). Some of these experiments have combined features which allow to address several use cases all together. Project Mariana and Project Venus are illustrative of these protean experiments.

These experiments have three main objectives: (i) to demonstrate how a wCBDC based on various technologies can respond to traditional use cases for CeBM; (ii) to assess the advantages of introducing a wCBDC into the existing ecosystem and explore how it can stimulate financial innovation; and (iii) conducting a thorough analysis of the potential impacts of a wCBDC on financial stability, monetary policy, and the regulatory environment.

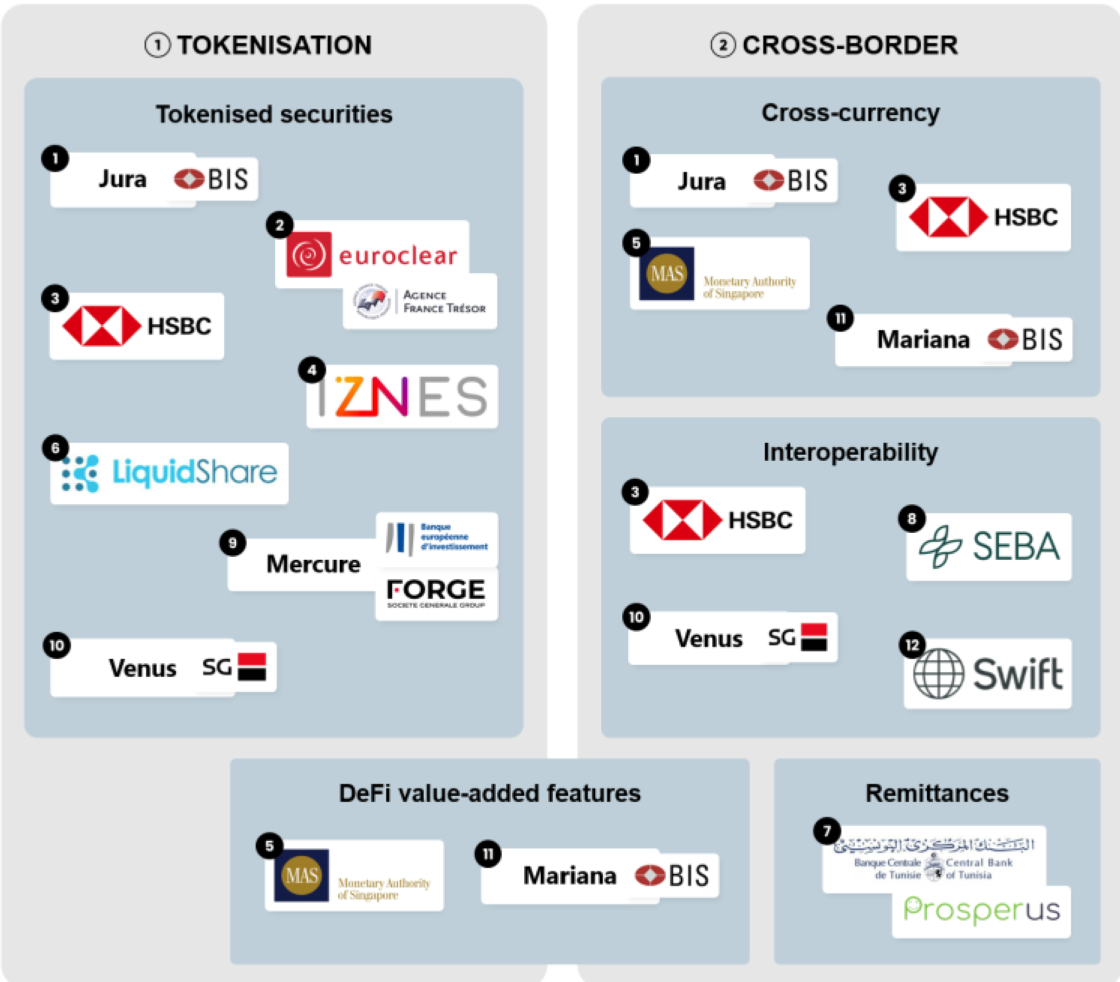

FIGURE 2 – Summary of the added value of the Banque de France's experiments

Throughout these experiments, the Banque de France worked on different ways of providing CeBM to settle transactions on DLT, and focused on issuing a wCBDC directly on DLT. On the basis of this experimentation programme, the Banque de France was able to conceptualise three models that represent three ways of providing a wCBDC, known as **INTEROPERABILITY**, **DISTRIBUTION**, and **INTEGRATION**. They address key aspects of wCBDC implementation and each provides different capabilities and functionalities, so they can be complementary rather than exclusive.

These three models take an active part in the Eurosystem's studies on the issue of CeBM settlement of tokenised assets. The Eurosystem is to look into how wholesale financial transactions recorded on DLT platforms could be settled in CeBM[23]. The purpose of this initiative is to gain insight into how different solutions could facilitate the interaction between TARGET Services and DLT platforms. Indeed, the Eurosystem's exploratory work will provide the opportunity to explore three different solutions of providing CeBM to settle transactions recorded on DLT among which the Banque de France's **INTEROPERABILITY MODEL**[24]. Alongside this Eurosystem work, the Banque de France is pursuing its reflections with its two other models.

The following section provides an overview of the three models, all of which have been the subject of a number of experiments.

2.1 The Banque de France has conceptualised three models for the provision of CeBM on DLT

2.1.1 Interoperability model

In the **INTEROPERABILITY MODEL**, the Eurosystem, as issuer of CeBM, would set up its own DLT infrastructure – the Eurosystem DLT – where TARGET participants could use euro wCBDC for settlement. In this model, the Eurosystem DLT can be connected to other DLTs, both cash and securities, owned by market participants or central banks within or outside the EU, so that they can be used for DvP or PvP in a domestic or cross-border situation. Within the euro area, one of the solutions[25] could be to issue wCBDC directly on a Eurosystem DLT to make CeBM available for settlement on a new market infrastructure, alongside existing Eurosystem infrastructures (T2, T2S and TIPS). The new centralised liquidity management module (CLM), introduced by the T2/T2S consolidation project, could enable market participants to allocate liquidity seamlessly between conventional CeBM and wCBDC across the different TARGET Services.

The interoperability of the Eurosystem DLT with other DLTs allows for the implementation of atomic DvP where the securities transaction on a market DLT automatically initiates a payment in euro wCBDC on the Eurosystem DLT through smart contracts. A similar mechanism applies in the case of PvP whereby the foreign wCBDC transaction on the DLT of a foreign central bank automatically initiates a payment in euro wCBDC on the Eurosystem DLT through smart contracts.

23 Eurosystem to explore new technologies for wholesale central bank money settlement, ECB, April 2023

24 The other solutions that the Eurosystem intends to test are: a Banca d'Italia solution based on an API between TIPS and third-party DLTs to ensure settlement of financial instruments in TIPS, and a Bundesbank solution involving a Eurosystem DLT to trigger payments in RTGS and settle financial instruments on third-party DLTs.

25 Other solutions exist, including the possibility of settling via so-called "trigger solutions" in conventional payment systems. Refer to Potential use of new technologies for the settlement of wholesale financial transactions in central bank money, Joint AMI-Pay/AMI-SeCo, December 2022.

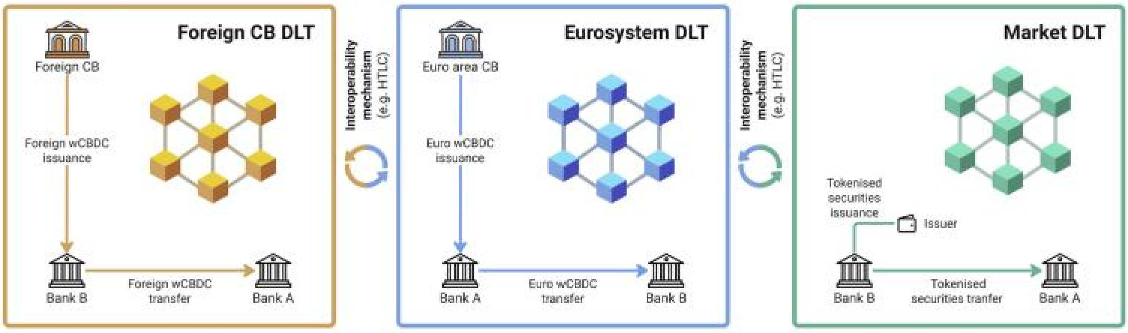

FIGURE 3 – Interoperability model

Description. In this applied interoperability model example, two cases are represented:

1. *A DvP transaction which involves the market DLT and the Eurosystem DLT. In this case, Bank A intends to buy tokenised securities from Bank B and plans to use wCBDC for payment. The euro wCBDC is issued on the Eurosystem DLT, while the securities are issued on the market DLT in a tokenised form. The DvP process utilises a trustless mechanism (e.g. HTLC) to interoperate between the two platforms. Both Bank A and Bank B must have wallets on both DLTs. The trustless mechanism locks the tokens on each respective DLT, and credits the wallet accordingly. Therefore, all tokens remain on the same DLT.*

2. *A PvP transaction which involves the foreign central bank DLT and the Eurosystem DLT. In this case, Bank A aims to exchange euro wCBDC for foreign wCBDC. Both the euro wCBDC and the foreign wCBDC are issued on separate DLTs. The trustless mechanism operates the PvP transaction by locking the tokens on each platform and subsequently crediting the wallets of Bank A and Bank B. For this to occur, both banks must possess wallets on both DLTs, and all tokens remain on the same DLT as well.*

Specific features of the INTEROPERABILITY MODEL

- Euro wCBDC circulates exclusively on the Eurosystem DLT.
- The Eurosystem DLT dialogues with other DLTs where digital assets or foreign wCBDC are issued, registered and circulate.
- The atomic settlement of the cash leg against the securities leg occurs with the joint execution of the euro wCBDC transfer on the Eurosystem DLT and the tokenised securities transfer on the market DLT. This joint execution is enabled though an interoperability mechanism.
- Similarly, the atomic settlement of the euro cash leg against the foreign cash leg occurs with the joint execution of the transfer of euro wCBDC on the Eurosystem DLT and the transfer of foreign wCBDC on the foreign DLT.

