



HONG KONG MONETARY AUTHORITY
香港金融管理局



BANK OF THAILAND

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Cross-Border DvP in the Age of Tokenisation: Interoperability for Carbon Credit Transactions

Project at a Glance

Pain Points in Cross-Border DvP

1. Slow Settlement

Long processing time



2. Lack of Connectivity

Manual reconciliation across marketplaces/platforms



Proposed Solution

The Interoperability Layer

A modular interoperability framework that bridges central banks networks (Project Ensemble & Project SAN)

Characteristics



Low Entry Barrier:

Light-weight plugin built on existing payment infrastructure



Programmable Escrow:

Implements lock-and-release mechanisms to enable atomic DvP



End-to-End API Integration:

Automated data exchange between marketplace, carbon registry and payment infrastructure

Execution Results

19

Total Validation Tests

14

Scenarios

tested under cross-border tokenised deposit transfer

5

Scenarios

tested under cross-border carbon credit DvP settlement

Faster Cross-Border Carbon Credit Settlement

Traditional settlement:
2 - 5 business days



Time required with project solution:

Around

40

Seconds



Other Benefits of the Proposed Solution

Reduces settlement risk through atomic settlement



Use of local currency



Automated ownership transfer upon transaction completion



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1. Executive Summary

Cross-border Delivery-versus-Payment (DvP) transactions can face practical challenges, including lengthy settlement processes and fragmented connectivity across market infrastructures, often requiring manual reconciliation among different platforms and financial institutions. Carbon credit transactions provide a relevant use case for exploring these challenges, as buyers and sellers are often located in different jurisdictions and transactions involve multiple parties, including marketplaces, registries and banks.

This report presents the outcomes of a year-long proof-of-concept (POC) led by the Hong Kong Monetary Authority (HKMA), the Bank of Thailand (BOT) and Hong Kong Exchanges and Clearing Limited (HKEX), exploring how tokenised deposits (TDs) and Central Bank Digital Currencies (CBDCs) coordinated through two central bank platforms could enable seamless cross-border DvP for carbon credit transactions.

This project aimed to investigate how interoperability between distributed ledger technology integrated financial market infrastructures (DLT FMIs) can streamline processes, reduce friction and scale participation. In addition, the project examined how carbon credit tokenisation and greater automation can enhance efficiency and scalability within the Voluntary Carbon Market (VCM).

HKMA and BOT tested interoperability between DLT FMIs under their respective domestic projects, Project Ensemble and Project SAN. Following this testing, HKEX piloted a tokenised carbon credits transaction use case in collaboration with InnoBlock, Northern Trust and Towngas. In this use case, application programming interface (API) integrations enabled real-time data exchange between the marketplace, registry and banks, demonstrating how automation can streamline workflows and bolster scalability.

The POC delivered two key sets of insights. On the cross-border DvP side, it validated a connector design that could be standardised into a technology-neutral framework for synchronised cross-border Payment-versus-Payment (PvP) and DvP. The findings also suggest that this connector design has the potential to scale and support bilateral connections across different jurisdictions. On the VCM front, it highlighted the potential for API integration and cross-border transaction of tokenised carbon credits.

Ultimately, this project underscores the transformative potential of digital innovation to address long-standing pain points and build more connected, efficient and transparent financial and environmental markets.

2. About Us

The following organisations collaborated to execute this POC:

The Hong Kong Monetary Authority (HKMA)

The Hong Kong Monetary Authority (HKMA) is the government authority in Hong Kong responsible for maintaining monetary and banking stability. One of HKMA's key functions is helping to maintain Hong Kong's status as an international financial centre, including the maintenance and development of Hong Kong's financial infrastructure. It provided the Project Ensemble infrastructure as the settlement environment.

Bank of Thailand (BOT)

The Bank of Thailand (BOT) is the central bank of Thailand responsible for maintaining monetary and financial stability and supporting the stability and efficiency of the financial system. One of BOT's key functions is to promote the development of Thailand's payment systems and financial infrastructure, including in response to technological and financial innovations. BOT has developed Project SAN, which explores an interoperability layer between DLT-based networks and existing payment systems. The Project SAN infrastructure provides an environment for exploring the potential of DLT and tokenisation to enhance payment efficiency and support the smooth and stable transition towards next-generation financial infrastructure.

Hong Kong Exchanges and Clearing Limited (HKEX)

Hong Kong Exchanges and Clearing Limited (HKEX) is one of the world's leading exchange groups (Stock Code: 388), offering equity, derivative, commodity, fixed income and other financial products and services, including the London Metal Exchange. HKEX is building a sustainable finance ecosystem that includes Core Climate, a marketplace that offers trading, custody and settlement functions for a selection of products in the environmental market, contributing to the realisation of global net-zero goals.

InnoBlock

InnoBlock is an Environmental, Social and Governance (ESG) technology company specialising in blockchain-enabled sustainability solutions. Through its flagship TT GREEN® platform, a blockchain-based carbon management Software as a Service (SaaS), InnoBlock empowers businesses to automate Greenhouse Gas (GHG) emission calculations for organisations and Products, ESG reporting, and carbon offsetting, helping them meet global disclosure standards and advance towards carbon neutrality.

In this instance, InnoBlock collaborated with HKEX to provide the carbon credit trading platform.

Northern Trust

Northern Trust Corporation (Nasdaq: NTRS) is a leading provider of wealth management, asset servicing, asset management and banking services to corporations, institutions, affluent families and individuals. Founded in Chicago in 1889, Northern Trust has a global presence with offices in 24 U.S. states and Washington, D.C., and across 22 locations in Canada, Europe, the Middle East and the Asia-Pacific region. As of March 31, 2026, Northern Trust had assets under custody/administration of US\$18.6 trillion, and assets under management of US\$1.8 trillion.

The Northern Trust Carbon Ecosystem™ is a fully digital, end-to-end platform that connects carbon project developers with institutional buyers to explore, transact and retire voluntary carbon credits, powered by Northern Trust Matrix Zenith™, its digital assets platform. Leveraging private ledger blockchain technology, the ecosystem enhances transparency and efficiency by digitising the entire carbon credit lifecycle, from issuance to settlement, while enabling direct market access, seamless tracking, and rapid transaction execution. By securely holding both funds and tokenised carbon credits, Northern Trust facilitates trusted, streamlined participation in the voluntary carbon market, supporting clients' climate objectives through scalable, technology-driven infrastructure.

