



July 2021

Digital Euro experiment Combined feasibility – Tiered model



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In September 2020 the Eurosystem’s High-Level Task Force on Central Bank Digital Currency launched experimental work on a digital euro with a view to assessing and gaining further insights into the technological feasibility of design choices identified in the Report on a digital euro (hereafter “the Report”).

Experts from the euro area national central banks and the ECB participated in the experiments, which were grouped into four work streams. The first work-stream (“**scale the existing**”) focused on a network architecture built on the existing, centrally managed architecture of the TARGET Instant Payment Settlement (TIPS) system. The experiments of the second work-stream (“**combined feasibility**”) focused on how to combine centralised technology with distributed platform(s) based on distributed ledger technology (DLT). The third work-stream (“**a new solution**”) assessed a solution using a blockchain-based platform and fixed value tokens (“digital bills”). Together with several companies selected via a procurement process, the fourth work-stream (“**bearer instrument**”) focused on the implementation of a hardware bearer instrument enabling offline payment solutions.

These work-streams assessed different design features covering four main areas: the digital euro ledger, privacy and anti-money laundering (AML), limits on digital euro in circulation, and end-user access. The objective was to address the key design questions that had been left open by the Report and that warranted analysis in terms of technical feasibility, and to acquire a broad understanding of the compliance of the different design possibilities with the principles stated in the Report. The experiments were conducted in a multidisciplinary environment and also involved participants from academia and the private sector, without endorsing any specific technical solution.

As part of the second work-stream, two approaches were considered. One of these is a **tiered approach**. This approach is based on a hierarchical structure in which a centralized ledger (the current version of TIPS) operated by the Eurosystem (Tier 1) is used to issue digital euros (D€) and provide central bank money (CeBM) to supervised intermediaries eligible for direct access to Target Services (Target2 and TIPS) under the Target system guidance. These institutions then distribute D€ to other supervised intermediaries, non-Target2 participants and also to end-users (citizens, merchants, firms, etc.) in Tier 2 systems.

The experiment on a tiered approach brought together several central banks from the Eurosystem, namely Banque de France, Banca d’Italia, Banco de España, Banque centrale du Luxembourg, Banque Nationale de Belgique, the European Central Bank, Lietuvos Bankas, and Oesterreichische Nationalbank.

The **first section** of the report introduces the rationale behind the design of the tiered model and presents the overall architecture of the model as well as its functional components. The **second section** then shares the main outcome and findings of the experiment on a number of features that are relevant to the design of the digital euro.

Overall, the experiment assessed that a tiered model such as the one described in this report could be a suitable architecture for the digital euro. From a technical point of view, it demonstrated the feasibility of combining centralized and distributed systems, which allows accommodating several use cases and supporting various functionalities of a potential future digital euro.

As this approach emphasizes the flexibility of the infrastructure, the resulting model can fit several requirements, allowing multiple ledgers to connect simultaneously to Tier 1, even when these ledgers are based on different technologies. This implies that requirements related to the level of privacy, the role of intermediaries, limits, or remuneration can, by design, be addressed differently in each ledger, according to a variety of purposes.

EXECUTIVE SUMMARY

Moreover, this approach would preserve financial intermediation while stimulating financial innovation by the private sector as well as bank competition also at the level of Tier 2 systems and underlying technologies. The tiered approach leaves room for various potential roles for private entities (distribution of digital euros, management of customer interface, compliance, development of value-added services and operation of some components of the system).

The work performed by the central banks involved in this experiment is intended to support policy discussions and Eurosystem decision-making on the design of a potential digital euro during the investigation phase launched on 14 July 2021.

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The results of this experiment provide input on design questions, thereby supporting policy discussions and design decisions on a possible digital euro. They do not pre-empt any decision or commit the Eurosystem to providing a digital euro. More generally, this experiment does not address the legal characteristics of the infrastructure for the distribution of the digital euro and the digital euro itself. The statements in this report about legal aspects of the design of a digital euro are only working hypotheses assuming that the legal framework could be adjusted to fit the needs of a digital euro. They are neither definitive nor binding for the central banks involved in this experiment.



Section 1: Overview of the model's design

1 Principles underpinning the model

The tiered model was developed with three overarching objectives in mind (beyond the obvious imperatives of resilience and performance):

- 1) Preserve a right balance between public and private actors, and build upon the central role of financial intermediaries in the economy, by ensuring, through the distribution model of D€, that supervised intermediaries keep interfacing with end-users.
- 2) Be fully interoperable with private sector front-end solutions.
- 3) Be built on a flexible model and on an architecture adaptable to future innovations.

2 Conceptual overview of the model

The model experimented as part of this work-stream is based on a tiered architecture, with each Tier fulfilling a different purpose:

The first Tier (Tier 1) is based on a centralized system (e.g. TIPS¹) in which the Eurosystem issues digital euro and provides them to supervised intermediaries. Access to Tier 1 is limited to supervised intermediaries that are direct participants to Target services (Target 2 and TIPS). Digital euros are made available to them through the accounts that they hold in TIPS (TIPS Dedicated Cash Accounts). To accommodate demand, these Tier 1 participants can then distribute digital euros to supervised intermediaries, including non-Target 2 participants (e.g. Payment Service Providers licensed as Payment Institutions or E-Money institutions), or directly to end-users (citizens, merchants, firms, etc.) through Tier 2 systems.