Settlement in the INTEROPERABILITY MODEL

Settlement in the INTEROPERABILITY MODEL differs from the other two solutions (i.e. INTEGRATION and DISTRIBUTION) because a two-leg transaction is settled on two different DLT platforms (the Eurosystem DLT and another DLT) and requires interconnectivity between the two DLTs during settlement.

Components involved in the INTEROPERABILITY MODEL

- An external DLT – i.e. a market DLT or a foreign central bank DLT – managed and operated by a third party (respectively, a market DLT operator or a foreign central bank) subject to a defined rule-based framework.

- An interoperability component that can take various forms, and provides the capability to communicate, share, exchange and access data or information across the Eurosystem DLT and the market DLT. It can be a trustless mechanism for locking and releasing cash that is deployed on the Eurosystem DLT to perform the euro cash leg of an atomic DvP or PvP transaction (e.g. a Hashed TimeLock Contract (HTLC)[26], or another protocol such as TIPS Hash-Link, developed by Banca d'Italia[27]).

BOX 8 INTEROPERABILITY MODEL USING DL3S: THE HSBC EXPERIMENT[1]

Overview of the experiment

The Banque de France collaborated with HSBC and IBM in December 2021 to conduct an experiment that explored the potential of wCBDC for improving cross-border and cross-currency DvP and PvP.

This experiment was specifically designed to assess the interoperability between DLTs for exchanging and transferring information and assets between different DLTs. It effectively demonstrated the ability of DLT to collaborate seamlessly and efficiently. The **INTEROPERABILITY MODEL** employed enabled atomic settlement, allowing for faster and earlier execution of operations within the asset lifecycle, such as FX transactions, while mitigating FX exposure. Furthermore, this model facilitated control over wCBDCs through programmability at multiple levels, including instruction creation and settlement. In the experiment, the bridge served as a technical interface, a distinctive feature of the **INTEROPERABILITY MODEL**, eliminating the need for trusted third parties to coordinate settlement and enabling the atomic processing of PvP instructions. This approach maintained the autonomy of each central bank, preserving their individual rulebooks, governance structures, participation criteria and underlying infrastructure.

This Proof of Concept (PoC) showcased the capabilities of DL3S in covering an end-to-end transactional lifecycle, involving:

- eBonds (issuance, ISIN dissemination, DvP across primary issuance and secondary trading, and coupon payments);
- wCBDC (minting and allocation);
- FX between two wCBDCs (FX rate provision, trade execution and PvP).

Interoperability between different market infrastructures was a significant aspect of the experiment. It was tested at two levels: (i) between DLTs (in this case between DL3S based on Hyperledger Fabric and HSBC's Corda-based systems); and (ii) between DLTs and conventional systems.

…/…

1 The interoperability of CBDCs across networks and currencies, HSBC, 2022.

26 The Hashed TimeLock Contract (HTLC) protocol allows buyer and seller to perform a cross-platform asset exchange without the need for third party intermediation, provided they participate in both platforms. While locking assets for the opposite party, the exchange of a secret and its hash, following a precise protocol, can guarantee all or none settlement.

27 Integrating DLTs with market infrastructures: analysis and proof-of-concept for secure DvP between TIPS and DLT platforms, Banca d'Italia, 2022.

DLT Interconnectivity

The experiment used a technical interface called "bridge", based on Weaver, which is an open-source interoperability tool. The bridge enabled the following:

- transfer of data and information related to bond creation, such as ISIN dissemination and corporate action events;
- transfer of assets, specifically wCBDCs, across different DLTs[2];
- exchange of assets through an FX transaction between two wCBDCs. The Banque de France operated three DLTs using Hyperledger Fabric technology, while HSBC operated their custody accounts management platform based on Corda. The experiment involved creating a fictional eBond settled in euro wCBDC, with details disseminated through the bridge. A fictional HSBC corporate client bought part of the eBond using euro wCBDC, and the bridge facilitated the asset transfer and atomic settlement.

Coupon payments were made and converted from euro wCBDC to another wCBDC based on an FX standing instruction. The entire process, including payment, conversion, PvP instruction, settlement, and accounting, was executed atomically using the bridge and DLTs.

To enable the circulation of wCBDCs, the Banque de France and a fictional central bank established issuer nodes on their respective DLT platforms, allowing for the issuance and destruction of wCBDC tokens on the respective DLT platforms.

2 This transfer functionality implemented in the experiment enabled testing this feature described for the **DISTRIBUTION MODEL** (refer to **section 2.1.3**).

2.1.2 Integration model

In the INTEGRATION MODEL also, the Eurosystem would set up its own DLT infrastructure, the Eurosystem DLT, which is particularly relevant for DvP transactions. Both legs – the cash leg and the securities leg – of a transaction could be settled on the same platform. This model offers real added value for cases where both the cash and securities legs have to be in a unified format. The Eurosystem DLT would complement current Eurosystem financial market infrastructures, specifically T2S, by replicating its functionalities on DLT, but also T2 RTGS by enabling PvP, since T2 RTGS currently only has multi-currency capabilities and no cross-currency capabilities. It would also transpose the benefits of existing Eurosystem infrastructures – safe settlement in CeBM and a single platform providing unity to European financial markets – to the tokenised world. This would be key for native digital assets and tokenised assets that fall under the category of unlisted financial assets and which cannot currently be settled using the existing TARGET Services. Further analysis would be needed to assess whether such a replication of the T2S model in the DLT environment would meet the expectations of the market.

The Eurosystem DLT would remain open to any central bank interested in issuing their own currency, in particular European Union central banks that are not part of the euro area. This would replicate what the Eurosystem is currently offering with its TARGET Services (i.e. multi-currency capabilities). For central banks that prefer to issue their currency on their own platform or on shared platforms, this model could be combined with other models (i.e. INTEROPERABILITY or DISTRIBUTION MODELS) to fully achieve the improvement of cross-border payments.

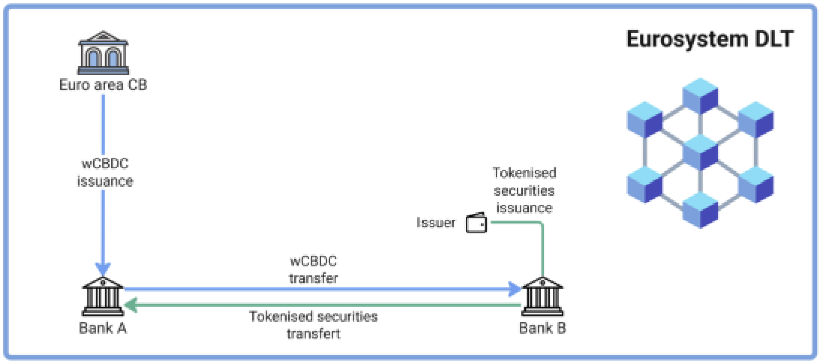

FIGURE 4 – Integration model

Description. In this applied integration model example, Bank A wants to purchase tokenised securities from Bank B and intends to make the payment using a euro wCBDC. In this example, all issuances and transactions take place on the same DLT, namely the Eurosystem DLT.

Tokenised securities are issued to Bank B and euro wCBDC is issued by a euro area central bank to Bank A; the DvP process is carried out through an atomic swap between the tokens held by Bank A and Bank B.

Specific features of the INTEGRATION MODEL

- Euro wCBDC only circulates on the Eurosystem DLT.
- Tokenised securities only circulate on the Eurosystem DLT. They can be issued either directly on the Eurosystem DLT platform or on another DLT, and then made available on the Eurosystem DLT for settlement through a distribution or an interoperability mechanism (refer to DISTRIBUTION and INTEROPERABILITY sections).
- The settlement of the euro cash leg and the securities leg occurs on the Eurosystem DLT.

Settlement in the INTEGRATION MODEL

In the INTEGRATION MODEL, settlement of a two-leg transaction occurs on a single DLT, the Eurosystem DLT.

Components involved in the INTEGRATION MODEL

- The Eurosystem DLT, which is managed and operated by the Eurosystem.
- A trustless mechanism (e.g. a Hashed StateLock Private Protocol (HSL2P) smart contract) for locking and releasing cash and securities, which is deployed on the Eurosystem DLT to perform an atomic DvP transaction between the cash and securities legs.
- In certain cases where securities are issued on a market DLT, the Eurosystem DLT might need to interact with this market DLT. This market DLT would be managed and operated by a third party subject to a defined rule-based framework. Such cases therefore necessitate the inclusion of an interoperability mechanism, which can take different forms and enables communication, sharing, exchange and access of data between the Eurosystem DLT and the market DLT. The interoperability mechanism allows the two DLTs to interoperate although it does not intervene in the atomic settlement performed on the Eurosystem DLT. The interaction with the market DLT only relates to the mirroring of digital assets (when required) on the Eurosystem DLT through the interoperability mechanism, enabling interoperability between the two DLTs.

