

Design Principles and Best Practices of Central Bank Digital Currency

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Abstract

Central bank digital currency (CBDC) is the digital representation of a specific country's currency that is issued by the government of that country. It is a virtual representation of the currency in the form of a digital token based on Decentralized ledger technology (DLT). The growing interest in cryptocurrency and the declining need for cash in payments have paved the way for CBDC since they offer solutions to the problems created by conventional cash. However, CBDC is still in its infancy and developing; not many countries have invested in this. This paper covers 14 CBDC projects and analyzes them according to different factors such as availability, operating model, transactions, architecture, framework, anonymity, and security. As the current work undertaken on CBDC is in the exploration stage, the analysis could be subject to change with time, as new technology and techniques emerge. In this study, various scholarly articles and reports were used to gain information about the current trend of CBDC and their different projects. Furthermore, we have examined the essence of a CBDC.

Keywords: CBDC; design principle; best practice; DLT

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1. Introduction

This study will explore different CBDC projects and compare them with respect to their design and security principles. Central bank digital currency, more commonly known as CBDC, is the digital representation of a specific countries currency and is issued by the government of that country. It is a virtual representation of the currency in the form of a digital token. CBDC is country-specific and is based on DLT, similar to bitcoins [1]. However, CBDC remains in its infancy, and consequently only a small number of countries have invested in this [2]. China is leading in this field as they are already performing experimental trials with a digital yuan across several cities [3].

This study covers 14 CBDC projects and analyzes them according to different factors such as scalability, availability, transactions, architecture, and framework. The paper is organized in a way that related research into CBDC is first explained. These papers present the current state of CBDC and how each country has decided to implement them. CBDC is being implemented on the domestic level, and each CBDC represents the equivalent of that country's currency. However, the implementation of CBDC differs between various countries due to numerous factors such as the country's legal framework. This paper provides an analysis of the 14 CBDC projects undertaken by the various central banks and evaluates the best model for implementing CBDC considering this analysis. The evaluation of these 14 projects is achieved through comparison, and subsequent consideration of the most applicable model for the successful execution of CBDC. As the CBDC projects are currently in the exploration stages, the analysis can change with time as new technology and techniques emerge.

2. Related Study

For this study, various scholarly articles and reports were used to gain information about the current trend of CBDC and their different projects. One such project was launched by the United States, known as the digital dollar. This study aims to digitalize the US dollar [4]. A Bank for International Settlements (BIS) survey conducted in 2018 by Barontini and Holden, for Committee on Payments and Market Infrastructures (CPMI), asked central banks about their current work on CBDC. The report suggested that much of the work being undertaken was conceptual, and that there were no plans on issuing CBDC for

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the near future [5]. However, a year later, the survey was conducted again, and this time a fifth of the countries in the world was posited as being likely to issue CBDC in a short time. The rest were trying to understand the impact of CBDC and how they could use them [5]. The COVID-19 pandemic has caused this process to accelerate significantly since the case in the US where people must wait for more than one month for the emergency relief policy response by the government [5]. This can be seen through the exponential increase in market capitalization of cryptocurrencies from USD 18 billion in 2017 to USD 287 billion in 2019 [6]. Therefore, the digital dollar represents a third type of currency issued by the central bank, that is fully exchangeable with cash and reserves of the government [4]. With the advent of cryptocurrency, it is a logical progression for the central banks to shift their attention from conventional payment methods to CBDC, or else they will be left behind in the current technology dynamics. Central banks can issue different types of CBDCs depending on their situations, as currently they are limited to domestic use. However, CBDCs can be broadly classified into two types: wholesale token based and general purpose [5]. Since most CBDC is based on blockchain technology they use distributed ledger technology, although other options are also being explored [5].

Although CBDC are based on blockchain technology, many of them do not offer token-based systems fully anonymous access. Instead, CBDC use account identification for their access framework [5]. Transaction cost in the international trade has become the most important cost, followed by transportation costs for goods [6]. This cost can be very difficult to bear for low and middle-income countries, as banks on international trade since the banks charge approximately 20 basis points instead of the two basis points for domestic trade [6]. The growing interest in cryptocurrency and the declining need for cash payments have paved the way for CBDC, since they offer solutions to the problems offered by conventional cash [6]. Central banks have been researching CBDCs for a long as in 2014, such as the Central Bank of Ecuador launched a CBDC called "Dinero electrónico" [7].