The second Tier (Tier 2) is made of multiple coexisting and interoperable systems where all supervised intermediaries open and manage accounts (account-based D€) or wallets (value-based D€) for end-users (figure 1). All supervised intermediaries obtain D€ from the Tier 1 system, either directly if they are Target2 participants or indirectly through intermediaries that are Target2 participants, to meet end-users' demand for D€. The experiment explored three types of Tier 2 systems:

- 1) Account-based DLT: D€ is exchanged through accounts held by supervised intermediaries.
- 2) Value-based DLT: D€ is exchanged in the form of tokens through wallets.
- 3) Account-based non-distributed ledger: D€ is exchanged through accounts held by supervised intermediaries.

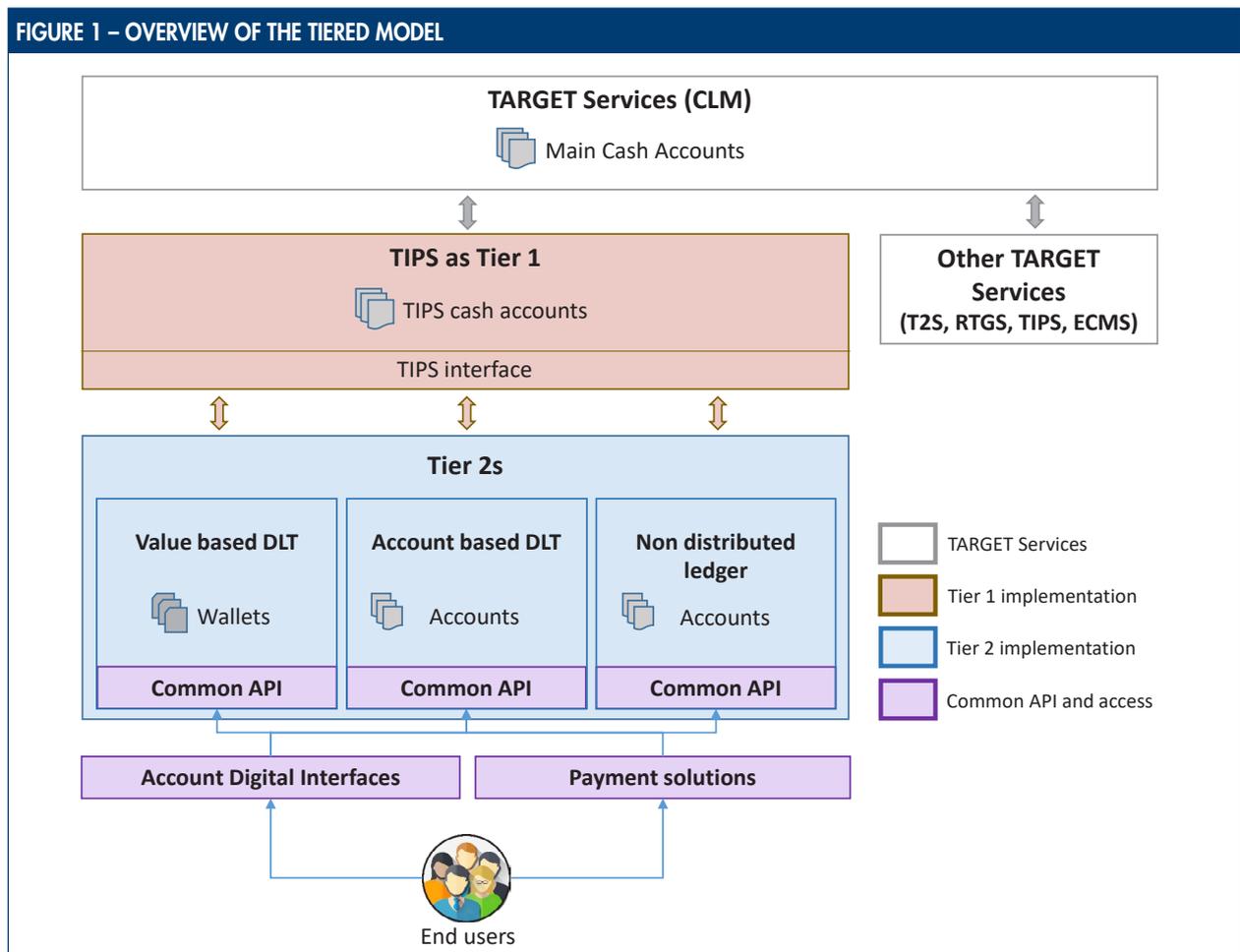
In all cases, D€ - whether account-based or value-based – is issued by the Eurosystem and remains **a direct liability of the Eurosystem**. However, central banks would not open accounts directly to the public and neither would they distribute digital euro to end-users. Private intermediaries would take on such responsibilities.

End-users would interact with this architecture thanks to a **common Application Programming Interface (API)** for all Tier 2 systems. This helps ensure that regardless of a Tier 2 system's underlying organisation and technology, D€ would be compatible with various payment solutions.