2.1.3 Distribution model

In the **DISTRIBUTION MODEL**, as in the **INTEROPERABILITY MODEL**, euro wCBDC and tokenised assets would circulate on different DLTs shared between the Eurosystem and third parties (e.g. foreign central banks, market participants). The Eurosystem DLT would remain under the control of the Eurosystem, and be used for liquidity management between the different DLTs.

The fundamental difference with the **INTEROPERABILITY MODEL** lies in the nature of the connection between the two DLTs:

- In the **INTEROPERABILITY MODEL**, this mechanism synchronises the transfers carried out on the two DLTs. In other words, the assets remain on their respective DLT and the DvP is performed between the DLTs.

- In the **DISTRIBUTION MODEL**, representative tokens of the euro wCBDC issued on the Eurosystem DLT are created on the shared DLT and the DvP is performed on the latter.

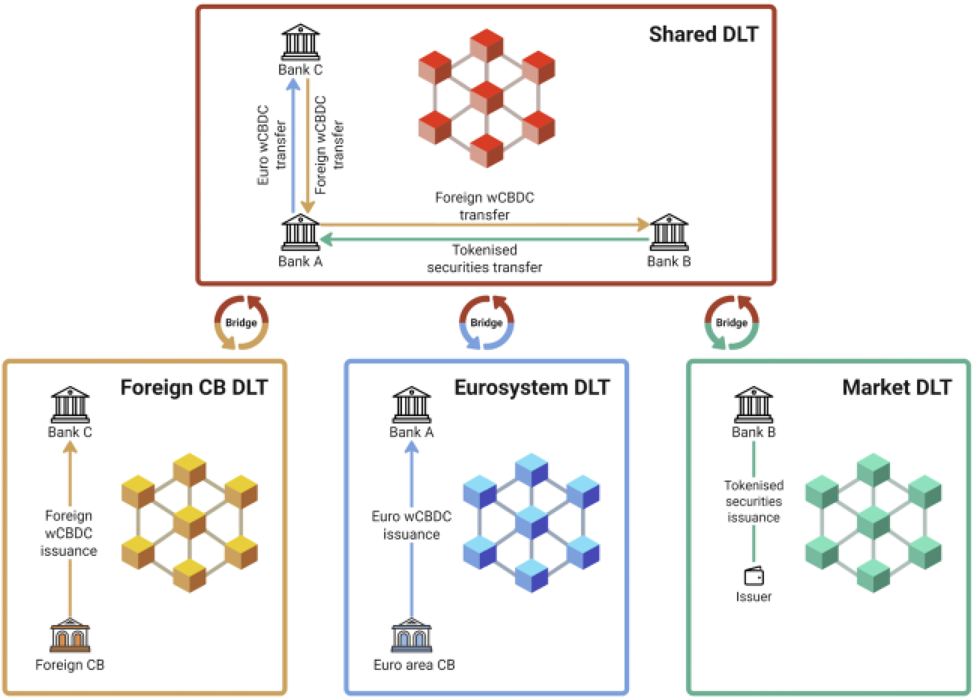

FIGURE 5 – Distribution model

<u>Description</u>. In this applied distribution model example, Bank B wants to purchase tokenised securities from Bank A and intends to make the payment using a foreign wCBDC. To facilitate the transaction, all domestic platforms (foreign CB DLT, Eurosystem DLT, and market DLT) are interconnected through bridges within a shared DLT.

The issuance of wCBDCs and tokenised securities occurs on the domestic platforms, and representations are then created on the shared DLT via bridges. The PvP and DvP processes take place on the shared platform. In this specific case, we suppose that Bank A can only hold euro wCBDC, which means it needs to execute a PvP on the shared platform with another bank (Bank C). Alternatively, Bank A could have opted for an FX transaction, possibly automated using an AMM, similar to what was tested in Project Mariana.

The DvP process also occurs on the shared DLT, where Bank B sells the securities in exchange for the appropriate payment.

Specific features of the DISTRIBUTION MODEL

- The Eurosystem issues euro wCBDC directly on its domestic platform (the Eurosystem DLT), and the other participants issue their assets on their domestic platforms. Representative tokens of these assets are then created on the shared DLT via bridges, where they can be used for PvP and DvP transactions.

- The settlement of the euro and foreign cash legs as well as the securities leg occurs on the shared platform exclusively.

- The DISTRIBUTION MODEL is relevant for cross-border payments.

Settlement in the DISTRIBUTION MODEL

In the DISTRIBUTION MODEL, settlement of a two-leg transaction occurs on a single shared DLT, where the Eurosystem owns and operates some nodes. Each external DLT where settlement occurs is connected to the Eurosystem DLT.

Components involved in the DISTRIBUTION MODEL

- The Eurosystem DLT, which is managed and operated by the Eurosystem.

- A shared DLT, which is managed and operated by a third party subject to a rule-based framework defined with the Eurosystem, and on which the Eurosystem operates its own node where representative tokens of euro wCBDC circulate.

- A bridge component, which provides the capability to communicate, share, exchange and access data or information across the Eurosystem DLT and the market DLT. In the DISTRIBUTION MODEL, this communication through the bridge allows for the creation of representative tokens of wCBDC (initially issued on the Eurosystem DLT, where they are also redeemed) on the shared DLT. The bridge does not intervene in the atomic settlement performed on the shared DLT. The euro wCBDC transfer on the shared DLT is carried out by the Eurosystem independently from the atomic settlement of the DvP (or PvP) transaction on the shared DLT.

In the DISTRIBUTION MODEL, the settlement of the cash leg and the security leg occurs exclusively on the shared DLT, using a DvP protocol. The shared DLT's protocol should comply with the defined Eurosystem standards on settlement (e.g. atomicity). These technical and operational features shall be part of the rule-based framework implemented with the shared DLT.

Depending on the protocol retained by the shared DLT, the settlement of the DvP or PvP transaction can either use a Hashed State Lock Private Protocol (HSL2P)-like protocol or a Notary Scheme based on a Trusted Third Party (TTP) mechanism.

In the case of an HSL2P-like protocol:

- The execution of the atomicity of both legs is guaranteed through the smart contract following a precise protocol which guarantees that both assets change hands or none of them.

In the case of a Notary Scheme mechanism:

- The execution of the atomicity of both legs is guaranteed by a TTP trusted by both the buyer and the seller, which delivers the assets upon receipt of payment in its escrow wallet, or leverages the programmable nature of most DLTs (smart contracts).
- An illustration of a Notary scheme protocol is available with Project Jura[28, 29] report that provides an example of atomic DvP and PvP settlement using a dual notary signing mechanism.

BOX 9 AN ILLUSTRATION OF THE DISTRIBUTION MODEL: PROJECT MARIANA[1]

The **DISTRIBUTION MODEL** presents another approach to interoperability by allowing the distribution of wCBDC issued on a domestic DLT to an external DLT operated by third parties. In the experimentation programme conducted by the Banque de France, this model was implemented as an issuance and distribution process within the Ethereum public blockchain.

As part of the Mariana project, multiple wCBDCs (i.e. Swiss francs, euros and Singapore dollars) were used to settle PvP transactions. The wCBDC token design was based on a uniform technical standard for interoperability (i.e. the ERC-20), making the tokens fungible and allowing them to be used within the same protocol.

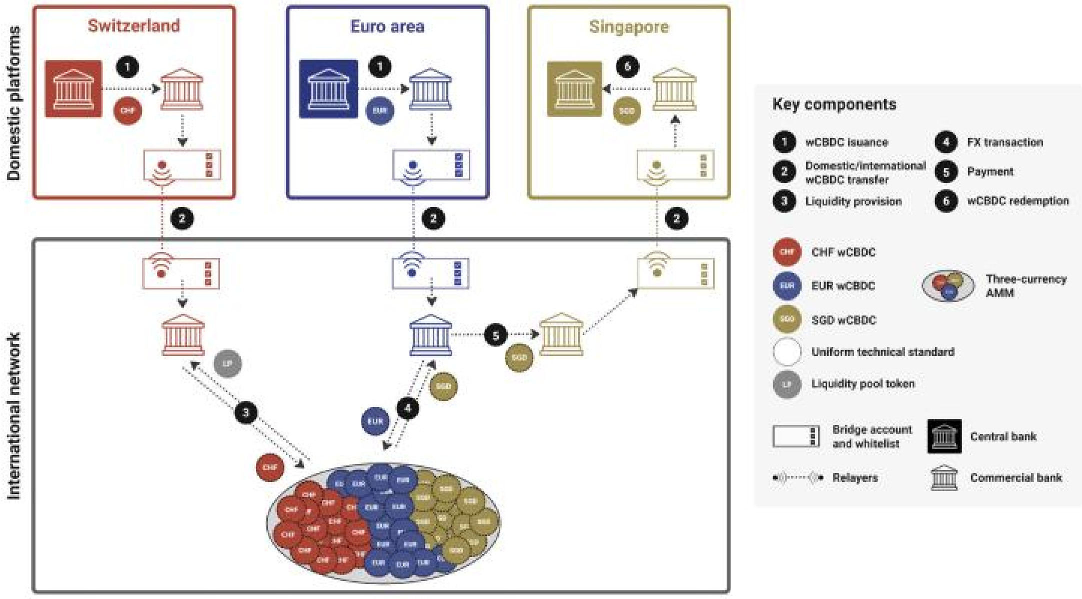

FIGURE 6 – Illustration of a PvP in Project Mariana (Source: BIS)

The wCBDCs were issued on three domestic platforms (the euro area DLT, the Singapore DLT, and the Swiss DLT), operated by central banks and developed using private Ethereum technology (Hyperledger Besu). Using bridges, the wCBDCs were distributed on a so-called international network.