3. What is CBDC

CBDC can be described as a digital currency that the central banks of various countries are now implementing with the increase of cryptocurrency in the financial landscape [7]. It is usually issued by, and as a liability of, the central bank or the monetary authority, managed through electronic means, accessible to the larger public, more widely accessible than reserves, interest bearing, and it can be used to settle payments or as a store of value. CBDC has a different operational structure as compared to other forms of money and has different forms of balances in traditional reserves or settlement accounts [8]. Various countries are now actively working to implement this cashless system, as cash in the digital age has become cumbersome, and problems associated with it have increased significantly [7]. CBDC advocates have also stated that if it were already implemented, governments worldwide would not have been so severely affected by pandemic [5]. CBDC has various approaches based on the different countries that issue them, for example, the digital dollar is divided into retail-based and wholesale-based payments [4].

3.1. Types of CBDC

Typically, the model followed by bitcoins, the popular cryptocurrency, can be seen as an example of token-based systems [9]. There is no third party required for authentications in token-based systems, and it can be directly transferred between parties [4]. Account-based systems provide a layer of authentication to this digital currency, therefore any transaction that takes place requires the validity of the parties involved [4]. Messages are sent to them both for confirmation, therefore, it can be seen as the extension of the existing bank framework. In account-based systems, the sender and receiver each have their balance updated, while in token-based, the token is directly transferred to the other party. Both account-based and token-based systems use digital ledger technology to store and process their transactions [4]. It can be argued that with the increase in the use of token based CBDC, there will be counterfeit tokens circulating in the market, as there is the case with physical cash. Consequently, a means to validate the tokens is crucial. Account-based tokens offer this authenticity, but they lose the anonymity or privacy that comes with the token-based systems [4]. As such, both systems require further exploration before it can be decided which is better for the future of CBDC. Figure 1 shows the comparison between token-based and account-based CBDC.

CBDC can also be divided into the two types of specific sectors they serve : retail and wholesale [8]. Retail CBDC and wholesale CBDC can be differentiated on the basis that one is available for use by everyone, and the other is limited to a particular faction of the people [9]. Physical cash is an example of retail CBDC, in that everyone uses it for a variety of transactions. Retail CBDC can offer portability and more straightforward transactions as compared to traditional cash. Wholesale CBDC describes the payments completed through a financial institution such as banks, that require accounts in the bank or related companies [4]. With the wholesale CBDC, many people without accounts can now work and be a part of this system.