Towngas

Founded in 1862, The Hong Kong and China Gas Company Limited (Towngas) is Hong Kong's first public utility enterprise. Guided by continuous innovation, Towngas has evolved from providing town gas for street lamps into a leading integrated clean energy supplier. Today, it delivers safe, reliable energy solutions, alongside water, environmental and lifestyle services across Hong Kong and the Chinese mainland.

Committed to carbon neutrality, Towngas invests heavily in the energy transition. The Group actively develops its green and new energy businesses, encompassing green methanol, hydrogen, and sustainable aviation fuel (SAF) tailored for sea, land and air transport, respectively. Concurrently, Towngas is expanding its renewable energy portfolio across distributed photovoltaics and energy storage sectors.

For this use case, Towngas served as the carbon credit issuer.

3. Introduction

The emergence of new technologies like distributed ledger technology (DLT) prompts us to reimagine how cross-border DvP could better support the future digital economy and the development of the tokenisation ecosystem.

At the heart of this evolution is the concept of an Interoperability Layer (IL), which serves as a vital bridge between distinct domestic financial infrastructures. In the traditional cross-border landscape, settlement often relies on a “hub-and-spoke” model or a single centralised ledger, both of which present scalability and sovereignty challenges. The IL introduces a decentralised alternative: a standard-based plane that enables different platforms to communicate seamlessly. By facilitating synchronised PvP and DvP, the IL reduces counterparty risks, ensuring that the movement of value across borders is efficient.

Carbon markets provide a relevant and high-impact context in which to explore cross-border DvP. As corporate decarbonisation efforts accelerate globally, carbon credits and the VCM play an increasingly important role in mobilising private capital for decarbonisation and funding carbon projects. Given that projects and buyers are often located in different jurisdictions, carbon credit transactions are inherently cross-border, introducing settlement complexity, foreign exchange (FX) uncertainty and operational fragmentation across marketplaces, registries, and banking systems.

Against this backdrop, technologies such as DLT, tokenisation and API integration offer the potential to improve market infrastructure. Tokenisation enables carbon credits to be represented digitally on-chain while preserving key project attributes. When combined with synchronised cross-border DvP, these innovations create the potential to reduce settlement frictions and enable more automated, synchronised exchange of assets and funds. Exploring carbon credit DvP therefore provides a practical test case, while supporting real-economy sustainability objectives.

In this project, trade settlement using TDs and CBDCs are orchestrated by two central bank platforms, facilitating a cross-border DvP trade settlement use case for the trading of carbon credits. The central banks, the HKMA and the BOT, explore interoperability between the DLT FMIs under their domestic projects, namely Project Ensemble and Project SAN, respectively. HKEX, in collaboration with InnoBlock, provides the carbon credit trading platform. Northern Trust acts as the carbon credit registry, while Towngas serves as the carbon credit issuer.

The vision of the project is two-fold. Firstly, it aims to foster seamless and secure cross-border DvP, through exploring interoperability of DLT FMIs and fostering connectivity across central bank platforms. Secondly, it seeks to enhance the efficiency and scalability of the VCM by tokenising carbon credits and integrating APIs. These innovations reduce operational frictions, support local currency usage and lower participation barriers, addressing existing pain points within the VCM.

This report outlines the cross-border trade settlement landscape and identifies existing pain points within the VCM. It details the technical experiments conducted during the POC and concludes with core insights, alongside recommendations for further exploration and collaboration.

4. Background

4.1. Carbon credit

Carbon credits are market-based instruments designed to incentivise the avoidance or removal of greenhouse gas emissions through the development of carbon projects. Each carbon credit represents one tonne of carbon dioxide (CO₂e) or carbon dioxide equivalent (CO₂e) avoided or removed from the atmosphere. By translating climate action into a measurable and tradable unit, carbon credits create a mechanism that links environmental outcomes with financial value.

Building on this foundation, carbon credits help advance climate commitments, lower the cost of new technologies, and channel finance towards nature-based solutions such as afforestation. Beyond direct carbon emission reductions, they also deliver other co-benefits, ranging from making clean energy access more affordable and providing cleaner cooking fuels to improving the health and resilience of forests. For companies, carbon credits provide a way to take responsibility for their emissions during the transition while contributing to global sustainability efforts.

Valued at approximately US\$1.4 billion in 2025 by MSCI, the global VCM is on track to at least triple in value by 2030.¹

Despite this immense potential, today's VCM faces persistent challenges that limit their effectiveness, including integrity issues and limited transparency. These issues can make it difficult for buyers to assess credit quality and can undermine confidence in the market as a whole.

4.2. Existing pain points

Various pain points exist in the cross-border DvP landscape. This section focuses on specific pain points found within conventional marketplaces,² namely i) inefficiency in cross-border transactions, ii) exposure to the variability of FX costs and iii) a lack of connectivity among marketplaces, registries and banks.

¹ MSCI. "Carbon Credits Come of Age in 2025." MSCI Research & Insights, 6 Jan. 2026, <https://www.msci.com/research-and-insights/blog-post/carbon-credits-come-of-age-in-2025>. Accessed 13 Aug. 2026.

² Carbon credit transaction can be facilitated on marketplaces, such as Core Climate, that act as a network connecting market participants. Transactions can also be facilitated by intermediaries.

1. Inefficiency in cross-border transactions

Emerging markets and developing economies face a significant climate finance gap, with public finance alone insufficient to meet Nationally Determined Contributions under the Paris Agreement.³ Against this backdrop, VCM plays an important role in mobilising private capital. However, carbon credit issuance in these economies is limited and highly concentrated, with just six economies accounting for over 75% of voluntary carbon credits,⁴ implying that the related transactions often involve international counterparties and cross-border payments.

These cross-border transactions usually require longer processing times than domestic remittances, reflecting differences in payment arrangements, the possible involvement of intermediary banks, and applicable regulatory and compliance requirements. Successful transactions can take up to several business days, depending on the payment rails used (e.g. correspondent banking or instant payment networks), along with time-zone differences and compliance checks.

2. Exposure to the variability of FX costs

In a cross-border carbon credit transaction, FX typically occurs either before or after the payment. The buyer may need to convert funds from their domestic currency into the currency accepted by the seller, or alternatively, the seller may receive payment in the buyer's domestic currency and subsequently convert the proceeds into their own preferred currency.

The actual cost of FX is influenced by bank charges, intermediary or correspondent banking fees, and the bid-offer spreads applied during currency conversion. Such spreads can vary significantly depending on the currency pair involved, prevailing market volatility and notional size. This variability is even more pronounced when one or both currencies are emerging market currencies, which frequently arises in cross-border carbon credit transactions.