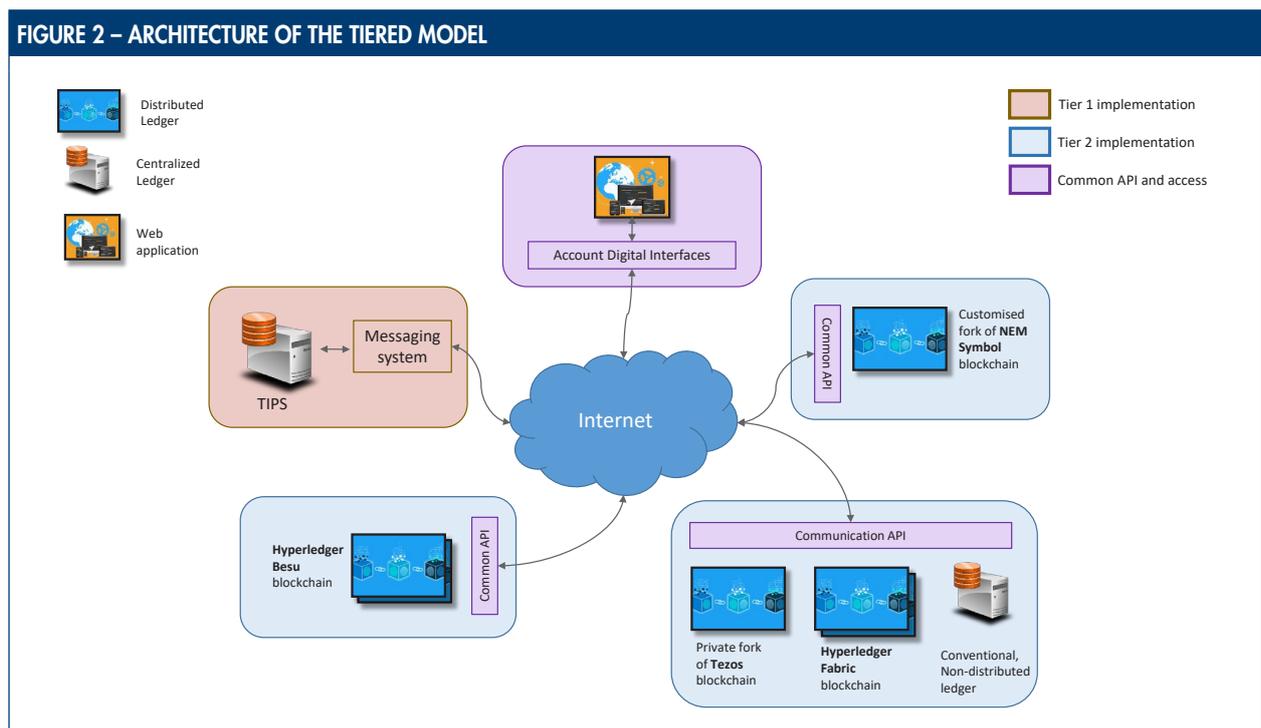
¹ TIPS was used as Tier 1 for the purpose of the experiment. However, other centralized systems could be developed to act as Tier 1.

SECTION 1: OVERVIEW OF THE MODEL'S DESIGN

The overall architecture can be summarized as follows:



All NCBs participating in this experiment provided assets and expertise to translate this conceptual model into a fully-fledged experiment. The overall architecture of the experiment was as follows:



3 Technical implementation during experiments

In the model, the Tier 1 system would be connected to Target services. The planned T2/T2S consolidation project will centralize liquidity management from all Target services (T2S, RTGS, TIPS, ECMS) within CLM (Central Liquidity Management). In the prototype, TIPS is used to simulate the Tier 1 system containing supervised intermediaries' accounts. Transfers from RTGS to TIPS simulate a transfer from CLM to the Tier 1 system. Regardless of the underlying technology used by each Tier 2 system, all of the Tier 2 platforms were able to establish a connection with the Tier 1 system through a module or interface, allowing them to interact with the Tier 1 platform's messaging system (Message Queues).

The second Tier consists of several ledgers with both value-based and account-based systems:

- Two distributed ledgers (based on Hyperledger Besu and Hyperledger Fabric) enabled the implementation of both an account-based and a value-based Tier 2 system.

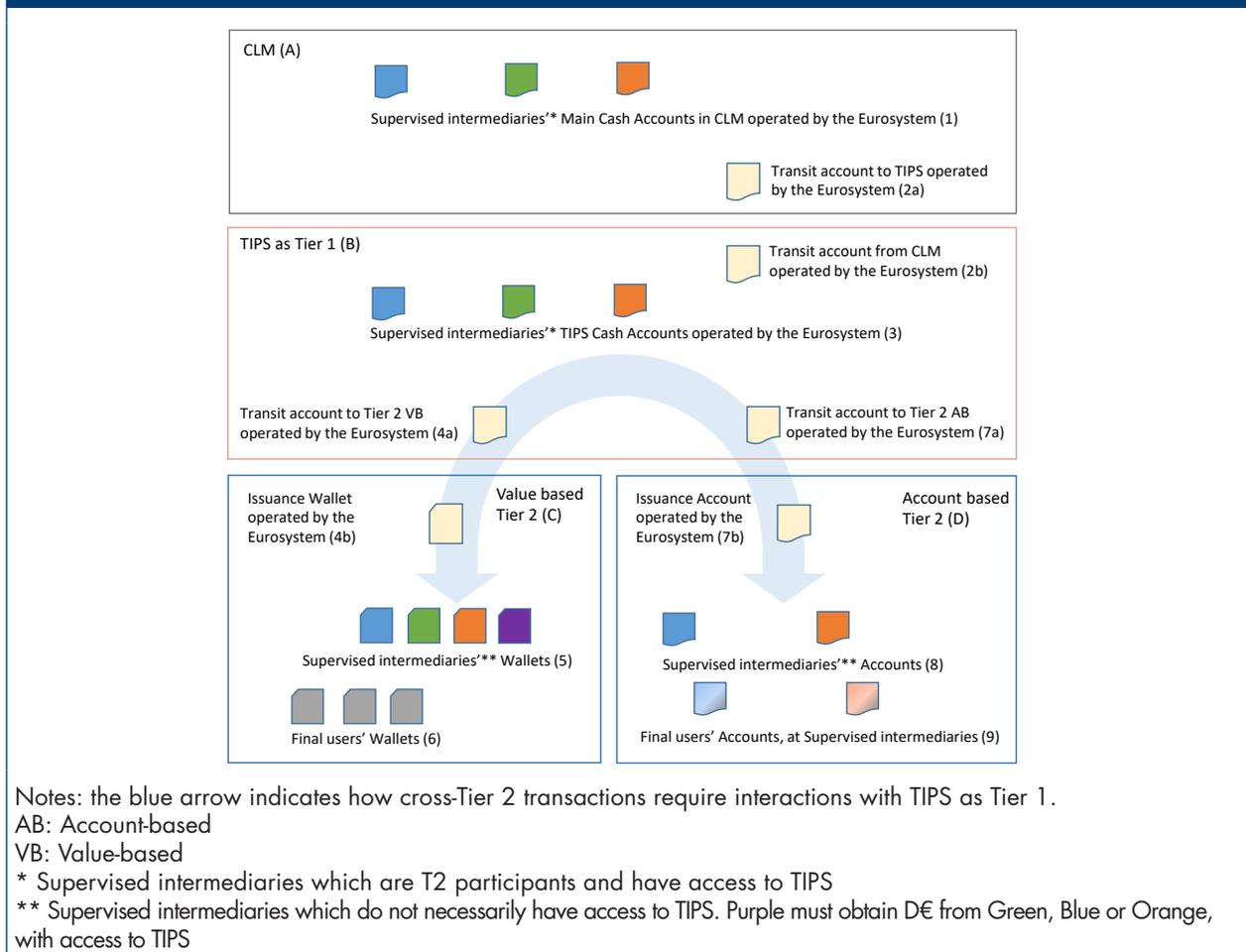
- Two distributed ledgers (a private fork of the Tezos blockchain and a customized fork of the NEM blockchain) enabled the implementation of a value-based Tier 2 system.
- One conventional non-distributed ledger implemented an account-based Tier 2.