This international network hosted an automated market maker (AMM) and served as an interbank FX on-chain market. The AMM was made of a three-token liquidity pool that acted as a counterparty in the FX transaction. The liquidity pool was supplied by participants in exchange for a liquidity pool token (LP token) representing their share in the pool. This determined the compensation for their deposit, which was paid by liquidity takers in the form of transaction fees. The network was independent/neutral with respect to the rules specific to each regional/domestic jurisdiction, and enabled participants authorised by their central bank to use it to hold wCBDC in a single portfolio.

1 Project Mariana: Interim report, BIS, 2023.

28 Project Jura: Cross-border settlement using wholesale CBDC, Banque de France, 2021.
29 The appendix of Project Jura report details the dual notary signing function developed by R3 for the benefit of the Jura experiment.

2.2 Benefits of studying our three models

Based on the insights gained from its experiments, the Banque de France has determined that each model fulfils specific use cases, and that they are not mutually exclusive but rather complement each other. Building on initial findings, one can, however, differentiate between them according to certain criteria:

- Contribution to and effectiveness in preserving the two-tier monetary system: refers to the capability of maintaining CeBM's anchoring role, meaning in practice that CeBM and CoBM are convertible at par, whatever the underlying technology.

- Considerations related to other settlement assets: refers to the model's ability to facilitate the cohabitation of different settlement assets, in particular CoBM. The two-tier monetary system is based on a public-private partnership that should be maintained.

- Scalability: refers to both the capacity (i.e. the ability to handle a large volume of transactions) and the future-proof nature of a DLT platform (i.e. the ability to upgrade the platform).

- Programmability: allows new features to be added to money, to supplement its store of value function. Programmability also enables management and automation, using code, and the definition of pre-conditions to be met for executing contracts between agents via smart contracts deployed on-chain.

- Security: refers to the level of protection and resilience against unauthorised access, fraud, tampering or other malicious activities. It involves assessing the robustness of the encryption and authentication mechanisms, data integrity access controls and overall cybersecurity measures in place to safeguard a DLT platform.

- Fragmentation: refers to the model's ability to optimise the various operations involved in a transaction so that they do not take place across several venues.

- Liquidity saving mechanisms: mean mechanisms and tools used to optimise liquidity management.

- Cross-currency capability: refers to the model's ability to enable frictionless cross-border transactions, involving FX operations.

- Governance: refers to the model's ability to facilitate the implementation of governance agreements.

These criteria play significant roles in assessing the models' effectiveness and efficiency. Each model will need to be tested and compared using these criteria. Based on our initial findings from the experiments conducted (refer to Appendix 1 for a comparative analysis), it becomes apparent that a mix of different models is necessary to cater to the diverse needs and objectives of various use cases.

While central banks face stringent constraints such as control over CeBM, the **DISTRIBUTION MODEL** has yet to prove its capacity for effective control, unlike the empirically verified **INTEROPERABILITY** and **INTEGRATION MODELS**. In terms of technology selection, the **INTEROPERABILITY MODEL** strikes the best balance, as the **INTEGRATION MODEL** necessitates continuous updates to attract the market to a single platform, while the **INTEROPERABILITY MODEL** only requires updates to the interoperability modules between DLTs.

Regarding the adoption of a specific technology, it is currently not feasible to make a definitive recommendation. The experiments conducted by the Banque de France have involved testing various types of DLTs (private or public, permissioned or permissionless blockchain). However, further research is required to conduct a comprehensive comparative analysis, particularly in terms of security which is a crucial criterion for public policy decisions, and heavily dependent on the technology employed.

By combining the strengths of different models, a more comprehensive and robust solution can be achieved. As new technologies and methodologies emerge, it is crucial to remain flexible and open to the possibility of incorporating novel approaches into a potential model mix. This applies to emerging concepts such as the BIS' *unified ledger*[30] and the IMF's *XC platforms*[31, 32], with which our three models could potentially interoperate through interoperability mechanisms.

2.3 Key takeaways: policy considerations for a path forward

In light of these considerations, the Banque de France supports a step-by-step approach to the global development of wCBDCs. As an initial objective, the Banque de France suggests prioritising efforts on interoperability and the development of standards, including the adaptation of existing standards that have proved their added value, such as ISO 20022. This focus on interoperability is essential at a time when most central banks are considering the design of a potential wCBDC. The challenge is to think early on about cross-border functionalities and the choices to be made to facilitate payments. Moreover, in the short and long term, the ability to communicate with other ecosystems, including DLT platforms and conventional systems, will be needed to preserve financial integrity. The possibility offered by the European Pilot Regime of relying on CoBM for settlement on DLT also provides an opportunity to reflect on the issues surrounding the need to guarantee the singleness of money on DLT, and hence the anchor value of CeBM.

At present, the INTEROPERABILITY MODEL stands out as the most straightforward to implement in a dynamic technological environment, making it worth further investigation. The Eurosystem's exploratory work[33] will be the opportunity to test this solution according to the aforementioned criteria, in order to ascertain its suitability for settling transactions on DLT using CeBM. Simultaneously, and in the long run, the INTEGRATION and DISTRIBUTION MODELS will need to be further explored and studied in the light of the above mentioned criteria, in order to better identify the use cases to which they are best suited. By allowing different types of assets to circulate on the same DLT or by facilitating interoperability between ledgers while placing wCBDC at the heart of their design, these three models are in line with the concepts of *unified ledger* and *XC platforms*, which echo the potential of these models for both domestic and cross-border use cases.

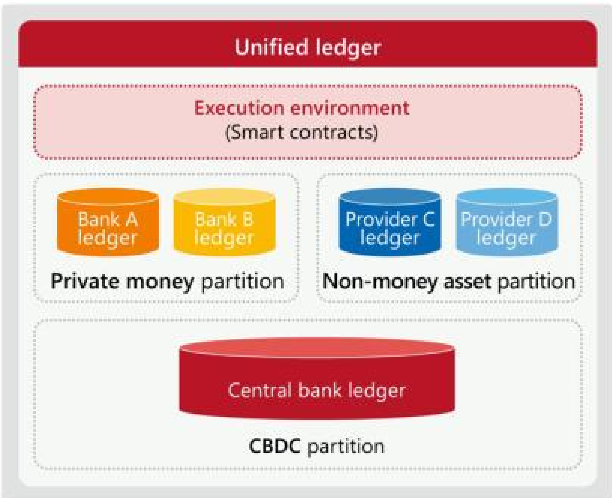

FIGURE 7 – The concept of unified ledger (Source: BIS)

30 Annual Economic Report, Section 3, BIS, 2023

31 A multi-currency exchange and contracting platform, IMF, 2022

32 The rise of payment and contracting platforms, IMF, 2023

33 Eurosystem to explore new technologies for wholesale central bank money settlement, ECB, April 2023.

This report highlights the following takeaways:

Key policy takeaways

1. To fully reap these benefits, central banks should provide a way to settle transactions on DLT in CeBM, and wCBDC is one of the solutions. By issuing a wCBDC, as a complement to a rCBDC, CeBM can retain its anchoring value for both retail and wholesale payments and ensure the finality of payments made on DLT platforms in coexistence with CoBM, including in tokenised forms. This would encourage the safe development of private initiatives while preserving the fungibility of the different types of money, and thereby the singleness of money.

2. International co-construction and collaboration are critical aspects of the digital currency ecosystem. Encouraging collaboration among nations, central banks and private sector entities fosters knowledge-sharing, best practices and innovation. By engaging in partnerships with the private sector, central banks can leverage external expertise and resources, facilitating the development and adoption of wCBDC. Additionally, international collaboration promotes consistency and harmonisation in regulatory approaches, contributing to a more globally inclusive and interoperable wCBDC framework.

3. Priority should be given to ensuring interoperability, as it is crucial to create the necessary conditions and frameworks to enable seamless data and transaction exchanges between different systems (conventional or DLT-based).

4. Climate-related concerns highlight the need to develop energy-efficient solutions. When implementing DLT-based systems, it is essential to prioritise the adoption of protocols and consensus mechanisms that minimise energy consumption. Selecting and implementing energy-conscious consensus mechanisms can help to mitigate the environmental impact of DLT transactions. This commitment to resource efficiency is aligned with broader sustainability goals and can ensure the responsible adoption of wCBDC.

Key technical takeaways

5. Technological advancements offer various means of maintaining central bank control over wCBDC. Permissioned networks, for instance, enable central banks to maintain oversight and authorise participants on the network, ensuring compliance with regulatory requirements. Whitelisting can be employed to establish a trusted network of participants, mitigating the risk of illicit activities. Smart contracts, on the other hand, enable the implementation of programmable features and conditions, enhancing central banks' ability to govern the use and circulation of its wCBDC.

6. It is important not to prematurely favour a specific technology or type of DLT. Instead, the emphasis should be on establishing standardised protocols and frameworks. Standardisation ensures interoperability, thereby fostering an environment that allows for the coexistence and interaction of diverse technologies, maximising the potential benefits and avoiding fragmentation.