Beyond the inherent FX volatility, the unpredictability of FX costs coupled with uncertainty around engaging with hedging tools to manage FX risks, further elevates the overall transaction costs. These factors reduce price transparency and may ultimately erode financial value for both carbon credit buyers and Project Proponents (PP). The resulting increase in transactional uncertainty is particularly problematic for market participants involved in high-value carbon credit transactions.

3. Lack of connectivity among marketplaces, registries and banks

Traditionally, the settlement of carbon credits via marketplaces requires manual reconciliation against multiple registries and banks. This fragmented process obliges marketplaces to separately verify payment completion, credit issuance and ownership transfers, often through manual checks and matching. The lack of real-time connectivity between marketplaces, registries and banks increases operational complexity and raises the risk of errors or delays. As transaction volumes grow, these manual processes become increasingly inefficient, leading to higher operational costs and risks, ultimately constraining the scalability and efficiency of the VCM.

³ UNFCCC. "In-session Workshop on Long-term Climate Finance in 2019: Summary Report by the Secretariat." United Nations Framework Convention on Climate Change, 6 Sep. 2019, para. 36, https://unfccc.int/sites/default/files/resource/cp2019_04E.pdf. Accessed 13 Aug. 2026.

⁴ United Nations Conference on Trade and Development. "The Least Developed Countries Report: Leveraging Carbon Markets in Least Developed Countries." UNCTAD, 4 Nov. 2024, <https://unctad.org/news/leveraging-carbon-markets-least-developed-countries>. Accessed 13 Aug. 2026.

4.3. Carbon credit tokenisation

As the global VCM expands and attracts more participants, the need for a more transparent, verifiable, and efficient infrastructure has become increasingly clear, creating fertile ground for digital innovation.

Carbon credit tokenisation refers to the process of converting carbon credits into digital tokens on a blockchain. Tokenised carbon credits retain the same information and characteristics of carbon credits, including project ID, vintage, project type and all associated data. Subject to registries' endorsement, carbon credits can be tokenised or brought "on-chain". Once on-chain, credits can be held, transferred or retired just as they would on traditional digital registries.

Tokenising carbon credits enables stakeholders, including corporations, investors, and individuals, to seamlessly transact and retire them, and use them in smart contracts.

4.4. HKMA and BOT's collaboration on cross-border DvP

The HKMA and the BOT's collaboration in exploring DvP tokenisation use cases aims precisely to address existing pain points in the cross-border transactions and tokenisation landscape. Conducted as a POC, the initiative focuses on cross-border DvP transactions involving tokenised carbon credits, with participation from an FX provider. It seeks to harness the potential of CBDCs and TDs to enhance the efficiency, scalability, and security of cross-border transactions. This is achieved through exploring interoperability between the DLT FMIs under Project Ensemble and Project SAN, respectively. The exercise is carried out in a testing environment and does not involve real-money transactions.

The collaboration between the HKMA and the BOT dates back to 2019, when they signed a MoU to cooperate in areas of fintech and financial innovation. Since then, they have been working closely on multiple projects, including Project Inthanon-LionRock and Project mBridge, which provided valuable insights not only for cross-border transactions but also for their respective domestic CBDC and tokenisation initiatives.

The HKMA's Project Ensemble, launched in 2024, seeks to set interoperability standards among tokenised assets, tokenised deposits and CBDC for industry reference, enabling industry participants to conduct end-to-end testing of tokenised asset transactions in practical business scenarios. In November 2025, the HKMA launched Ensemble^{TX}, the pilot phase of Project Ensemble, to enable faster, more transparent, and efficient settlement of real-value tokenised transactions. The initial focus is on empowering market participants to utilise tokenised deposits in settling tokenised money market fund transactions, and to manage liquidity and treasury needs in real time.

The BOT's Project SAN, an internal initiative started in June 2024, aims to build, and test a prototype for the tokenisation ecosystem. This includes a wholesale settlement engine, EVM-compatible ledgers⁵ supporting tokenised private money and assets, and interoperability mechanisms. To date, Project SAN remains at the POC stage and has not been deployed for real-value transactions.

Through their collaboration, the HKMA and the BOT aim to generate practical insights into the interoperability of tokenised assets, tokenised money and DLT-based financial market infrastructures across jurisdictions. The findings are expected to inform future tokenisation and cross-border settlement initiatives.

4.5. HKMA and HKEX's collaboration on cross-border transactions for tokenised carbon credit

HKEX has worked closely with the HKMA on carbon credit-related use cases since joining the Project Ensemble Sandbox, bringing practical insights from live market operations and end-to-end transaction experience. This collaboration aims to ensure that emerging tokenisation solutions are grounded in real-world market needs, operational considerations and user workflows.

Under Project Ensemble, the HKMA and HKEX are focused on advancing practical, commercially viable approaches to tokenised carbon credit transactions, including cross-border flows and DvP settlement models.

HKEX contributes market and infrastructure expertise drawn from operating its carbon marketplace, Core Climate. In doing so, HKEX helps to shape use-case scenarios, define transaction flows, and reflect relevant market practices within the Project Ensemble Sandbox. Through this joint initiative, the HKMA and HKEX are also engaging a broader ecosystem of industry stakeholders to test and iterate tokenised transaction workflows. This collaboration generates practical learnings to inform the broader evolution of carbon credit tokenisation and related market infrastructure initiatives in Hong Kong.

⁵ EVM-compatible ledgers are blockchain-based systems designed to run applications and smart contracts built for the Ethereum Virtual Machine (EVM), allowing them to use a common execution environment across different networks.

5. Use Cases

5.1. Overall workflow

The project is designed to address the aforementioned pain points that arise in the VCM. It brings together key stakeholders, including a buyer and seller, a marketplace, a registry, banks, and central banks hosting the CBDC networks.

Current market pain points	Project solutions
Inefficiency in cross-border transactions	Showcase streamlined processes in cross-border DvP carbon credit transactions, thereby eliminating delays and improving efficiency.
Exposure to the variability of FX costs	Reduce FX costs involved in traditional cross-border carbon credit transactions with the use of CBDC Sandbox under Project Ensemble.
Lack of connectivity among marketplaces, registries and banks	Eliminate manual operation between marketplaces, registries and banks through API connection, which traditionally introduces operational costs and risks.