This variety of ledgers at Tier 2 level demonstrated the model's ability to add Tier 2 systems regardless of their underlying technology (non-distributed and distributed, private or public blockchain).

A simple interface meeting the requirements set by the Second Payment Services Directive (PSD2) and web application emulates how an end-user would access its account or wallet and initiates payments through supervised intermediaries. This access should not be dependent on the Tier 2 in which its account is located. Therefore, communication layers should anticipate multiple systems operated at Tier 2 by design to ensure that cross-system transactions are feasible.

The following diagram shows how the different Tiers are organized in the model:

FIGURE 3 – COMPOSITION OF EACH TIER



SECTION 1: OVERVIEW OF THE MODEL'S DESIGN

Tier 1 system

The first Tier (B), accessible only to some supervised intermediaries (participants to TARGET2), is mainly a gateway to serve the end-user D€ accounts/wallets located in multiple Tier 2 systems. It consists of:

- A unique Target2 / Centralised Liquidity Management (CLM) transit account for the Tier 1 system (2) operated by the Eurosystem. This account allows to transfer CeBM from a supervised intermediary's CLM Main Cash Account, in the form of balances in Target services (1) to its Tier 1 account (3), in the form of digital euros;
- One transit account per Tier 2 system (4, 7) also operated by the Eurosystem. These provide a global overview of the liquidity in circulation in a given Tier 2 system and are used to transfer D€ to Tier 2 accounts (5, 6, 8, 9);
- Supervised intermediaries-Target2 participants' Tier 1 accounts (3). These accounts are where D€ is credited once intermediaries transfer CeBM (i.e. Target services balances) from CLM².

Therefore, to accommodate retail demand in D€, the following process occurs in the model:

- 1) A supervised intermediary obtains D€ by transferring CeBM from its Main Cash Account in CLM to its account in the Tier 1 system (from 1 to 3);
- 2) The intermediary makes D€ available in Tier 2 systems by transferring D€ from its account in the Tier 1 system to the relevant Tier 2 transit account (from 3 to 4a or 7a). Because Tier 1 and Tier 2 systems are connected, the same amount is recognized on the issuance account / wallet in the Tier 2 system (4b or 7b) and transferred to a supervised intermediary's Tier 2 account/wallet³ (5 or 8);
- 3) This supervised intermediary transfers the requested amount of D€ to its client's account/wallet in Tier 2 systems (6 or 9).

Symmetrically, for D€ redemption, the transit account is used to transfer D€ from Tier 2 systems to the Tier 1 system where supervised intermediaries can transfer it to CLM as CeBM.

As a result, the total amount of D€ is the sum of the balances of supervised intermediaries in Tier 1 (3) and all funds transferred by them from Tier 1 to the various Tier 2 systems, i.e. the sum of 4a and 7a.

Tier 2 systems

Tier 2 systems (C and D) are accessible to all supervised intermediaries, including non-Target 2 participants, as well as end-users (citizens, merchants, firms, etc.) Thus, each Tier 2 system consists of:

- Supervised intermediaries' accounts / wallets (5, 8): if those intermediaries have access to the Tier 1 system (participants to Target2), they can distribute D€ directly to end-users. Else (e.g. Payment Service Providers licensed as Payment Institutions or E-Money institutions), they would first have to obtain D€ from other supervised intermediaries before distributing it to end-users;
- End-users' accounts / wallets (6, 9) containing the D€ obtained from supervised intermediaries in exchange for commercial bank money or cash;
- An issuance account / wallet (4, 7) from which D€ from the Tier 1 system is transferred to the relevant supervised intermediary's account / wallet in the Tier 2 system.