7. DLT offers significant opportunities for improving efficiency and security in asset settlement and delivery, as well as for enhancing cross-border transactions. The implementation of DLT-based platforms could lead to tangible benefits, such as enhanced transparency, increased automation of financial markets thanks to the generalisation of DvP mechanisms, and enhanced cost-efficiency thanks to the facilitation of the straight-through processing of trade and post-trade activities – in particular for investors who do not have access to DvP. DLT provides transparent and auditable transaction records. By leveraging DLT, financial authorities can also improve their capacity for market supervision and oversight. This increased supervisory capability can contribute to overall financial stability.

8. Continuing our experiments is crucial to advance our analysis and our efforts to develop an operational framework. The Banque de France's track record of experiments and its learning-by-doing approach serve as a solid foundation to build upon and strive towards the realisation of such a framework. There are still several aspects to explore, such as scalability and the emerging use cases within the DeFi ecosystem. The Eurosystem's exploratory work will be the opportunity to test and benchmark different solutions at the domestic level, while at the international level, further experiments with international partners are essential to effectively improve cross-border payments.

Appendix 1 A comparative analysis of the three models

MODEL	INTEROPERABILITY[a]	DISTRIBUTION[b]		INTEGRATION[c]
		Public blockchain	Private blockchain	
POSSIBLE USE CASES[d]	Open solution by design, but requires a multiplication of interoperability mechanisms.	DvP, PvP, trade and FX settlement in the tokenised world, DeFi apps for institutional (e.g. DEX, lending, derivatives, insurance and asset management) by leveraging directly or indirectly the ecosystem of public blockchain[e].	Same as for the INTEGRATION MODEL.	Complex governance to extend the use cases and allow other types of assets on the platform.
CROSS-CURRENCY CAPABILITY[f]	Other wCBDCs can be distributed on the Eurosystem infrastructure (e.g. other currencies in the European Union) for single platform settlement but complex governance.[g] Otherwise, PvP occurs on two distinct platforms with simpler governance.	Same as for the INTEGRATION MODEL.	Same as for the INTEGRATION MODEL.	Other wCBDCs can be distributed on the Eurosystem infrastructure (e.g. other currencies in the European Union) for single platform settlement but complex governance.
GOVERNANCE[h]	Bilateral agreements are simpler to negotiate and implement because they only concern the interoperability bridge.	Supranational governance is complex.	Same as for the INTEGRATION MODEL.	Compulsory adherence by central banks to the Eurosystem framework.
MARKET PREFERENCE[i]	2	1		3
FRAGMENTATION (liquidity and securities)	Low fragmentation risk for cash, as there is no transfer outside the domestic DLT, so no fragmentation. Risk of fragmentation for securities, depending on the number of market DLTs connected.	High risk of cash and securities fragmentation, but manageable depending on the number of DLTs accepted. Controls through smart contract functions.	Same as for the INTEGRATION MODEL.	Low risk of fragmentation (cash and securities), as there is no transfer outside the Eurosystem DLT.
LIQUIDITY SAVING MECHANISMS	Since the CeBM and the tokens reside on different systems and that Liquidity Saving Mechanisms (LSMs) typically involve both (e.g. collateral against funding), LSMs could be implemented but would be subpar compared to the other scenario were both reside on the system.	The public blockchain allows for the concentration and mutualisation of liquidity, which could lead to a more efficient rate for takers and less risks for liquidity providers.	Same as for the INTEGRATION MODEL because difficulty to involve participants in private networks (same logics of deployment of market place in Intranet, Extranet and Internet).	Liquidity saving mechanisms could be easily implemented, similar for example to the existing T2S mechanisms (e.g. optimisation algorithms, auto-collateralisation)
SCALABILITY (capacity)	Not considered very scalable because it requires the creation of point-to-point interfaces (i.e. interoperability mechanisms) to be used and depends on the other DLTs.	It depends on the type of public blockchains layer network, i.e. layer 1[j] or layer 2[k], the latter providing a higher transaction speed.	Same as for the INTEGRATION MODEL.	Depends on the selected DLT.[l]
SCALABILITY (future-proof)	Requires managing technology evolution (including market DLTs, interoperability mechanisms, etc.) but less complex in terms of governance.	Benefits directly from open innovation from the public blockchain ecosystem. However, the central bank has no control over product strategy.	Same as for the INTEGRATION MODEL from a governance perspective.	Risk of being occasionally outdated due to the evolution of the technology and the fact that updating the platform is demanding in terms of resources and governance.

(a) In this case, the Eurosystem is a solution provider and operator.
(b) In this case, the Eurosystem is a solution consumer.
(c) In this case, the Eurosystem is a solution provider and operator.
(d) In terms of the type of assets and business models that can be handled.
(e) Most security tokens have been issued on public blockchains, specifically Ethereum, Polygon and other layer 2 blockchains.
(f) Cross-currency capability is technically feasible for all three models, but they differ in terms of the level of governance complexity required to achieve it.
(g) Within the European Union, there would be no governance problem since some non-euro currencies already participate in our RTGS. However, it seems unthinkable that all currencies would be issued on an integrated Eurosystem platform. One solution might be to combine integration and interoperability in this case.
(h) Understood in the broadest sense, not just with regard to cross-currency transactions.
(i) Potential use of new technologies for the settlement of wholesale financial transactions in central bank money, Joint AMI-Pay/AMI-SeCo, December 2022.
(j) Ethereum can currently process around 30 transactions per second, Avalanche 4 500 transactions per second.
(k) Polygon, Optimism, and Arbitrum can currently process up to 65 000, 2 000, and 40 000 per second respectively.
(l) It all depends on the DLT chosen by the Eurosystem. At the moment, the DLT solution provided by the Banque de France in the context of the European Pilot Regime and the exploratory work is DL3S, knowing that scalability (in the sense of capacity) was one of the criteria for choosing DL3S, which is based on Hyperledger Fabric.

MODEL	INTEROPERABILITY[(a)]	DISTRIBUTION[(b)]		INTEGRATION[(c)]
		Public blockchain	Private blockchain	
PROGRAMMABILITY[(m)]	In this case, the CeBM DLT and the other DLT theoretically interact on very specific events (typically settlement or cash events such as coupons). This means that programmability can be assessed on two levels: on the Eurosystem DLT and on its interaction with the other DLTs[(n)]. On the pure cash side, the Eurosystem could implement any level of programmability it would see fit. Regarding interaction with other DLTs, a reasonable assumption would be that the Eurosystem would publish and maintain a set of standards by which the selected DLTs would interact with the Eurosystem DLT.	Depends on the framework offered by the destination DLT. If it is a public blockchain, this will enable the full potential of smart contracts and financial applications requiring liquidity and collateral management to be exploited (i.e. the possibilities offered by DeFi accessible to institutional players). Should be in blockchains protocols built to enable smart contracts (Ethereum and all EVM, Solana, etc.)		Technically feasible, but complex in terms of governance as the Eurosystem has control over the degree of programmability. Participating commercial banks could have less opportunity to innovate by deploying their own smart contracts in the most open and widely used standards.
SECURITY[(o)]	The systematic use of interoperability mechanisms between DLTs is a weakness, but this can be offset if the two blockchains are permissioned.	Depends on the consensus protocol and the number of nodes used to validate transactions. Provides more security through the higher number of nodes on the network. However, increases the attack surface since the codes are open source. Finally, the use of bridges introduces potential vulnerabilities.	Same as for the INTEGRATION MODEL but the use of bridges introduces potential vulnerabilities.	Strong security *a priori*. This will depend on the number of validation nodes, and the level of decentralisation, which secure the network.

(m) Understood as the ability to manage and automate, using code, the conditions for executing contracts between agents via smart contracts deployed on-chain.
(n) By definition the programmability of the other DLTs is out of scope.
(o) In all cases, the issue of key management is essential to ensure an optimum level of security. However, the consequences of improper key management are more daunting when using public blockchains.

Appendix 2 Added value of our experiments

N°	PROJECT OR PARTNER	PARTICIPANTS	USE CASE		TECHNOLOGY		MODEL(S) TESTED	ADDED VALUE
			Tokenisation	Cross-border	Public blockchain	Private blockchain		
1	Jura	Swiss National Bank, BISIH, Accenture, Crédit Suisse, Natixis, R3, SIX Digital Exchange (SDX), UBS		DvP of French commercial paper (NEU CP) and PvP of EUR wCBDC against CHF wCBDC		Private permissioned DLT (based on Corda)	DISTRIBUTION MODEL	Deploy wCBDC on a third-party platform being multi-assets and multi-jurisdictions and provide non-resident financial institutions with access to wCBDC.
2	Euroclear	Euroclear France, Agence France Trésor, BNP Paribas, BP2S, Crédit Agricole CIB, HSBC, Société Générale	DvP of French government bonds on primary and secondary markets			DL3S (based on Hyperledger Fabric)	INTEGRATION MODEL jointly operated by the Banque de France for the cash leg and Euroclear for the securities leg	Replication on DLT of the vast majority of T2S features, including settlement optimisation, repos, and auto-collateralisation.
3	HSBC	HSBC	DvP of bonds on primary market and secondary market, coupon payment			DL3S (based on Hyperledger Fabric) and HSBC Digital Vault for the custody of assets (based on Corda)	INTEGRATION MODEL for the primary market operation; INTEROPERABILITY and DISTRIBUTION MODELS for secondary market and FX/PvP	Extended interoperability across different DLTs. Control over the CBDC by the NCBs. Atomic settlement of DvP and PvP within seconds.
4	IZNES	IZNES, OFI AM, SELT, CACEIS, CITI, Groupama AM	DvP of fund shares	FX and PvP of EUR wCBDC against simulated foreign wCBDC		SETL blockchain	DISTRIBUTION MODEL	Improve DvP of fund shares.
5	MAS	MAS, JP Morgan		FX and PvP of EUR wCBDC against SGD wCBDC		Quorum blockchain	DISTRIBUTION MODEL	Introduction of automated market marker (AMM) for the trading and settlement. AMM as unique counterparty for FX transactions.
6	LiquidShare	LiquidShare, Euroclear, BP2S, ODDO BHF, CACEIS bank, La Banque Postale, Crédit Agricole titres, SG SS, CDC, OFI AM, ODDO AM, AXA IM, Euronext, Kriptown	DvP of both listed and unlisted corporate shares			DAML on Besu	DISTRIBUTION MODEL	Primary and secondary markets for tokenised listed and unlisted securities.
7	ProsperUS	ProsperUS, Banque Centrale de Tunisie, BIAT Tunisie, BIAT France, Banque Wormser		Cross-border payments (remittances)		ProsperUS DLT	DISTRIBUTION MODEL	Used existing central banks banking relations to execute faster and cheaper remittances.
8	SEBA Bank	SEBA Bank, Banque Internationale à Luxembourg, LuxCSD	DvP of bonds		Public blockchain Ethereum		DISTRIBUTION MODEL and reverse Trigger	Use of conditional settlement function in T2S, based on purchasing power provided in wCBDC.