To further define the boundaries of this workflow, the POC focuses on two primary use cases:

- 1. Cross-border Tokenised Deposit (TD) Transfer:** Demonstrating interoperability between Project Ensemble and Project SAN to facilitate cross-border TD transfers.
- 2. Cross-border Carbon Credit DvP Settlement:** Utilising HKEX's Core Climate as an asset platform to ensure that the delivery of carbon credits is contingent upon the successful escrow of funds through the cross-border TD transfer mechanism.

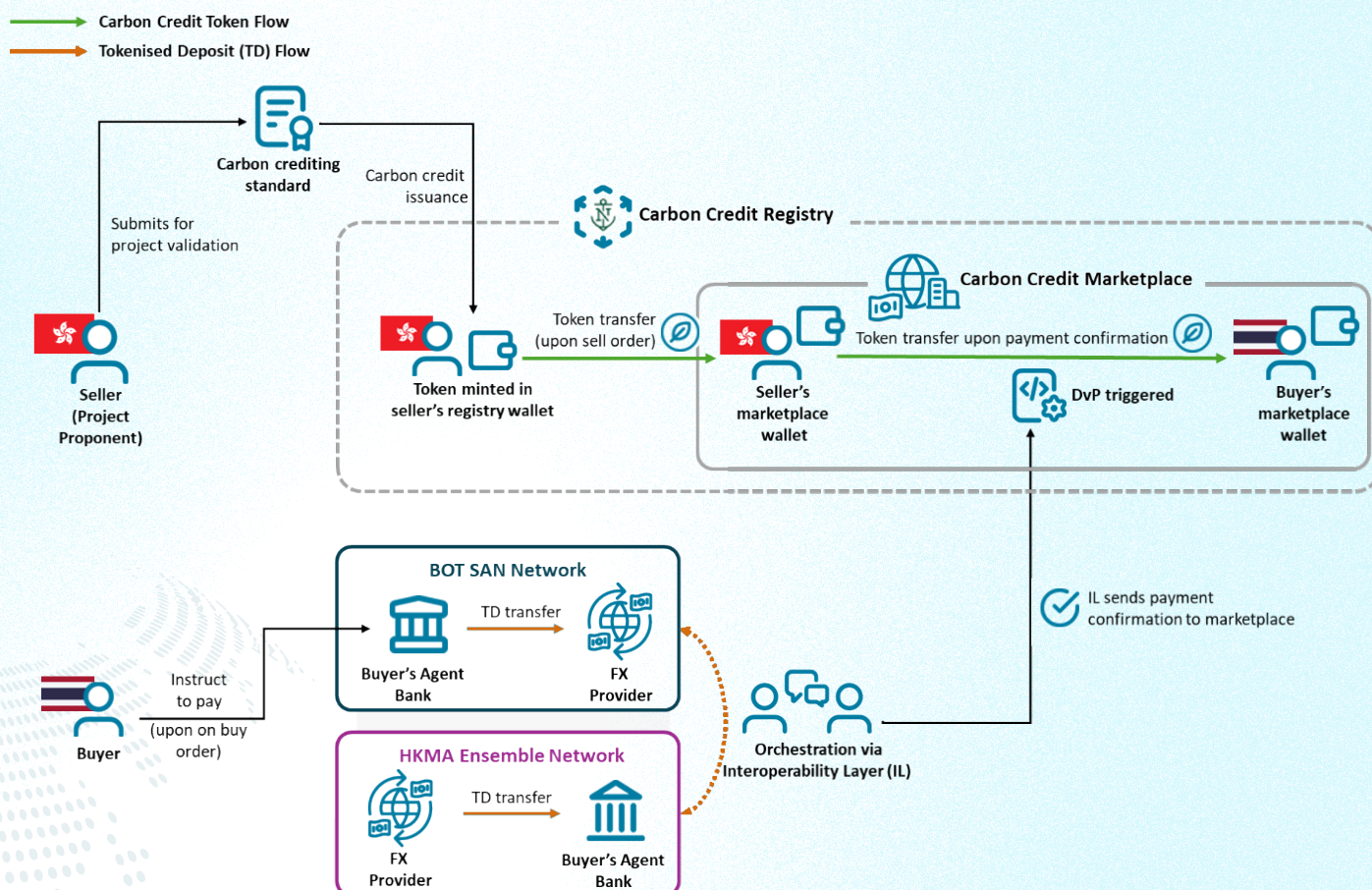
The following operational assumptions and parameters were applied to the testing environment:

- **Fixed FX Management:** A pre-agreed, fixed FX rate was applied to all payment instructions to ensure consistency in settlement amounts across both systems.
- **Liquidity Model:** A prefunding model is adopted. Transactions were rejected immediately if participating parties lacked sufficient liquidity, rather than being queued.
- **Settlement Cut-off:** A strict settlement window was defined with a hard cut-off at 5:00 PM HKT / 4:00 PM BKT.

The combined workflow across the two use cases was validated through 19 distinct tests, comprising 14 scenarios under the cross-border TD transfer and 5 carbon credit DvP scenarios. The test cases covered standard successful transactions as well as various exceptions, including invalid master data (e.g. incorrect Business Identifier Codes or wallet IDs), liquidity constraints, settlement cut-off breaches.

Additionally, technical timeouts were tested to evaluate manual intervention and recovery procedures.

Specifically for **the cross-border carbon credit DvP use case**, the workflow is as follows:



To streamline processes, an API connection⁶ between the marketplace and registry as well as between the marketplace and bank are established, and synchronised cross-border TD transfer is enabled through the linkage between Project Ensemble and Project SAN. Transactions are settled using TDs facilitated by the Project Ensemble Sandbox.