End-users would access D€ in Tier 2 systems through an account digital interface or through payment solutions. Overall, end-users could access D€ in various ways, given that the system would be interoperable with front-end solutions from the private sector.

² D€ would be a Eurosystem liability and a new form of central bank money, which is currently made available to intermediaries in the form of Target balances. The exact step during which CeBM in its current form is exchanged for D€ has not been precisely identified. It is clear that liquidity in all Tier 2 is D€ and that liquidity in CLM is CeBM. In Tier 1, D€ could appear at different steps, on a transit account or when credited to banks' Tier 1 accounts. As a simplification, D€ appears upon being credited to supervised intermediaries' Tier 1 accounts hereafter in this report. This identification would depend on further analysis as to the legal nature of D€, outside the scope of this report.

³ If the intermediary has access to Tier 1, they transfer D€ to their own Tier 2 account / wallet to meet their clients' demand. Else, they request D€ from an intermediary with access to Tier 1 to meet their clients' demand (typically, the case for a PSP).

Aside from issuance and redemption of D€, only transactions between two Tier 2 systems (from C to D) would involve interactions with the Tier 1 system, represented by the blue arrow in figure 3:

- To exchange D€ within a given Tier 2 system, for instance in the case of an account-based Tier 2 (D), transactions are settled through their supervised intermediaries' Tier 2 accounts / wallets;
- To exchange D€ between Tier 2 systems (from C to D), settlement occurs through supervised intermediaries' Tier 1 accounts in the following way: the payer's Tier 2 account is debited while its supervised intermediary's Tier 2 account is credited. The intermediary transfers D€ to the Tier 2 issuance account. D€ is transferred to the appropriate Tier 1 transit account and is introduced in the other Tier 2 system. Then, the process is similar to the issuance process described earlier.

Tested use cases during experiments

The experiment implemented a number of use cases covering the entire transaction chain:

- D€ was issued / redeemed in TIPS (Tier 1 for the purpose of the experiments) and transferred to Tier 2 systems;
- D€ was deposited and withdrawn by simulated end-users from supervised intermediaries' accounts or wallets;
- D€ was exchanged between accounts / wallets in each Tier 2 system (intra-system transaction);
- D€ was exchanged between different Tier 2 systems (cross-system transaction);
- Initiation of payments through a web application or existing payment solutions through the use of a common user interface powered by a common API, regardless of the Tier 2 system in which their account / wallet is located.

In addition, two key features of the model were successfully implemented for all Tier 2 systems:

- 1) Programmed remuneration, including tiered remuneration for end-users;
- 2) Programmed limits on both D€ holdings and transaction flows, including differentiated limits⁴ and a waterfall scheme.⁵

Experimentations even covered the ability to add Tier 2 systems to the overall system without disruptions. Indeed, while experimentations were ongoing and other Tier 2 systems had already been connected to Tier 1, an additional system was successfully connected to Tier 1 and the other Tier 2 systems.

⁴ Within a Tier 2 system, at least one wallet / account has a specific limit. Such feature could be used to set higher transaction limits for merchants compared to citizens, for instance.

⁵ Any transaction breaching the holding limits leads to an automatic conversion of the excess D€ into commercial money.



Section 2: Main outcome of the experiment

1 Ledger choice

The experiment showed that the tiered architecture presented above offers multiple benefits. Each Tier fulfills different and complementary roles, simultaneously allowing the central bank to retain full control over the digital euro while enabling flexibility, innovation and resilience.

The tiered architecture enables the Eurosystem to have full control over the issuance and quantity of digital euros in circulation. It also guarantees full convertibility at par with other forms of money.⁶

The existence of a Tier 1 directly operated by the Eurosystem in which digital euros are issued and provided to supervised intermediaries that are Target2 participants is essential to guarantee that **D€ is a liability of the Eurosystem**. This tiered architecture also ensures that the Eurosystem **controls the amount of D€ in circulation** in all Tier 2 systems as each transit account in Tier 2 systems operated by the Eurosystem provides an aggregate view of the total digital euro units in circulation in each Tier 2 system.

The model enables **convertibility at par of digital euros into other forms of central bank money** (banknotes, central bank reserves) and **commercial bank money**. Acquisition or redemption of digital euros in exchange for other forms of euro is ensured through the use of supervised intermediaries' Target 2 accounts (CLM accounts in the future), in conjunction with their D€ Tier 1 accounts. The two-Tier model allows **real-time settlement of all transactions**, whether these occur within the same Tier 2 system (as instantaneity of settlement would be native requirement for any Tier 2 system) or across two different Tier 2 systems (through the use of TIPS as Tier 1).

In addition, a tiered architecture with multiple Tier 2 platforms increases the flexibility and supports the resilience of the system.

The tiered architecture is **flexible** enough to enable the implementation of multiple Tier 2 systems, each one potentially offering different features and functionalities. For example, a particular Tier 2 system designed to foster financial inclusion could be created with stricter limits but less restrictive AML-CFT rules (e.g. easier onboarding through reduced KYC). Moreover, the model can add additional Tier 2 systems later on to allow future innovative use cases, such as programmability features, evolving over time to adapt to needs expressed by all stakeholders. As a technologically agnostic architecture, the tiered model can accommodate both public and private DLTs, combining the benefits of each, and implement various types of consensus mechanisms, allowing to have energy-efficient validation consensus (e.g. proof of stake and proof of authority).