N°	PROJECT OR PARTNER	PARTICIPANTS	USE CASE		TECHNOLOGY		MODEL(S) TESTED	ADDED VALUE
			Tokenisation	Cross-border	Public blockchain	Private blockchain		
9	Mercure	SG Forge, Goldman Sachs, Santander, EIB	DvP of bonds issued by the EIB		Public blockchain Ethereum		DISTRIBUTION MODEL	Use of smart contract capabilities and programmability for controlling wCBDC on a public blockchain (e.g. white listing, freeze function).
10	Venus	Banque Centrale du Luxembourg, Goldman Sachs, Société Générale, Santander, EIB	Issuance of a native bond on DLT			DAP (based on DAML on Besu) and DL3S (based on Hyperledger Fabric)	INTEROPERABILITY MODEL	Joint management of wCBDC by 2 NCBs, shortening to T+0 the issuance process and managing sub-wallets for final investors (under cash custodian responsibility).
11	Mariana	BIS IH centers of the Eurosystem, Switzerland and Singapore, MAS, Swiss National Bank		Interoperability between domestic platform and international network and multi-wCBDC exchange	Public blockchain Ethereum	Domestic platforms (based on Besu)	DISTRIBUTION MODEL	Multi-tokens pools. Improve the pricing of exchange. Access the economic model for liquidity provision. Collapse trading and settlement in one atomic transaction.
12	SWIFT	Deutsche Bundesbank, MAS, BNP Paribas, HSBC, Intesa Sanpaolo, NatWest, Royal Bank of Canada, SMBC, Société Générale, Standard Chartered, UBS		Clean payments across different DLTs and between a DLT and a simulated RTGS system		Two permissioned wCBDC networks (based on Corda and Quorum) and a simulated RTGS system communicating with ISO 20022 messages in a sandbox hosted on a cloud-based service	INTEROPERABILITY MODEL	Interoperability between DLTs and between a DLT and a legacy system.

Appendix 3 DL3S

Introductory remarks

The Banque de France has made notable strides in the realm of distributed ledger technology (DLT). Collaborating with IBM France, the institution has developed its own DLT platform called DL3S (for Distributed Ledger for Securities Settlement System), which has been used in numerous experiments. However, the Banque de France's efforts extend beyond DL3S alone. In addition to this proprietary platform, the institution is actively pursuing research and experiments with Ethereum Virtual Machine (EVM) technology. This strategic approach allows the Banque de France to leverage the unique strengths of both DL3S and Ethereum, demonstrating its commitment to embracing diverse technological assets.

DL3S has been chosen as the DLT solution for the Banque de France's offering during the European Pilot Regime. This section serves as a comprehensive guide for the utilisation and understanding of DL3S, providing stakeholders with a detailed overview of this technology. Furthermore, DL3S will also be utilised during the Eurosystem's exploratory work, which aims to test different new technologies for the settlement of wholesale financial transactions in CeBM.

1. DL3S technical description

DL3S, the cash DLT platform used in the Banque de France's experiments, is a private and permissioned distributed ledger technology, for which the Banque de France is both provider and operator. DL3S is based on the open-source Hyperledger Fabric technology and embeds state-of-the-art components created by IBM research centres.

This technical description aims to provide a general overview of DL3S's architecture, with a focus on the following features:

- capabilities (digital asset issuance, asset custody, lifecycle and events, transaction creation, settlement, optimisation, interconnectivity);
- confidentiality and privacy management;
- interconnectivity mechanisms with TARGET Services and with other DLTS;
- performance (latency and throughput).

1.1 DL3S capabilities

The platform offers the following capabilities:

- **Digital asset issuance:** the platform enables the creation and distribution of assets in a digital form, such as money (wCBDC) and securities (e.g. bonds and shares). The assets data model can be customised depending on the use case. Assets can therefore live in the ledger both in traditional accounts and via wallets as fungible or non-fungible tokens.
- **Asset custody:** assets live on the platform and are managed by asset custodians. Managers in the network are accountable for the custody of their own wallet and those of their clients. Depending on the asset implementation model (account-based or value/token-based), managers can manage accounts or wallets, ensure proper accessibility to the assets and be involved in transactions in the case of a change in ownership.

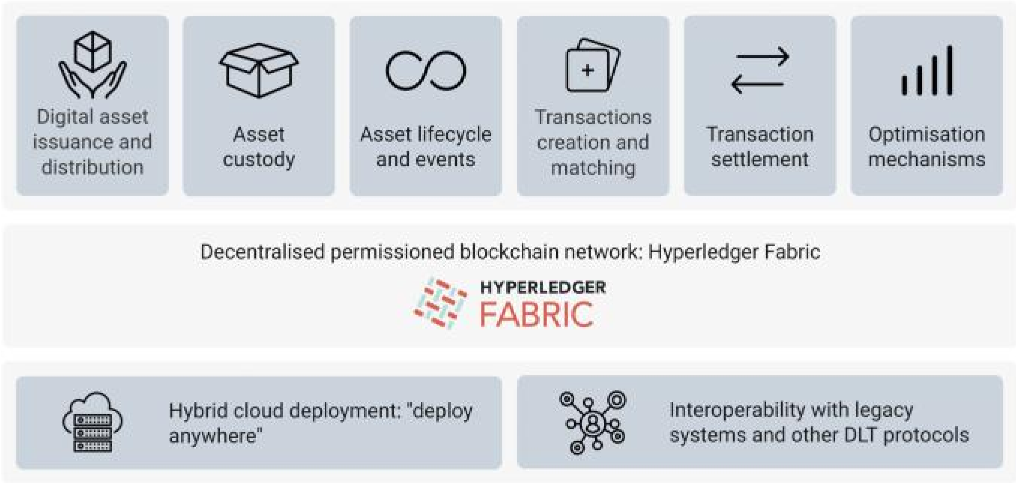

FIGURE 1 – DL3S capabilities

- **Assets lifecycle and events:** the platform covers the full asset lifecycle – and specific actions can be carried out depending on the asset type (e.g. for a tokenised security, a coupon payment can be executed on the platform). Concerning wCBDC, redemption can be requested from a participant, or executed at a regulator level, for example. In some experiments, the Banque de France implemented broad redemption mechanisms to ensure that the wCBDC only existed for a period of one business day.

- **Transaction creation:** the platform allows the creation of transaction workflows that meet the requirements of both securities settlement operations (DvP, FoP, PFoD and DwP) and wCBDC operations (wCBDC issuance, transfers and redemption). Several business rules are embedded in the transaction creation process and every step of the workflow is notarised with confidentiality in the ledger. There are currently several ways to create transactions (forms from a dedicated user interface, file batch, APIs, ISO20022 messages).

- **Settlement:** the platform offers a unique settlement engine that ensures atomicity of transactions and, if required, rollbacks, while preserving confidentiality of transaction content, anonymity of users and auditability of transactions by supervisors. The engine covers settlement of asset swaps (e.g. DvP, FoP, PFoD and DwP) and simple transfers (e.g. wCBDC payment). The engine stores in the ledger the settlement steps and the finality of each transaction.

- **Optimisation:** specific optimisation features have been developed for all securities related trades, such as recycling (recurring attempts to settle eligible transactions) or auto-collateralisation on flows (wCBDC funding in exchange for collateral deposit).

- **Interconnectivity:** the platform enables cross-network digital asset exchange and monitoring. It supports cross-network PvP, DvP, coupon payment, and data transfer with Hyperledger Fabric and Corda DLT based networks.

1.2 Confidentiality and privacy management

Confidentiality is a key requirement that has been addressed from the start of the platform journey. Several mechanisms and features are used in combination to ensure financial confidentiality within the platform.

- Access control (*addressing data accessibility*): at an application level, roles have been defined that have an impact on the data a user can access. Leveraging standard Access Control List (ACL)/Role-Based Access Control (RBAC) methods ensures that users only access data they are entitled to.

- Local Collections (*addressing data privacy*): Local Collections are a feature that is unique to Hyperledger Fabric. It enables the communication of information between parties without revealing it on the public ledger but storing a hash of the information exchanged in the ledger.