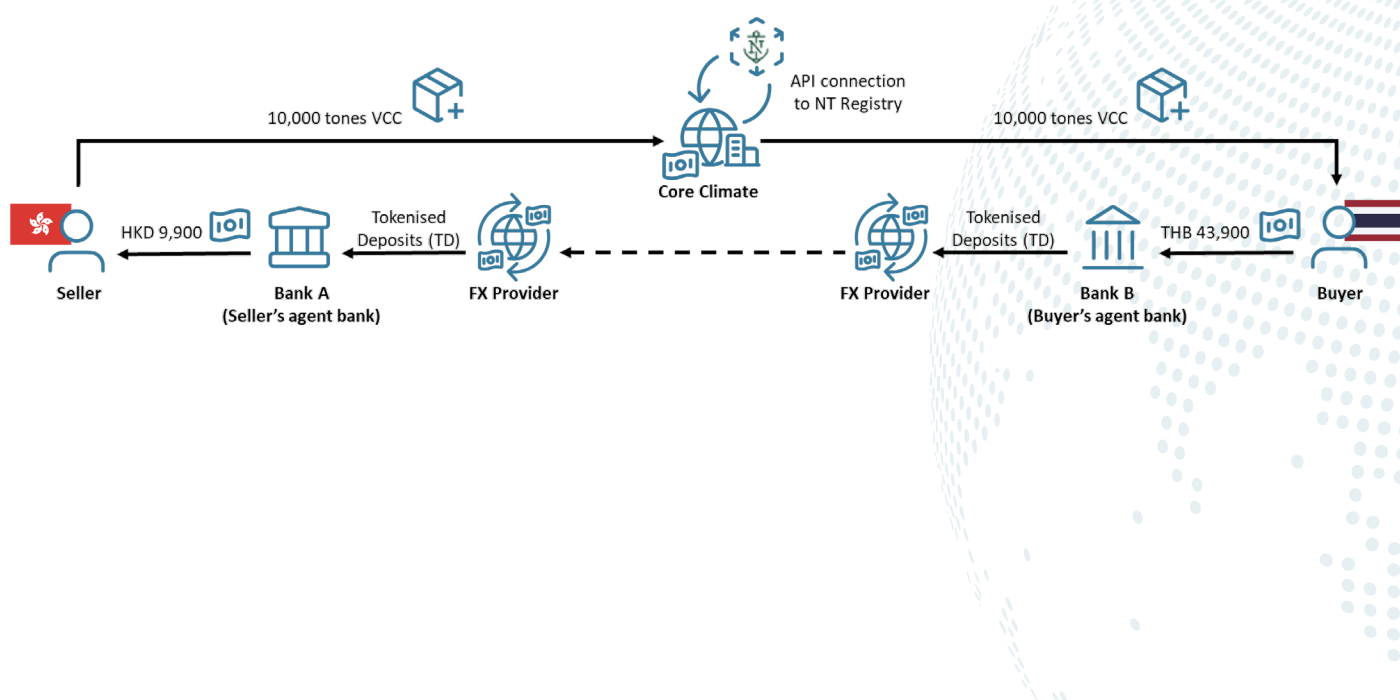
PPs submit the validated and verified project documents to the carbon crediting standard. After reviewing these documents, the carbon crediting standard issues carbon credits, which are then minted into PPs' wallets on the registry.

Under a DvP model, a seller intending to sell carbon credits through a marketplace transfers the tokenised carbon credits to the marketplace's wallet, which will be held under the name of the seller on the registry. The PP can then place a sell order on the marketplace.

Buyers can transact directly through the marketplace, making payment through their agent bank, which are then credited to the seller's agent bank with the assistance of a FX provider.

Once the transaction is completed, the corresponding tokenised carbon credits are automatically transferred within the marketplace's wallet, from the seller's name to the buyer's name, on the registry.

Carbon credit retirement can also be facilitated through the marketplace. After a buyer submits a request to retire credits, the marketplace logs onto the registry and sends a retirement instruction in the name of the buyer. The registry sends a burn token instruction, representing the intentional, irreversible removal of the token from circulation, to the marketplace's wallet and confirms that the token has been burnt. To complete the retirement process, the registry generates a retirement certificate under the name of the buyer and sends it to the marketplace, which passes it on to the buyer.



⁶ The APIs allow for automated movement and retirement of carbon credits and funds in the registry and bank, respectively.

5.2. Technical design

Architecture overview

The high-level architecture adopts a modular interoperability framework designed to enable standards-based synchronised cross-border PvP and DvP settlement among central banks, while preserving the integrity of domestic financial market infrastructures. At its core is the IL, which serves as a coordination and control plane for cross-border transactions between the HKMA's Project Ensemble and the BOT's Project SAN. The IL does not maintain balances or operate as a settlement system. Instead, it orchestrates the transaction lifecycle across each jurisdiction's domestic infrastructure and central bank system to ensure synchronised atomic settlement.

The IL coordinates a conditional lock-and-release mechanism across jurisdictions. In a cross-border transaction, the funds involved are first placed into escrow within their domestic systems. Through structured status exchanges, the IL verifies that predefined conditions have been met on both sides before triggering a simultaneous release. If conditions are not satisfied, both legs are cancelled or unlocked. In this manner, the architecture ensures atomic settlement without requiring disruptive changes to domestic infrastructures.

The IL is implemented through two complementary components, the Open Connector (OC) and the Adaptor, both designed as RESTful API frameworks.⁷ Together, they form a lightweight plug-in model that separates cross-border orchestration from domestic execution. This layered structure enables interoperability across systems while allowing each jurisdiction to retain full control over its local settlement infrastructure, legal framework, and operational rules. A key design principle of the framework is its technology neutrality. By adopting the ISO 20022 payment messaging standard, the architecture supports a high level of interoperability. The modular design also provides scalability and extensibility, facilitating future participation by more jurisdictions.

Open Connector (OC)

The OC functions as the cross-border coordination interface between participating central banks. Utilising the ISO 20022 messages, it provides standardised payment messages through which payment instructions, status updates and control signals are exchanged to support PvP and DvP workflows.

The OC operates strictly as a coordination mechanism. It does not interact directly with domestic settlement systems. Its role is to facilitate a shared and synchronised understanding of transaction states across jurisdictions.

⁷ RESTful APIs are standardised interfaces that allow different software systems to communicate and exchange data over a network using common web-based protocols.

The Adaptor connects the OC to each jurisdiction's domestic payment infrastructure. Serving as the local integration interface, it enables domestic systems and commercial banks to participate in cross-border workflows.