Finally, having multiple Tier 2 systems makes the overall architecture **resilient** as it **avoids having single points of failure**. Should the Tier 1 system (TIPS) become unavailable, all supervised intermediaries can still use the existing liquidity in a given Tier 2 system to settle transactions. Should a Tier 2 system become unavailable, other Tier 2 systems can still operate normally and interact with Tier 1 and other Tier 2 systems. Finally, within a given DLT-based Tier 2 system, the failure of a supervised intermediary, which could operate a node on the blockchain, does not impact the ability of the system to validate the transaction.

⁶ Although this model offers this possibility from a technical point of view, the experimentation does not cover the legal aspects of the convertibility of the D€, nor that of its legal tender.

2 Role of intermediaries

The proposed model allows a potential **high degree of involvement of the private sector**, foreseeing various possible roles that intermediaries could take on. These roles could include the distribution of digital euros to end-users, and the provision of innovative services.

The tiered model clearly distinguishes between the issuance (in Tier 1 system), which would be under the sole responsibility of the Eurosystem, and the distribution of digital euros to end-users (in Tier 2 systems), which would be left to private intermediaries. This breakdown of responsibilities allows the Eurosystem and financial intermediaries to remain in their respective areas of expertise, leveraging their experience.⁷

In the tiered model, intermediaries would be in charge of distributing digital euros to end-users and managing compliance with regulatory requirements, such as KYC, AML-CFT, as well as local laws and regulations (e.g. reporting to tax authorities on accounts opening and interests earned⁸). Additionally, some of these rules could be programmed directly into the Tier 2 system as properties of end-user accounts or wallets.

The proposed architecture would also allow third party providers (TPP) to offer value-added services, fostering innovation. Drawing on the framework from PSD2, this set-up would allow TPP to contract with account / wallet holders to provide them with value-added services (e.g. account aggregation services, payment initiation services). TPP would connect to a single PSD2-like interface ("common API"), regardless of the Tier 2 platform where the end user's account / wallet is located.

⁷ Clearly distinguishing issuance and distribution of D€, which occur in different systems (Tier 1 and Tier 2, respectively) in the tiered approach could have some additional benefits. For instance, it could facilitate the definition of compensation scheme of the digital euro, as issuance would be managed in Tier 1 by the Eurosystem, similarly to current Target services, with a compensation framework defined by the Eurosystem while the private sector would define the pricing of the services it provides as part of the distribution of D€ (AML-CFT, fraud management, cybersecurity, etc.)

⁸ Remunerating accounts means that the account owner may earn additional income, which may be subject to taxation (interest income might also be deducted from taxable income if it is negative). Some countries also require the person (natural or legal) to report the (positive or negative) income they pay to another party to the tax authorities. Some countries also require the person paying the income to compute and withhold taxes paid on behalf of the person they pay interest to. Supervised intermediaries already have the system to comply with tax laws, which could be another argument in favour of the NCB/ECB not to directly deal with end-users.

⁹ This pairing would be irrelevant in the case of a specific Tier 2 for financial inclusion or for non-residents.

Additionally, in the case of Tier 2 systems based on distributed ledger technology, intermediaries could provide these value-added services through the deployment of smart contracts, on behalf of their clients. As a result, in the tiered model, programmability can be implemented through two complementary avenues, API and third party access on the one hand, and smart contracts on the other hand.

3 Privacy and AML

The public consultation organized by the Eurosystem on the digital euro between 12 October 2020 and 12 January 2021 highlighted that respondents considered privacy a key feature for the digital euro. However, privacy must be balanced with compliance with KYC, anti-tax avoidance and AML-CFT regulation. Due to the plurality of Tier 2 platforms, the tiered model allows for simultaneously implementing different schemes responding to both privacy and financial integrity priorities.

For example, it is possible to add a Tier 2 platform with limited AML/KYC rules for specific uses like facilitating financial inclusion and allowing non-residents to access digital euros. This could in turn require stricter limits on holdings and transactions. Experiments highlighted that anonymous P2P payments were technically feasible on value-based systems.

In the proposed model, intermediaries would play a central role in ensuring compliance with AML-CFT standards. In any case, intermediaries would take care of KYC, both during onboarding of new customers and for withdrawals and deposits of digital euros. Additionally, depending on the level of privacy implemented in a given Tier 2, they would also handle flow filtering and reporting of suspicious transactions if needed.

Upon onboarding of new customers to a specific Tier 2 system, supervised intermediaries would complete KYC checks and ensure that the end-user does not already have an account / wallet in digital euros. This check could help ensure that limits and / or tiered remuneration frameworks cannot be circumvented by users opening multiple accounts or wallets. This "unicity check" could be performed through automatic exchange of data. The newly created account/wallet could be linked to the user's existing checking account⁹, facilitating

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conversions between digital euros and commercial bank money and enabling the implementation of a “waterfall” mechanism (see section 2.4 below).

Aside from supervised intermediaries, Tier 2 KYC / AML-CFT service providers may be responsible for checking transactions’ compliance with those regulations and reporting suspicious transactions.

However, to ensure appropriate privacy in the use of digital euros, Tier 2 platforms would have to meet the following requirements:

- Information shared between parties to a transaction is strictly limited to the information that is required for regulatory reasons and non-participants to a transaction cannot access the information exchanged in a given transaction.
- Compliance with privacy laws and regulation, including the General Data Protection Regulation (EU) 2016/679 of 27 April 2016 (“GDPR”),

must be ensured. This would involve establishing a clear governance, determining the respective roles and responsibilities of all participants to the Tier 2 systems (e.g. “controller”, “processor”) and ensuring that the principles relating to personal data processing and the rights of the data subject are properly implemented.