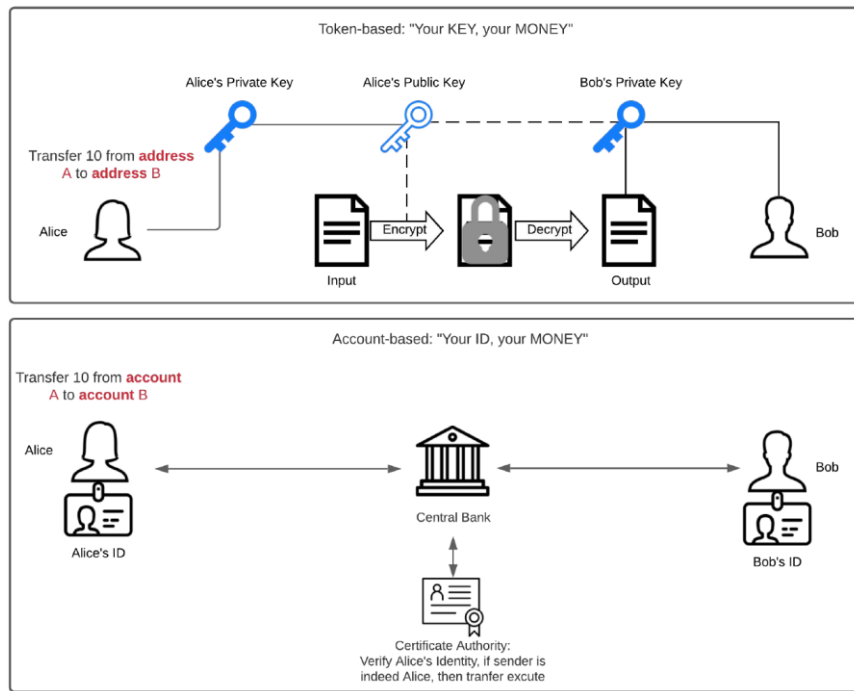


Figure 1. CBDC Access Model: token-based vs account-based

3.2. Benefit, Risk, and Trade-offs of CBDC as a Payment

Numerous benefits are offered by the CBDC, such as resilience, increased payment diversity, supporting public privacy, and improving cross-border payments [10]. CBDC, though overcoming the pitfalls and shortcomings of traditional cash methods, come with their own potential problems. These risks, if left unchecked, can lead to severe financial instability. Some of these factors are cyber-resilience, misdirection of funds, data loss or leakage, and third-party dependency of the CBDC [11]. A significant trade-off currently of the CBDC is the anonymity that cryptocurrency originally offers. Therefore, a significant drawback requiring a solution is the user anonymity in CBDC. Challenges faced by the governments include not only the security aspect of the process, but the design needs to be considered similarly [12]. The challenge centers around the implementation of appropriate architecture for the CBDC, that satisfies its original intention while ensuring the safety and security of the transactions [12]. Currently, three architectures have been identified: indirect CBDC, direct CBDC, and hybrid, a fusion of the previously mentioned two architectures [12]. Figure 2 shows the side-by-side comparison between those three architectures of CBDC.

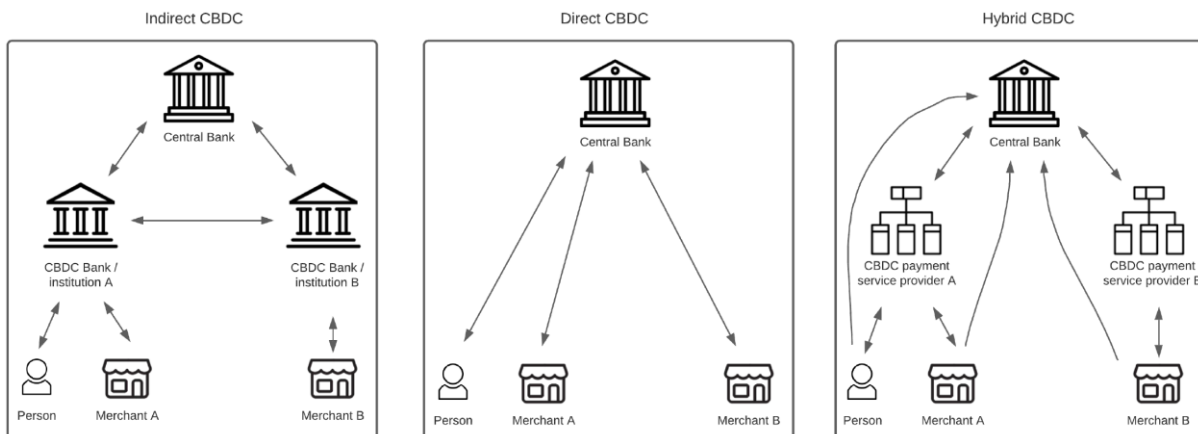


Figure 2. CBDC Architecture: indirect vs direct vs hybrid

4. CBDC Design Choice and Best Practices

This section will investigate, explain, and analyze some of the design choices for Central Bank Digital Currency in recent studies. Those studies have aimed to provide guidance and an identification of the best practices for CBDC design. Their main focuses and major contributions are shown in Table 1.

Table 1. The classification and major contributions of studies on CBDC Design

Category	Focus	Ref.	Year	Major contribution
Empirical analysis	Systemic review of CBDC	[9]	2021	Provided a systemic perspective of CBDC, including discussions on the purpose of CSDCs, CBDC proposals used in existing payment systems, risks and effect analysis of CBDC, proposed a CBDC banking model.
Empirical analysis	Technical review of CBDC	[7]	2020	Conducted empirical analysis on the motivations, drivers, and approaches for central bank to issue CBDCs, introduced technical challenges and solutions of CBDC, discussed taxonomy of CBDC.
Empirical analysis	Systemic review of CBDC	[4]	2020	Conducted empirical analysis on the motivations for US dollar to be tokenized, designed a model of tokenized digital dollar, use case analysis of CBDC, discussed taxonomy of CBDC.
Empirical analysis	Systemic review of CBDC	[6]	2021	Conducted empirical analysis on the challenges of existing cross-border payment systems, as well as the opportunities, risks, and benefits of CBDCs for international and domestic payment.
Empirical analysis	Survey on CBDC	[5]	2020	Give an overview of CBDC proposals, presented the motivations and opponents of CBDC, and showed the taxonomy of CBDC.
Guidance and best practice	Guidance for CBDC design	[13]	2019	Proposed a blockchain-based framework for CBDC, introduced key business processes of CBDC's lifecycle, explained the transaction process of CBDC for cross-border payment
Guidance and best practice	Guidance and best practice for CBDC design	[8]	2021	Introduced multi-tier ledger design, proposes ten enablers for CBDC mass adoption and implementation.
Guidance and best practice	Guidance for CBDC design	[14]	2021	Introduced the design principals and technical trade-offs of CBDC, provided a review on the motivations, challenges, and risks of CBDC for international and domestic payment
Guidance and best practice	Technical design choice of CBDC	[12]	2020	Introduced the design principals and technical trade-offs of CBDC
Guidance and best practice	Design choice of CBDC	[11]	2020	Examined key design considerations of retail CBDC, discussed CBDC insurance and policy, provide a structured framework for central bank to decide whether or not to issue CBDC.
Guidance and best practice	Technical design choice of CBDC	[15]	2020	Introduced the technical design challenges and state of the art solutions of CBDC