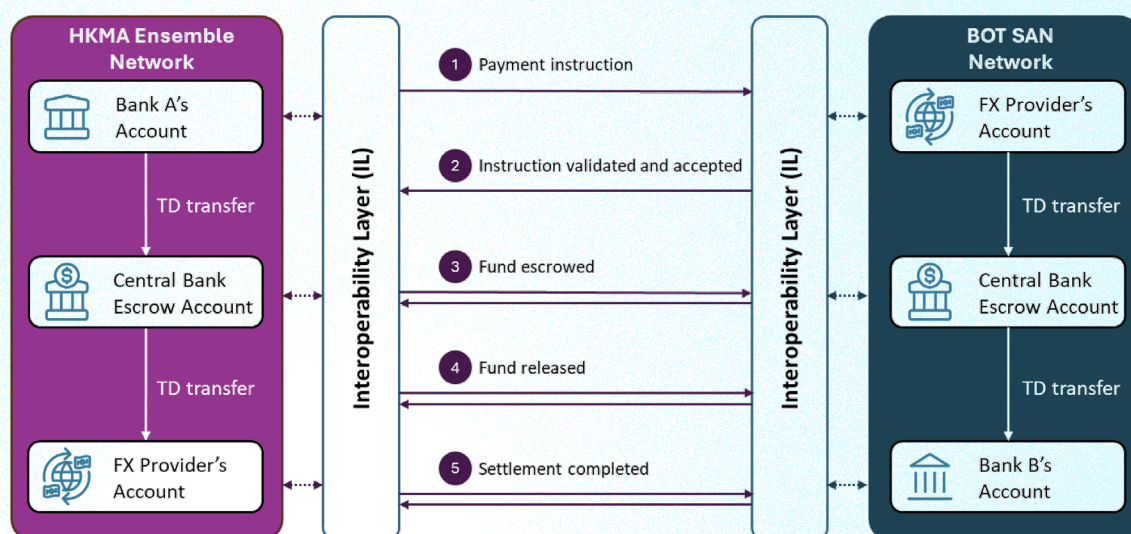
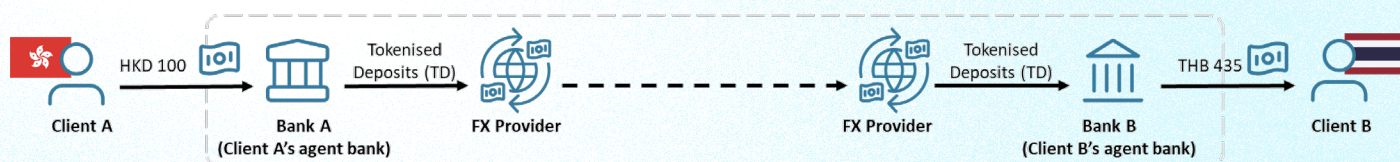
In this way, settlement continues to take place within each jurisdiction's own infrastructure, under its respective legal and operational framework.



5.3. Technical experiments

5.3.1. Cross-border tokenised deposits transfer with FX

The use case examines transactions between two entities in different jurisdictions over central bank infrastructures through their local banks. Settlement is made using TDs in their respective local currencies and the value is converted by a FX provider, which has settlement access in both locations.



In addition, the use case also aims to achieve atomic settlement among all participating entities in the transaction.

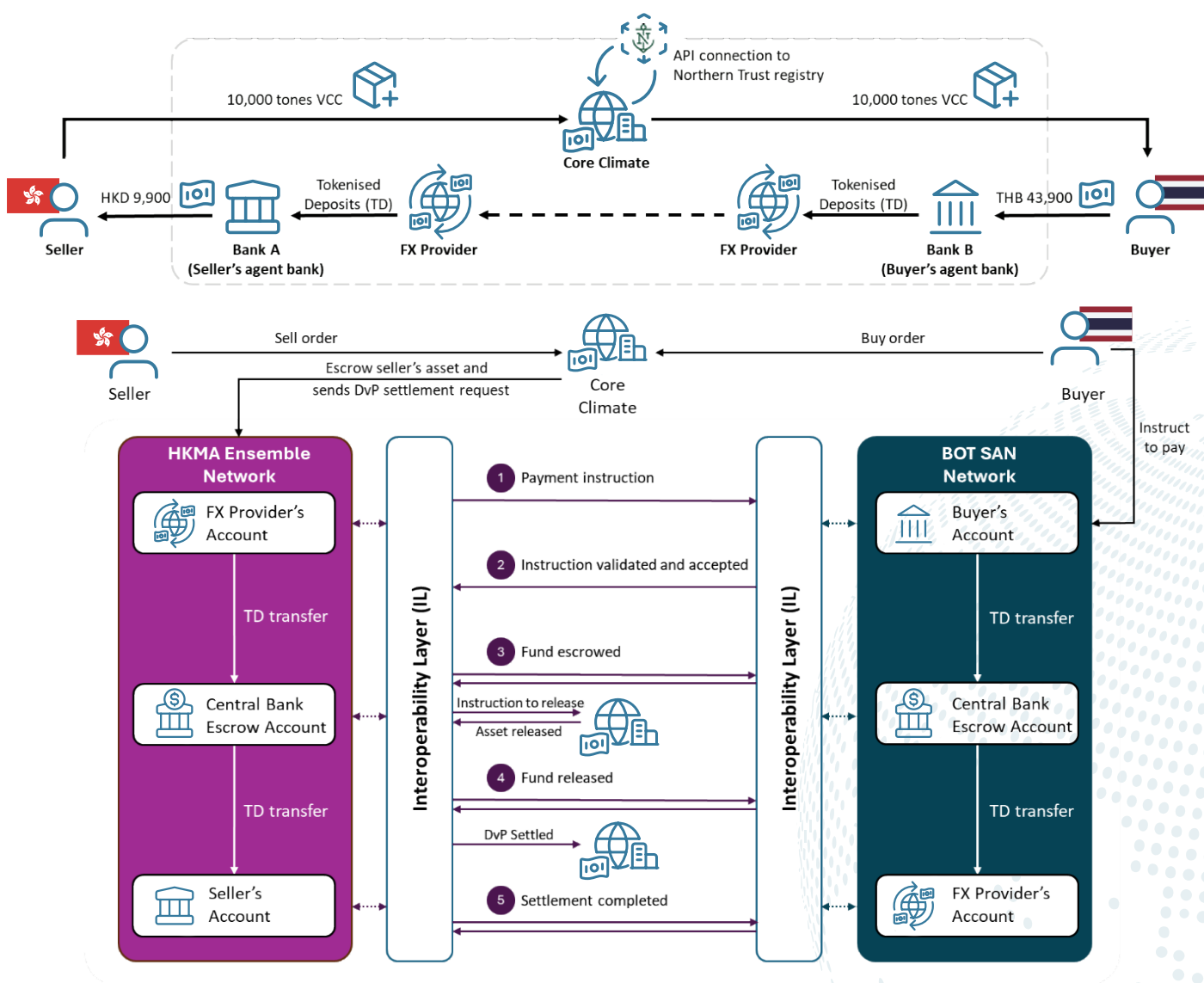
Execution result:

The HKMA and BOT jointly executed and completed 14 scenarios covering positive and negative tests with payments remitting in both directions within the test environment. On average, the end-to-end transaction took approximately 20 seconds to complete the atomic settlement process.