The tiered model can implement a variety of privacy techniques to meet these requirements, with each technique differing in terms of features and maturity levels. Each technique has implications in terms of costs and performance. For example, implementing advanced cryptographic techniques entails higher investments. In addition, it would use a lot of bandwidth and could impact transaction throughput, slowing down the system. Based on this analysis (see table below), Zero Knowledge Proof and External Identity techniques appear most likely to be deployed, as they could be implemented easily with little impact on the performance of the system while guaranteeing a high degree of privacy.

TYPE OF TECHNIQUE	PRIVACY LEVEL	AVAILABILITY & FEASIBILITY FOR FINANCIAL TRANSACTIONS
Zero Knowledge Proof (ZKP): Cryptographic protocol by which the prover can prove to the verifier the knowledge of a certain value, without disclosing any other information – e.g. a user proving they are over eighteen years old without providing a date of birth.	High	Already available on multiple systems, requires storage of personal data by supervised intermediaries, thus enabling required AML checks to be performed
Data encryption with specific decryption keys: On-chain data encryption with decryption keys shared between specific participants. Not a long-term solution due to hard-to-predict progress in decryption power.	High short-term, Low long-term	Easy to implement, lowers transaction throughput
External identity provider and identity token on chain: The only attribute circulating on-chain is a random attribute that allows linking a user’s account to an identity. This attribute can be verified by inquiring in the external database provider.	High	Easy to implement, requires identity databases off-chain
Secret sharing & Multi-signature: sensitive data are disclosed only when an adequate number of entities (e.g., three of five) agree.	Medium	Already available on some systems. Does not enable AML checks in every case.
Channels: transactions are shared with a limited number of participants. However, a new channel needs to be created for every interaction with a new supervised intermediary. It is hard to implement If the number of intermediaries is high.	Low	Not Scalable, already available on certain DLTs only
Private transactions: are a way of pushing a transaction only to transaction participants and parties. A notary node gets a hash of the transaction. Simple and efficient. No one else can see the data.	High	Available on certain DLTs only
Multi-party computation: several entities securely contribute their data to a combined dataset, e.g. for fraud detection, while keeping their data private from one another.	High	Already available on some systems

4 Limits

As explained by the Report, the introduction of a digital euro could lead to excessive shifts of commercial bank money into CBDC impacting the business model of banks. Imposing limits on holdings and transaction flows appears as one of the possible ways to mitigate the impacts of disintermediation and, in case of crisis, of aggravated bank runs.

Enforcing holdings and transactions limits would also help mitigate AML/CFT risks. Existing regulation already includes such limits intended to combat money laundering, e.g. banknote withdrawals¹⁰, monthly payment transactions using reloadable payment instruments.¹¹

The experimentation investigated the possibility to implement both types of limits using programmable features. The main takeaways for each type of limit were as follows:

- Limits on holdings

The tiered model allows setting limits on holdings to address these risks. Furthermore, it is flexible enough to differentiate limits across Tier 2 platforms and across users within a given Tier 2 platform.

Setting different limits across several Tier 2 platforms would allow the Eurosystem to have, for example, a Tier 2 platform with stricter limits, but less stringent AML-CFT rules, to foster financial inclusion or for use by non-residents.

Likewise, differentiating limits across users within a given Tier 2 platform would enable taking into account differences in the legal nature and business models of each economic agent. In this regard, merchants could presumably benefit, at least on an intraday basis, from a higher limit than consumers would. To reflect this, the default limit configuration implemented in the experiment for

Tier 2 systems was customized for some accounts / wallets which were programmed to have higher holding limits.

Regardless of the amount, the introduction of a limit on holdings would raise a number of practical issues. **An incoming D€ transfer could lead to a breach of the holding limit, triggering two possibilities, both of which were tested in the experiment:**

- 1) An error message to the payer indicating a negative settlement outcome because the payee would breach its D€ detention limit. Given that the payee's balance is classified as transactional data with high confidentiality, this would result in a breach of the D€ payee's privacy and is not a viable option.
- 2) An automatic cash sweep to the payee's checking account (so-called "waterfall mechanism"), which was linked to its D€ account upon opening of the D€ account. In that case, the amount in excess of the threshold would be automatically converted into commercial bank money for example at the end of the business day. **This increases D€ settlement process's complexity and the number of D€ transactions in the system but the experimentation demonstrated that it could be a viable option: in the experiment, some wallets or accounts were configured in order to transfer the amount above the defined holding limit to a supervised intermediary's account so that this intermediary could credit the end-user's current account in commercial bank money**

- Limits on transaction flows

In addition to limits on holdings, the tiered model also allows the implementation of limits on transaction flows. These limits would apply to outgoing transactions only. Any transaction to another wallet or account above a predefined threshold would thus be automatically rejected. However, no limit on redemption should be implemented. Users would be able to convert freely D€ above this threshold into commercial bank money through their supervised intermediary. In the experiment, Tier 2 systems were configured by default to limit the maximum amount per transaction and set a maximum amount for transactions on a rolling 7-day period.

¹⁰ For example, French regulation bans the use of cash for payments over 1,000 EUR for consumers purchasing goods.

¹¹ Article 12.1 of the 5th Directive on the prevention of the use of the financial system for the purpose of money laundering or terrorist financing.