  A collection is the combination of two elements:

  i. The actual private data sent peer-to-peer via gossip protocol only to the organisations authorised to see it. This data is stored in a private state database with the peers of authorised organisations (sometimes referred to as a side database (Side DB)), which can be accessed from the dedicated Local Collection chain code at these authorised peers. The ordering service is not involved here and does not see the private data.

  ii. A hash of that data is endorsed, ordered and written to the ledger of every peer on the channel. The hash serves as evidence of the transaction and is used for state validation and can be used for audit purposes.

  Collection members may decide to share the private data with other parties if they get into a dispute or if they want to transfer the asset to a third party. The third party can then compute the hash of the private data and see if it matches the state on the channel ledger, proving that the state existed between the collection members at a certain point in time.

- Identity mixer (*addressing anonymity*): Identity Mixer (Idemix) is an anonymous credential system. It provides strong authentication as well as two privacy-preserving features:

  o Anonymity: the ability to transact without revealing the identity of the transactor (minimal attribute disclosure).

  o Un-linkability: the ability for a single identity to send multiple transactions without revealing that the transactions were sent by the same identity.

  This can be achieved by using zero-knowledge proofs, a cryptographic protocol by which one party (the prover) can prove to another party (the verifier) the knowledge of a certain value, without disclosing any information apart from the fact that they know the given value.

- Confidential tokens (*addressing transaction data privacy*): Zero-Knowledge Asset Transfer (ZKAT) is a token management system that allows users in Hyperledger Fabric to request token operations (i.e. issue, transfer and redeem) in a privacy-preserving manner.

- Built at the application layer of Hyperledger Fabric, ZKAT leverages Smart Fabric Client (SFC) and a chaincode. SFC is used on the users and issuers' side to compose ZKAT requests (e.g. issue, transfer and redeem), whereas the chain code (called ZKATCC) verifies that the requested token operations satisfy system's invariants. This architecture trusts the endorsement policy associated to ZKATCC.

- Settlement engine (*addressing transaction execution privacy*): at the heart of the platform lies a fully decentralised, atomic, and confidential settlement engine capable of settling all kinds of operations and upon which a distributed application implementing business workflows has been created.

1.3 Interconnectivity[34]

Some of the Eurosystem DLT modules and functions are built on technical primitives that allow it to interoperate with external systems, either:

- on a low-level integration (as simple data transfer, with any platform supporting HTTP REST API style communication); or
- as part of an application level protocol (asset transfer such as liquidity transfer from/to T2 RTGS), and asset exchange/swap as in DvP/PvP use cases in the **INTEROPERABILITY MODEL**).

1.3.1 Interconnectivity with TARGET Services

Current interconnectivity use cases with TARGET Services revolve around liquidity transfers from/to T2 RTGS, although they may evolve in the future. Due to their non-DLT nature, TARGET Services may only interoperate with DL3S through a notary scheme at applicative level, managed by the Eurosystem.

The technical interfacing between DL3S and TARGET Services leverages appropriate message formats and secure APIs that are supported, at the communication layer, by both DL3S and the ESMIG technical gateway for TARGET Services. DL3S can consume and create ISO20022 messages for exchange with TARGET Services APIs.

The Eurosystem application has to atomically execute the respective steps of the liquidity transfer use cases and secure the sequence with classic failover mechanisms.

1.3.2 Interconnectivity with other DLTs

Beyond interactions with TARGET Services, the interconnectivity of DL3S with other DLT solutions and platforms needs to support more use cases (*asset transfer and asset exchange*, as per **DISTRIBUTION** and **INTEGRATION MODELS** respectively), and can be achieved through a larger number of secure atomic mechanisms (*notary schemes, HTLC*).

Note. Irrespective of the chosen application-level interconnectivity protocol, the communication layer is HTTP Rest API-based, with the added flexibility – compared to interfacing with TARGET Services – of using message formats other than ISO 20022 (depends on the respective market DLT offering).

Asset transfers between DL3S and a market DLT can be implemented through a "lock and mint" approach that supersedes the inter-services liquidity transfer description, both in asset choice (cash or securities) and their ledger holding representations (wallets instead of accounts, if market platform is DLT-based). Governance wise, if the transferred asset is the euro (as in the **DISTRIBUTION MODEL**), the Eurosystem needs to be the Trusted Tier Party (TTP) that ensures the atomicity of the process. Otherwise, if securities are transferred (as in the **INTEGRATION MODEL**), any third party entrusted by the participants may play this role.

Asset exchange protocols for implementing DvP and PvP cases with other DLT solutions benefit from several technical interconnectivity patterns at the application level: intermediary scheme, settlement operator scheme (both are notary schemes, i.e. employing TTPs to ensure atomicity) and the HTLC protocol.

34 The interconnectivity capability features the ability of the DL3S platform to interoperate with external systems. This feature is usually called interoperability but is referred to as interconnectivity in this document to avoid confusion with the **INTEROPERABILITY MODEL** presented in the core report.

1.3.3 Intermediary scheme

This scheme implies having a TTP act as intermediary and having wCBDC transferred to its wallet on DL3S, and securities to its market DLT wallet (or account, if the other platform is not DLT-based). Upon receipt of correct quantities of both assets, the intermediary delivers them to their intended recipients, thus effectively implementing an atomic "joint execution" transaction by exclusive use of simple payments on the DL3S cash leg.

Note that, beyond the trust assumption, the intermediary is also required to hold escrow wallets/accounts on both platforms and have funds transit through its own balance sheet.

1.3.4 Settlement Operator scheme (also DvP operator scheme)

A more advanced variant of the notary scheme can leverage the programmable nature of DL3S and of most DLTs by implementing conditional payment services (*lock and release*) that considerably reduce both trust assumptions and operational/legal requirements for the notary party. The seller and buyer in this case initiate the transfer of assets towards each other, but the finalisation of these legs is blocked (thanks to a smart contract setup) until the TTP unlocking action –typically based on the successful audit of the two locks with respect to assets, quantities and beneficiaries.

The TTP plays the role of settlement operator without, at any time, taking possession of those assets. This considerably reduces the risks, trust assumptions and contractual arrangements.

1.3.5 HTLC protocol

The Hash Time Lock Contract (HTLC) protocol allows the buyer and seller to perform an – exclusively DLT-based – cross-platform asset exchange (as in the **INTEROPERABILITY MODEL**) without the need of any third party intermediation, provided they participate in both platforms. The assets are locked for the opposite party, and a secret and its hash are exchanged, according to a precise protocol, guaranteeing that both assets change hands or neither of them.

1.3.6 General implementation considerations

To provide the various interconnectivity capabilities (data transfer, asset transfer, asset exchange) that underlie the market DLT interface module, DL3S implements application and communication layer constructs (e.g. HTLC, API) and relies on a general-purpose interconnectivity framework called Weaver. This open source product, which provides an out-of-the-box set of primitives for trustworthy information communication across ledgers, has been experimented with R3's Corda technology-powered networks, and can be extended to networks built with other technologies that will be supported in the future (e.g. Hyperledger Besu).

1.3.7 Performance

The performance of DL3S can be measured using transaction latency and throughput:

- Latency: from a business transaction latency perspective, our platform ensures settlement of transactions (whether atomic swaps or token transfers) within a two-minute timeframe once the transaction instructions have been accepted. This SLA has been tested in experiments involving several financial institutions.

- **Throughput:** the Hyperledger Fabric layer has been tested in a dedicated two-month performance exercise, capturing nearly 300 metrics and using a dedicated testbed environment composed of 16 virtual machines hosted at the Banque de France.

- The tests show that:

  - o Fabric Token SDK and Fabric protocol are capable of supporting several thousand transactions per second and that a number of optimisations are possible, based on technology choices, configurations, hardware setup and network topology;

  - o transaction confidentiality comes with a reasonable and addressable cost to performance. Anonymity remains an area for optimisation.

2. DL3S participants

DL3S market participants are TARGET participants. The following section details the roles and responsibilities in DL3S. Roles and responsibilities are defined according to current market practices and can be applied regardless of the technology chosen.

2.1 Cash custodians

Cash custodians are T2 RTGS participants, meaning that they are directly connected to T2 RTGS. To be officially declared as a DL3S participant, a cash custodian must agree with the overall DL3S membership framework. This framework is formalised in a legal contract signed by the cash custodian representatives, the Banque de France and the central bank in the cash custodian's jurisdiction.

The cash custodian is governed by the national central bank (NCB) in its own jurisdiction. Once authorised by the latter, DLT access is granted via the attribution of a node and wallet.

The cash custodian manages overall cash operations for itself and any third parties. Payment executions are triggered by market events taking place on the market DLT connected to DL3S. They are performed under the cash custodian's responsibility.

The cash custodian and securities custodian are managed in a consistent but independent manner within the cash and market DLT. When an event is triggered, such as the delivery of a security from a seller to a buyer, both the security custodian buyer and the cash debiting custodian can differ respectively from each other in both DLTs. Each security (or market) custodian has to define a cash custodian representing its overall business interests on DL3S.

The role of the cash custodian encompasses two types of actions static data management and payment instructions for itself and its clients:

Static data management consists in:

- creating, monitoring, amending and closing wallets for its investors. The wallet is a technical object where wCBDC balances are managed, payment operations are instructed and instruction histories can be accessed by the cash custodian;

- holding the investors' private keys and, more broadly, ensuring that their investors have read-only access to their dedicated wallet, their cash balances and payment instruction history on the DL3S platform.