5.3.2. Cross-border carbon credit DvP Settlement with FX

Leveraging the cross-jurisdictional TD transfer, this second use case further extends functionality to settle cross-border DvP carbon credit transactions through HKEX's carbon marketplace, Core Climate. A seller in Hong Kong transfers the carbon credits to Core Climate for sale, while a buyer in Thailand purchases the carbon credits from Core Climate. Project Ensemble and Project SAN orchestrate the escrow and release processes of the carbon credits in Core Climate and the funds in the respective local banks, achieving atomic settlement to the cross-border DvP transaction. After the transaction is settled, the ownership of the carbon credits is transferred to the buyer, while the funds are credited to Core Climate's agent bank. In a separate transaction, Core Climate transfers the funds to the seller after deducting fees.

In addition to Project Ensemble and Project SAN, the use case was executed jointly with InnoBlock, which supported the testing by acting as Core Climate for the carbon credit transactions.



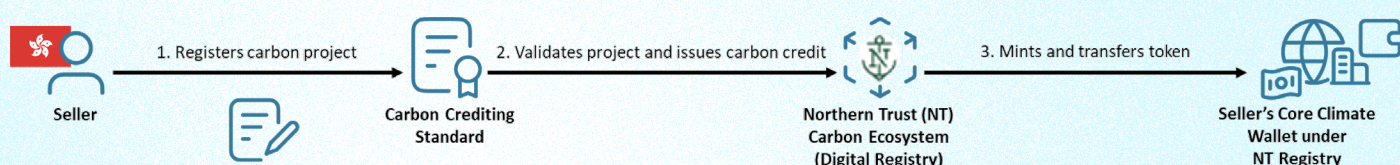
Execution result:

A total of 5 DvP scenarios covering positive and negative tests were jointly executed and completed by the HKMA, BOT and InnoBlock (acting as Core Climate) in the test environment. On average, the end-to-end transaction took about 30 seconds to complete the atomic settlement process.

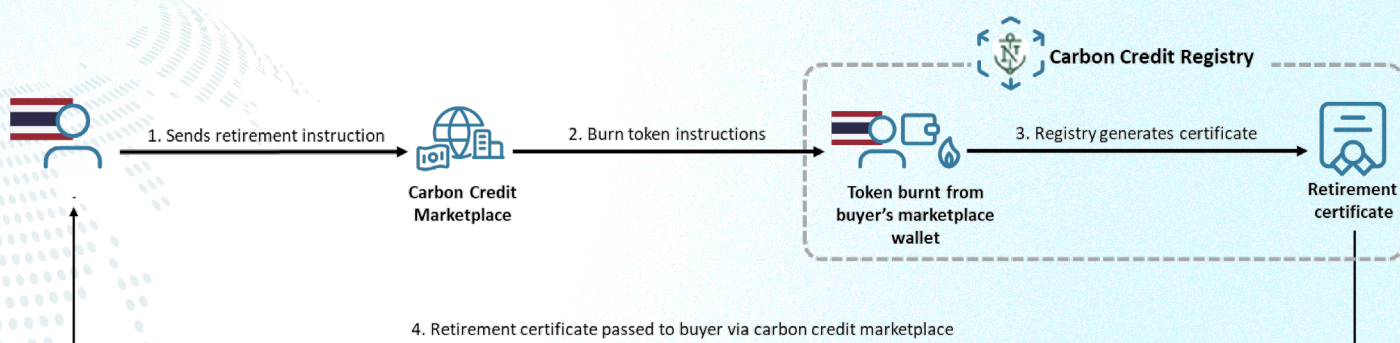
5.3.3. Primary issuance and transaction of carbon credits

The cross-border DVP settlement use case is further extended by introducing a registry to identify, record, and track issued carbon credits. The registry is integrated with the marketplace so that carbon credit ownership information is synchronised in real-time at trade settlement. This use case demonstrates a comprehensive model for carbon credit issuance, transaction, and settlement through central bank infrastructures.

As the PP, Towngas registers a carbon project to the carbon crediting standard. The carbon crediting standard then validates the project documents and subsequently issues the corresponding carbon credits by minting the carbon credit tokens via the Northern Trust registry to Towngas' wallet on its blockchain, establishing Towngas' ownership of the carbon credits. Next, Towngas transfers the tokens from its wallet to Core Climate's wallet on the Northern Trust registry.



A similar process to the second use case begins at this point. A buyer in Thailand initiates a DvP transaction with Core Climate for the purchase of carbon credits. With the API connection between Core Climate and the Northern Trust registry, the change of carbon credit ownership from the seller to the buyer in the registry will happen automatically upon settlement. In a separate transaction, Core Climate transfers the funds to the seller after deducting fees.



Execution result:

A successful end-to-end transaction scenario was jointly executed in the test environment by the HKMA, the BOT, and InnoBlock (acting as Core Climate). Following execution, the change of carbon credit ownership was accurately reflected on the Northern Trust registry as expected.

6. Findings

6.1. Commercial insights

The adoption of carbon credit tokenisation and its corresponding automation introduces significant advantages for market participants, directly addressing pain points and inefficiencies in traditional cross-border carbon transactions. Compared with conventional cross-border carbon market processes, which often rely on multiple intermediaries, the proposed model offers a more integrated transaction flow. By enabling the use of local currency, integrating greater automation and lowering participation barriers, this architecture reduces operational costs and risks, ultimately supporting a more efficient and scalable VCM ecosystem.

1. Enabling the use of local currency for cross-border carbon credit transaction

On the fund side, cross-border carbon credit transactions can be executed more efficiently on the marketplace, significantly improving the overall user experience. In a traditional cross-border transaction, participants must independently manage foreign-currency funding and coordinate FX conversion. Under Project Ensemble, buyers can transact entirely in their local currency for a cross-border trade, eliminating the administrative burdens and settlement delays associated with traditional FX processing. Similarly, sellers receive proceeds directly in their local currency, removing the need to manually convert and repatriate foreign funds. This streamlined process enhances operational efficiency and encourages broader participation in VCM.

It should be noted that FX conversion remains involved in the background and the associated costs are ultimately embedded in the transaction price, although these may be reduced through the central bank's payment facility.

2. Reduced operational costs and risks

API integration allows seamless automation across the marketplace, registry and banking systems by automating data exchanges and transaction updates. For example, once a settlement is completed, data between the marketplace and registry is automatically synchronised via APIs, eliminating the need for manual credit transfers. This process removes time-consuming manual checks, minimises the risk of human error, and ensures that all platforms maintain consistent and accurate records in real time.