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5 Remuneration

As stated above, the introduction of a digital euro should not lead to disintermediation of the banking system. In addition, it should not disrupt the transmission of monetary policy. Designing a proper remuneration framework appears as a possible way to fulfill these two requirements. The experiment concluded that various remuneration frameworks, including **tiered remuneration**¹² **calibrated differently depending on the legal nature of the digital euro holder**, could be implemented to prevent the risks of substantial disintermediation and preserve the transmission of monetary policy. As was the case of limits, reliance on DLT Tier 2 platforms allows using programmable solutions to implement this remuneration scheme.

The following development illustrates a possible implementation of this type of remuneration for supervised intermediaries and end-users.

In the case of **supervised intermediaries**, one possible option would be to remunerate digital euro holdings in a similar way as banknotes pending distribution to end-users (i.e. remuneration at 0%). However, issuing a zero-remunerated CBDC in a negative interest rate environment – without limits on holdings – would encourage supervised intermediaries to demand large amounts of digital euro to avoid negative rates on their reserves, undermining the possibility to implement a negative interest policy (Bindseil and Panetta, 2020). On the other side, remunerating all digital euros holdings at negative interest rates – like reserves today - could lead supervised intermediaries to hold insufficient liquidity in D€ Tier 2 systems, limiting their ability to meet customers' demands and reducing the resiliency of the overall system.

A proposed solution to these issues would be to apply **tiered remuneration** to all deposits held by supervised intermediaries in Tier 1 and Tier 2¹³: in this setup, under a given threshold, supervised intermediaries' digital euro holdings would be treated like cash (i.e. not remunerated). These holdings would provide the necessary liquidity to meet retail demand should access to Tier 1 be temporarily disrupted. Above that threshold, supervised intermediaries' digital euro holdings would be treated like reserves, remunerated at the Deposit Facility Rate (DFR).

A similar reasoning would apply to end-users, where holdings up to a certain amount would be remunerated at zero or above and holdings in excess of this amount would be subject to a lower interest rates, which could be negative. Such a set-up would facilitate usage of D€ primarily as a means of payment while preventing the risks of large bank disintermediation. To complement this technical analysis, thorough impact assessments of a digital euro on the transmission of monetary policy should be conducted.

6 Programmability

Programmability is one of the value-added services that could be supplied to D€ end-users. From a technical point of view, programmability could be used for a number of use cases, including:

- (1) Programmable payments: in this business case, payments would execute automatically when specific, pre-defined conditions are met. Escrow-like functionalities where the reception of incoming assets releases the assets including for Delivery-versus-Payment and Payment-versus-Payment use cases, would also fall into this category.
- (2) Programmable money: programmability allows central banks to define the properties of money. It can endow the tokens with properties such as remuneration, limits on transaction amounts, whitelisting/blacklisting of some recipients.

While the ability to program an infrastructure to execute tasks automatically is hardly new, the emergence of distributed ledger technology paves the way for an increased use of programmability enabling new, innovative functionalities. This programmability can either be based on **smart contracts**, API or a combination of both.

A **smart-contract** is a digital version of logical condition that execute between parties, whose provisions are embedded into a piece of code, executing when some pre-specified requirements are met.

¹² The possibility to have a tiered remuneration was introduced by Panetta (2018), and subsequently developed in Bindseil (2020). In a tiered remuneration, digital euro holdings would be remunerated at a given rate under a certain thresholds while holdings above that threshold would be remunerated at a lower rate to disincentivize the use of digital euros as a store of value.

¹³ If remuneration only applied to Tier 1, banks could place large amounts of D€ on their Tier 2 accounts, hence the necessity of applying a remuneration to their consolidated D€ holdings.

SECTION 2: MAIN OUTCOME OF THE EXPERIMENT

On the other hand, an **API** is a layer enabling interfacing between two separate information systems. It allows a given information system to access data or initiate tasks on another information system.

From a technical perspective, the tiered model allows for the implementation of programmability through both avenues (smart contract, API), as highlighted in section 2.2. Indeed, the experiments confirmed the viability of both approaches by:

- Putting in place a common PSD2-like API, implying that programmability could be provided by Third Party Providers as is often the case today in conventional systems.
- Performing the experiment, for Tier 2 systems based on DLT, through the deployment of smart

contract for the creation of D€ tokens, their redemption, and payments, as well as limits and remuneration features.

However, the experiments did not benchmark these two methods, comparing and contrasting their respective merits. This analysis could be performed along different criteria, including **flexibility, accessibility, resilience** and **cyber-risk exposure**.

Finally, the Eurosystem would likely exercise some control over programmability deployed or implemented by intermediaries on behalf of their clients. This question is especially relevant in the case of DLT-based Tier 2 systems as intermediaries could directly deploy smart contracts in this case.



Conclusion

The work-stream combined feasibility – tiered approach experiment demonstrated that **combining centralized systems and DLTs was feasible from a technical point of view, as experiments successfully combined diverse technological components** (various types of DLT as well as a non-distributed ledger system) and linked them with existing systems. The successful testing of several use cases showed that the tiered approach is a suitable architecture for the issuance, distribution and exchange of digital euros, capable of accommodating some new functionalities (e.g. programmability).

Beyond these purely technical aspects, the tiered model also proved to be **able to address several open design questions and policy challenges** identified by the report on a digital euro, thanks to its open architecture and flexible design, as well as the high involvement from the private sector it allows.

The tiered approach's openness and flexibility also allows it to support the issuance of both retail CBDC and CBDC for interbank settlement.¹⁴ Beyond the retail use cases tested in the experiments, the addition of other Tier 2 systems would allow accommodating other usages, including wholesale use cases, such as the settlement of securities, cross-border and cross-currency payments.

¹⁴ Often referred to as wholesale CBDC in the literature.