4.1. Operating Model Design

The transaction method of CBDC is not the same as the one used in physical currency. Since the transaction is performed in the digital world, it is only suitable for a digital ledger to maintain these transactions. The users' bank balance and other cryptocurrency data will be maintained in that ledger. This data will be maintained as a global state by the bank, and each transaction will be an update in the state such that the ledger will have each customer's transaction data in a single block [15]. Some rules need to be defined to perform these transactions, as without them blocks can be removed and become a liability of the system, causing problems such as transaction reversal. The central banks will primarily provide the issuance of CBDC, since digital currency being offered is against the assets in the central bank directly. The Payment Service Providers (PSP) will be granted the right to be intermediaries to the end-user. This is the general pattern currently being researched by the central banks, as they want to include as many vendors and end users as possible in the CBDC. Therefore, the Platform operating model is developed where the central bank issues the CBDC and the PSP use Application Programming Interfaces (API) to link themselves to the core ledger; hence the users can effectively use the CBDC [11]. This approach has been successfully implemented in China, where the People's Bank of China (PBC) issues the digital yuan, and the different PSP vendors offer them as a payment option in conjunction with physical money [8]. The transactions taking place in CBDC are not simply the exchange of digital currency, as previously stated in the paper, since CBDC is a token on the DLT.

4.2. Security and Privacy Design

The confidentiality, security, and availability of the CBDC need to be ensured for it to be successful, as is the case with any digital currency [15]. To accomplish this, CBDC uses distributed and decentralized technology. In distributed systems, the ledger data is maintained by a group of machines and it is kept in a geographically different location [15]. In case of a power outage, the data can then be used from the separate location, keeping different copies, and syncing them in real-time. Decentralized systems are a type of distributed system, but in their case the ledger is not under the control of a central authority [15]. In essence, decentralized systems are a mix of the following traits:

- 1) **Role Separation:** Role separation is the most critical part of a decentralized system as this is the weakest link and needs to be carefully managed. The account management role of payment Interface Provider (PIP) proposal by the Bank of England's CBDC is an example of a role separation in a decentralized system [15].
- 2) **Trust Dispersal:** When the role is separated in decentralized systems, the trust is similarly dispersed across the PIPs [15]. Therefore, each PIP deals with a limited population, restricting the amount of damage done by a PIPs fall. However, the risk here is that if the PIP serves a large enough population, it can even cause the system to fail as it would lose credibility quickly that is a PIP becomes too large, and its failure can now lead to the downfall of the system [15].

3) **Threshold Trust:** Threshold trust is where the user can choose whether to trust a single authority or not [15]. Users can also choose to spread their trust across multiple authorities such that no one authority has influencing power. In decentralized systems, the threshold trust can be offered by combining multiple authorities across a group of servers so that even if one of them is offline, the server can still function [15]. Similarly, this coalition cannot act alone but requires the approval of its members, similar to a board of directors. CBDC needs to offer some security safeguards since it is a digital currency aside from the cybersecurity threats the CBDC needs to have. These security attributes can either be tailored for the end-user or for the protection of the CBDC against threats to itself [3]. Some of these are as follows:

- **Double Spending:** Since each CBDC is unique (each token of the digital currency has a unique ID), steps needed to be taken to ensure that once transferred, no other spending can be undertaken [3]. This means that the CBDC held by the users' needs to be updated in real-time in the core ledger to reflect the current state of the user wallet. Using DLT in CBDC can achieve this desired effect as the ledger is distributed and replicated [11]. With this, the ledger needs to be simultaneous across the different distributed participants, effectively lowering the chances of double spending [8,21]. However, DLT lowers the central bank's control on the ledger. A tiered approach can also be used here while implementing the centralized architecture.
- **Replication/Forgeability:** CBDC, like physical currency, can face the problem of forged digital currency. While on the blockchain, it is guaranteed by using the proof of work approach popularly [3]. In the case of CBDC, considerations for this will vary according to the architecture chosen for the implementation. As such, before the spread of forged CBDC, anti-forging techniques must be embedded in the CBDC framework so that there is no financial risk associated with the widespread use of CBDC [3].
- **Verifiability:** For the successful implementation of the CBDC, the central banks need to develop validation techniques for CBDC offered by them. In central architecture, this is a considerable challenge financially because of the work involved in monitoring each transaction taking place [3,11]. However, in DLT, this burden can be alleviated somewhat since the validation and risk involved would also be borne by the PSP providing this service to the users [1]. The PSP providers will need to implement validation techniques so that the transactions can be performed successfully without the need for the central bank to invest their time and money in this endeavor [1].
- **Privacy:** Popular cryptocurrencies, such as bitcoin, offer anonymity and privacy to their users. Although this feature is also found in physical money, CBDC does not offer complete anonymity like them [3]. Since they need to monitor user transactions to ensure valid transactions occur and limit the amount any user can hold on to in their wallet [3]. If the central banks do not monitor the users' wallet and do not impose holding limits, it can quickly lead to banks runs in the worst cases [3,11].

4.3. Availability and Limitations Design

Constant user Availability of CBDC needs to be considered clearly since cases of power loss, cyber-attacks, and other factors can interfere in their distribution. CBDC is currently in the exploration phase, and each country is pursuing a different approach according to their country-specific factors that determine the attractiveness of their CBDC to the vendors and users [11]. Smart chip-enabled banknotes, rechargeable cards, and quick response (QR) based prepaid cards, are examples of CBDC being available to provide offline capabilities if any catastrophic situation occurs. CBDC pilots running in countries have imposed holding limits on them (e.g., the Bahamas "Sand Dollar"). so that it can be made as close as possible to cash [11]. If there were no limits on the amount that a user can hold in CBDC, it could cause a reduction in the demand for deposits, causing commercial banks reserve to decrease. This can lead to financial instability (as the banks will face a liquidity shortage), subsequently causing a market panic resulting in bank runs [8].

4.4. Smart Contracts and Programmability Design

Smart Contracts are code deployed on the blockchain [16]. The primary objective of smart Contracts is to spontaneously affect the terms of an agreement after specific terms are achieved. It can be written to enable participants to run specific features of transactions automatically [17]. Though not required for the CBDC to function on its own, smart contracts and programmability design provide a unique feature that existing digital currencies do not have [10]. Despite its benefit, due to the difficulty of updating the live smart contracts, it is of utmost importance that a smart contract is fully tested before employment outside the test network, as faulty smart contracts can expose business systems to security threats. A prominent example is the DAO and Parity hack which directly resulted in the total loss of over \$200 million worth of Ether due to the broken code in the smart contracts [18]. Common vulnerabilities and attacks do often exist in Smart contract specific programming languages (e.g., Solidity and LLL), such as mishandled exceptions, access control, unchecked return value, bad randomness, race condition, timestamp dependency, and short address [19,20].

Some CBDC will most likely never offer the capability of programming the Smart Contracts to general public, such as the digital yuan, since it can be argued that it separates the CBDC from its intended purpose [11]. It provides the ease of programming the contract in currency but makes CBDC more like a contract than a digital currency. This can cause a shift from the need for a traditional contract required for a transaction to just transacting CBDC, as it offers them both [11]. In a DLT-based platform, there is no need for arbitrators to enforce these contracts as they are self-executing and self-enforcing due to being programmed in the CBDC. However, this could cause the CBDC to transition to a form of negotiable security and therefore make the CBDC currency circulation slower. There are three approaches advocated for smart contracts in the CBDC [11]. The first is to aim for maximum programmability of the CBDC, that is making use of the full potential offered by smart contracts. The second approach is to separate smart contracts from CBDC and make it a separate module, removing this functionality from the core ledger. The third approach ensures this functionality affects the core ledger minimally and allows the PSP to create the programmable functionality while setting up security standards so that the smart contracts can function efficiently and securely between the user and PSP.