While traditional cross-border carbon token settlement can take 2 to 5 business days due to fragmented, manual balance validations across multiple global registries, this project achieved successful end-to-end atomic carbon credit DvP settlement in approximately 40 seconds. This significant reduction in processing time lowers operational costs and risks, while optimising efficiency, enabling more streamlined workflows and greater scalability for cross-border carbon credit transactions.

3. Expanding the participant base

By enabling transactions to be settled using TDs, Project Ensemble broadens participation by removing many of the traditional frictions associated with cross-border transactions. Participants who already hold TDs, whether financial institutions, corporates or professional investors, can seamlessly trade carbon credits within the marketplace without the need to set up pre-fund accounts in multiple currencies. This increases the marketplace's appeal to a wider range of institutions already active in digital-asset or wholesale-CBDC environments.

6.2. Technical findings

The design of the cross-border settlement infrastructures is guided by a set of foundational design principles derived from global CBDC frameworks and real-world interoperability challenges. These principles ensure security, scalability, regulatory compliance, and long-term sustainability across systems from different jurisdictions.

From the test results, typical cross-border settlement could be processed within 20 to 40 seconds under standard operating conditions. However, certain scenarios involving liquidity shortages, insufficient balance or specific asset platform exhibited higher latency, ranging from approximately 13 to 20 minutes.

Beyond performance outcomes, the key technical findings include:

1. Interoperability through a standard-based Interoperability Layer

The experiment successfully validated that a standard-based modular IL is sufficient to enable cross-jurisdictional operations. By acting as a translation plane, the IL coordinates transactions among domestic commercial banks, central bank money rails, and ILs in other jurisdictions through standardised connector APIs.

The IL coordinated payment instructions, status synchronisation, fund escrow, and release processes across multiple parties and jurisdictions. This architecture avoids the need to establish a shared ledger, thereby reducing legal, governance, and technical complexity. Participating systems remain operationally independent, allowing jurisdictions to retain control over their domestic infrastructures, while achieving cross-border interoperability.

2. Settlement finality in central bank money

All atomic settlements are anchored in central bank money, utilising either CBDC or RTGS systems. This ensures finality and legal certainty with minimal credit and liquidity risks, aligning with the “Principles for Financial Market Infrastructures” (PFMIs).

Digital assets are exchanged for irrevocable, real-time payment via central bank money, eliminating counterparty risk and settlement delays.

3. Atomic settlement via programmable escrow

Settlement is governed by synchronised, conditionally atomic logic, implemented through programmable escrow mechanisms. In the testing phase, process disruptions were simulated, and the IL successfully executed automated rollbacks of the cash leg, ensuring that no partial execution occurred.

For both cross-border TD transfer and DvP arrangements, the parallel escrow operations were undertaken across debtor/creditor agents and settlement agents. This reduced counterparty exposure during transaction. The findings underscored that atomic settlement in a multi-party, cross-border environment requires precise state tracking, consistent interpretation of completion events, and robust exception-handling mechanisms across interconnected systems.

4. Use of canonical data model and standardised semantics

All transaction data is expressed in a common, ISO 20022-aligned canonical data model, such as pacs.008 for payment initiation and pacs.002 for status reporting. This establishes a payment messaging standard across systems. It ensures consistent interpretation and interoperability across jurisdictions, while still supporting flexible local customisation through optional custom fields.

5. Scalability and future-proofing

The architecture is designed to support multiple forms of money, including central bank money and TDs from multiple jurisdictions, and across diverse tokenised asset types. It is inherently modular and extendible, making it suitable as a foundational layer for broader digital asset ecosystems.

6. Areas for further enhancement

While the core design was successfully validated, several areas for enhancement were identified during testing.

Firstly, communication between Project Ensemble and Project SAN in failed transaction scenarios lacked sufficient clarity. When a transaction was rejected, only a generic rejection message was transmitted to the counterparties, without specifying the underlying reason. The findings suggest that payment status messages should incorporate more granular rejection details, to improve transparency and user communication during failure scenarios.

Secondly, certain test cases revealed instances of redundant messaging, including the simultaneous issuance of rejection and rollback instructions. These instances highlight the need for better synchronisation of transaction statuses between systems to ensure only a single instruction is issued for any given failure. Introducing mutex-style control mechanisms to prevent simultaneous state update could improve synchronisation and prevent redundant instructions during exception processing.

Finally, while the escrow model was successfully validated, the experiment highlighted the potential to explore alternative approaches, such as earmarking mechanisms. Under an earmarking model, funds would be reserved within the originating account rather than transferred across wallets during the escrow phase. This approach may reduce operational complexity while preserving conditional settlement logic.



7. Conclusions

This project showcases the power of collaboration between public and private sector stakeholders in tackling key challenges across the cross-border DvP landscape and VCM ecosystem. The HKMA, the BOT and the HKEX extend their sincere gratitude to all the partners in this project for their dedication and invaluable contributions.

These collaborative efforts have yielded tangible benefits including invaluable insights that will shape the future of cross-border PvP and DvP and asset tokenisation in the years to come. The HKMA and the BOT will leverage these fruitful learnings, spanning operational workflows, technical implementations, and policy design, to inform their domestic CBDC and tokenisation initiatives.

The experiments also facilitated meaningful dialogue among central banks on improving interoperability and cross-jurisdictional connectivity. The results demonstrate that technology-neutral, interoperable models are feasible without a shared ledger. Building on this progress, further work could explore extending these models to additional jurisdictions, examining how a broader network of interoperable connections could enable atomic cross-border PvP and DvP across a wider range of use cases among central banks and market infrastructures.

On the carbon market front, the project highlighted the potential of tokenisation and automation to reduce friction, increase transparency and scale participation. It also reinforced the importance of interoperability with registries, settlement infrastructures and payment systems in supporting efficient and trusted carbon credit transactions.

Moving forward, HKEX will build on these insights, continuing to explore technological solutions to enhance the accessibility of its Core Climate platform and other climate finance offerings, with a view to supporting long-term market development and adoption.

Looking ahead, the HKMA, BOT and HKEX remain deeply committed to advancing financial innovation. Continued dialogue and joint exploration of new ideas, experiments and projects among public and private sector stakeholders will be key to unlocking the full potential of digital finance, ultimately driving innovation and progress in the cross-border PvP, DvP, the VCM and beyond.