Regarding payment execution, cash custodians can manage their wCBDC positions on the DLT using a unique wallet for all market DLTs (or one per market DLT, depending on their choice of account structure). This action consists in:

- receiving wCBDC when they send a request for it to the RTGS system;

- executing cash transfers between their own wallet to their clients' wallets or payments to other cash custodians;

- executing payments triggered by a market operation executed on the market DLT. The market operation types that trigger a wCBDC payment are defined in the operating and business model defined jointly by the cash custodians and market DLT operators;

- holding wCBDC for their own accounts as well as for their clients';

- requesting wCBDC destruction (and triggering a cash payment from the central bank's escrow account to its T2 RTGS account).

The DL3S custodian is a wallet owner and wallet custodian as it is entitled to create, amend and delete its clients' wallets.

2.2 Cash custodian clients

The cash custodian is solely in charge of maintaining relationships with its clients according to the contractual framework agreed between both parties. The cash custodian remains the final holder of the wCBDC credited to each client's wallet. The cash custodian client is granted a specific read-only access to DL3S. The client cannot interact directly with DL3S. Any action related to payment execution is performed by the cash custodian. It can open a dedicated wallet for segregation purposes, called a "sub-wallet", which remains under the name of the cash custodian and is operated on behalf of its client by the cash custodian.

The client's read-only access encompasses cash balances and overall payment operations corresponding to market executions such as DvPs, coupon distribution, redemption or any market event triggered by the market DLT. The client wCBDC balance represents the purchasing power allocated by the cash custodian; it is reflected in the sub-wallet. Sub-wallets are connected to the cash custodian wallet, which is itself connected to the T2 RTGS account belonging to the cash custodian. The cash custodian remains the instructing party for all market DLT operations that trigger payments.

With the sub-wallet feature, the Banque de France aims to offer the capacity to cash custodians the capacity to segregate cash positions and operations at investor level. This service remains optional; the cash custodian can represent its investors, i.e. client purchasing power on a net or gross basis in a single or multiple sub-wallets.

2.3 Central banks

Central banks participating in DL3S are members of the Eurosystem. They carry out various roles, as described below.

- Central banks participating in the DL3S platform form a consortium of central banks which is in charge of:
  - o issuing, distributing and redeeming the wCBDC;
  - o supervising overall DLT activity, which means they have access to the overall balances in cash custodians' wallets and sub-wallets, and to the transactions carried out by members participating in DL3S in their jurisdiction;
  - o ensuring that the regulations are enforced and that best market practices are used in accordance with the market DLT operator.
- Central banks participating in the DL3S platform are in charge of managing the cash custodians in their own jurisdiction. Therefore, they:
  - o hold an escrow account in T2 RTGS on the cash custodians' behalf. The cash custodians transfer amounts in euro to this account, and an equivalent amount of wCBDC is then issued and distributed to them;
  - o grant and remove cash custodians' DL3S access, which is equivalent to whitelisting participants. Each central bank is in charge of authorising the cash custodians in its respective jurisdiction on DL3S. From an operational point of view, this involves creating, modifying or deleting the wCBDC wallets granted to the cash custodians;
  - o have the same right and ability to interact with DL3S as any other cash custodian (holding wCBDC and performing transactions);
  - o consult the wallet balances and transaction histories of cash custodians in their own jurisdiction.
- The DL3S platform operator:
  - o operates the DL3S platform;
  - o manages the overall configuration of the network with the establishment or removal of DL3S participants, i.e. grants DL3S access to central banks and cash custodians via the creation of nodes and wallets;
  - o monitors the interoperability components between the cash and securities DLTs, to ensure trustless wCBDC payment execution.

3. Liquidity management: how wCBDC is operated

3.1 Key principles

The central banks consortium is composed of central banks participating in DL3S governance, who use a single shared wallet (central banks consortium wallet) to issue (or mint), distribute and redeem (or burn) the wCBDC upon request from the cash custodians.

wCBDC issuance and distribution are be executed when cash transfers take place in T2 RTGS. For each wCBDC issuance and distribution, there is an associated T2 RTGS cash transfer for the same euro amount between a commercial bank and the NCB in its jurisdiction.

The overall process is conducted as follows:

- DL3S participants manage their wCBDC liquidity and needs in connection with funds transfers executed in T2 RTGS; they use their own T2 RTGS accounts to credit funds to and receive funds from the escrow account of the central bank in their jurisdiction.
- Central banks use their escrow account to issue and distribute the same wCBDC amount received in their escrow account to the cash custodian's wallet.
- When the wCBDC is destroyed, the same amount is credited to the cash custodian's T2 RTGS account.

3.2 Illustrations

Cash custodians are T2 RTGS participants and rely on their national central bank as an entry point for all TARGET transactions. Each central bank is in charge of defining, with the cash custodian, the account structure and overall process for wCBDC liquidity management.

Each central bank is in charge of monitoring wCBDC issuance, distribution and redemption in alignment with RTGS transfers.

3.2.1 wCBDC issuance, distribution and redemption high level view

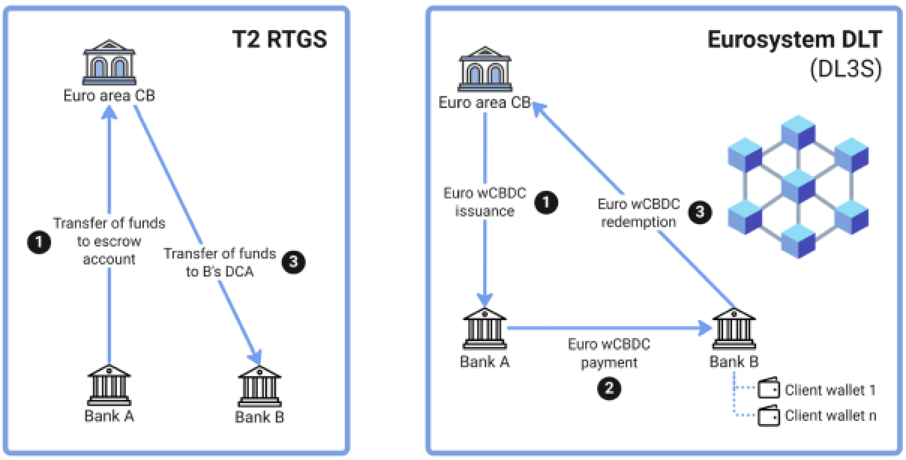

FIGURE 2 – wCBDC issuance, distribution and redemption high level view

Step by step description:

1. Issuance: Bank A transfers funds to its NBC's escrow account and the NCB issues the corresponding amount of wCBDC.
2. Settlement: Bank A makes the payment in wCBDC to Bank B and, according to the account structure and investor wallet set up, the wCBDC amount is transferred to 1 or n sub-wallets.
3. Redemption: Bank B transfers its wCBDC back to the NBC and receives the corresponding amount of funds in its RTGS DCA.

When the overall wCBDC distribution has been completed, including in investors' sub-wallets, the amounts are reflected in investors' and cash custodians' balances. The wCBDC distribution takes place according to the instructions provided by investor ahead of the daily transactions.

3.2.2 Security delivery versus wCBDC payment (DvP) use case

The DvP is defined as an operation whereby the security delivery and payment are performed in an all or none basis (atomic transaction). Within the INTEROPERABILITY MODEL, it is reflected as a cross-chain DvP execution made via an interoperability component set up between both the cash DLT and the market DLT.

The figure below illustrates how transactions such as a DvP could be handled between a seller and a buyer of tokenised securities.

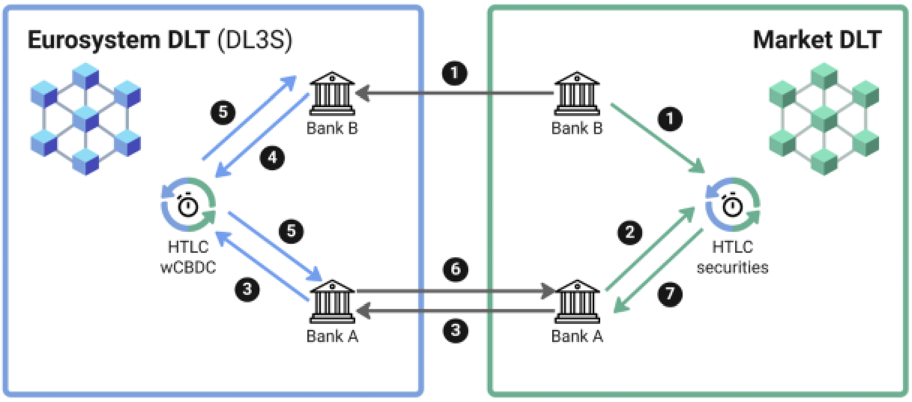

FIGURE 3 – Security delivery versus wCBDC payment (DvP) use case

The key steps undertaken for executing cross chain DvP are described below:

1. The seller's market DLT custodian (Bank B) locks the securities with a pre-defined time lock *Ts* and sends the lock information to the seller's DL3S custodian (Bank B).

2. The buyer's market DLT custodian (Bank A) audits the securities lock.

3. The buyer's market DLT custodian (Bank A) informs the buyer's DL3S custodian (Bank A) who locks wCBDC with a pre-defined time lock *Tc* (assuming $Tc < Ts$).

4. The seller's DL3S custodian (Bank B) audits the wCBDC lock.

5. The seller's DL3S custodian (Bank B) claims the wCBDC using a secret before the end of the time lock *Tc*; the secret *s* is revealed to the buyer's DL3S custodian (Bank A).

6. The buyer's DL3S custodian (Bank A) sends the secret *s* to the buyer's market DLT custodian to claim the securities (Bank A).

7. The buyer's market DLT custodian (Bank A) claims the securities with secret *s* before the end of *Ts*.

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