4.5. State-of-the-Art CBDC Design and Solution

Since the CBDC approach followed by each country is different, there are various ways to implement the CBDC. Each country is conducting pilot projects to find the best way to implement them [11]. CBDC, though inspired from the blockchain technology, do not necessarily need to follow the same pattern as seen by the example of the PROC, which does not use it in their CBDC but instead uses the Digital Currency Electronic Payment (DCEP) [8]. DCEP used by the PROC follows a tiered approach and has shown great promise as their digital yuan has been running successfully in multiple cities [8]. Therefore, a tiered approach is best followed in the case of successful CBDC implementation by the central banks of the different countries. However, this depends on the country-specific factors [8,11]. In a single-tier model the central banks can perform all the tasks, from issuing CBDC, to redeeming it, maintaining the user wallets, and all transaction-related tasks [11]. While in a multi-tier model, the central bank needs to involve the private sector for various services (e.g., distribution and payment services) but the issue and redeeming of CBDC is retained by the central bank [11]. Figure 3 shows the side-by-side comparison between a single-tier model and a multi-tier model of CBDC.

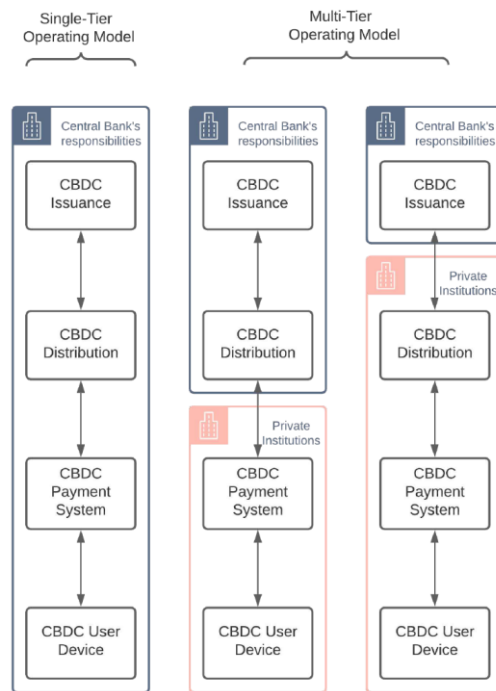


Figure 3. CBDC Operating model: single-tier vs multi-tier

Presently CBDC has another form known as synthetic CBDC (sCBDC), that in essence are offered by the private sector payment service providers (PSP) against assets held in the central bank. These are not CBDC since the user would not have a claim at the asset in the central bank [10,22]. Instead of this, the platform model offers a better approach for fast implementation of CBDC, since the central bank would allow private-sector payment interface providers (PIP) direct access to the core ledger, but the access will be regulated and monitored, with this the user can easily use the CBDC through the PIPs [11]. Similarly, this multi-tiered model is more accommodating, allowing third parties to build on top of the existing structure, thus speeding up the integration of new technology in CBDC [11]. The PBC is an example of this, as they have piloted a two-

tier model that allows selected banks and payment platforms to distribute the CBDC to the end-user [11]. Figure 4 shows a simple operation model of a sCBDC.

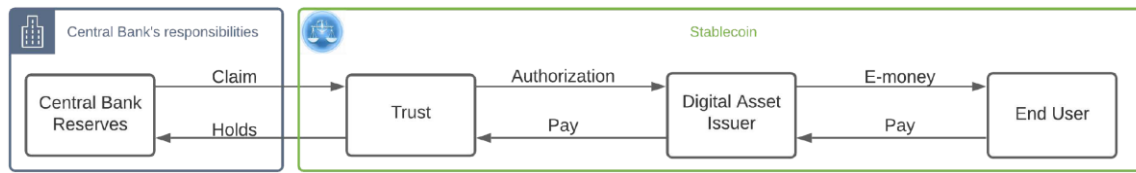


Figure 4. sCBDC Operating model

5. Comparison of the CBDC Projects

The 14 CBDC projects chosen for evaluation and analysis are E-ringgit, E-ruble, E-AUD, Digital-Yen, E-euro, E-hryvnia, Bakong, E-pound, Digital Fiat, E-euro, DC/EP, Sand Dollar and Rafkróna. The projects have been launched respectively by the central banks of Malaysia, Russia, Australia, Japan, France, Ukraine, Cambodia, United Kingdom, Brazil, European Central Banks (ECB), PRC, Bahamas, and Iceland. The key design choices of the included CBDC projects are summarized in Table 2, which provides a comprehensive classification based on 11 attributes, among which 7 are related to the functional design, and 4 are related to the non-functional design.

5.1. System Architecture, Framework, and Operating Model Aspect

The digital yuan uses a two-tier architecture and it is issued by the PROC. The digital yuan is not a third party coin based digital currency, but made using DCEP, since the PROC has banned all cryptocurrency [23]. The E-euro has been developed by the European System of Central Banks (ESCB) in DLT by their EURO chain research network and uses a two-tier model [24]. The architecture used in the Rafkróna is made by keeping in mind the real-time gross settlement system used by the central banks it is made with DLT that is Jasper [25]. Sand Dollar follows a similar approach as DLT, however, some of the features have been deprecated, such as anonymity [26]. Tokens made from small digital signed registers are used to make the Digital Fiat Currency that can represent the possession of arbitrary value of a person or legal entity [21]. The CBDC, in the case of Malaysia, works on the DLT, following a decentralized system [27]. In Malaysia, it is regarded as the government cryptocurrency employed through a direct architecture. However, various frameworks have been suggested on how they could be implemented in the country. The design and architecture of CBDC are quite distinguished from the private digital currencies and the e-money [27]. On the contrary, the digital ruble (or the e-ruble) is actively gaining stimulus in the Russian banking sector. The government has introduced CBDC, which works through a multi-level framework to function securely [28]. It is designed by employing the DLT, following a centralized infrastructure. [28]. The e-AUD, or the CBDC of Australia, is also progressing towards a digital currency transition employing a self-regulated framework used on a blockchain platform [29]. The e-AUD follows the New Payments Platform (NPP) as its payment infrastructure. It also encourages the users to join the NPP either as a direct participant, indirect participant, identified institution, or connected institution. [29].

The Digital-yen or the CBDC in Japan is currently not structured or backed by the Bank of Japan [30]. However, the country has projected to work on a “general purpose” CBDC that would provide maximum utility to the people. The Digital-yen would be working on a two-tiered payment and settlement system of both private and central banks [30]. The Japanese CBDC would also support an offline system that enables maximum efficiency to the users [30]. The payment instrument it would utilize will be a direct liability of the central bank, ensuring both security and protection to the users. The E-Euro of France, which falls under the framework of the Eurosystem, would provide a beneficial payment and transaction method to the EU Member States [31]. The introduction of CBDC in France would allow the central banks to provide a solution to settle transfers of tokenized securities that maintain both the DLT environment's benefits, for instance, peer-to-peer management [31]. The CBDC of Ukraine, also known as the E-hryvnia, is linked not only to the digital cash, but also serves the purpose of interbank settlement, an efficient monetary policy instrument, and the equivalent of an account opened at the central bank [32]. The e-hryvnia is also legislated under the EU Directive PSD2 [32]. The CBDC in Ukraine considers the use of DLT and is implemented through the Electronic Hryvnia Platform [32]. CBDC in Cambodia is regarded as Bakong [33]. Bakong allows the users to indulge in monetary transaction activities through the National Bank of Cambodia (NBC) mobile application [33]. Still, significant progress remains to be made by the government to expand the digital money in Cambodia further [33]. The CBDC in England is yet to be introduced. However, it would be regulated under the Parliament after the formulation of a policy framework [34]. Unlike other countries' CBDC, England is not yet assured to be using the CBDC based on DLT as it promoted decentralization, data sharing, and the use of cryptography. Instead, England would require a core ledger and a technology platform to introduce CBDC all over the country.

Table 2. The key design choices of the 14 CBDC projects

CBDC Project	Country	Status	System Design									
			Architecture	Operating model	Infrastructure and framework	Domestic or International	Wholesale or Retail	Access technology	Plan of issuance	Performance and scalability	Security	Privacy
Rafkrona	Iceland	Research	Direct	Single-Tier	DLT, Jesper	Domestic	Both	account-based	connecting with existing payment system	Moderate	High	Moderate
Sand Dollar	The Bahamas	Pilot	Direct	Single-Tier	DLT	Domestic	Retail	account-based	connecting with existing payment system	High	Deprecated	High
DC/EP	China	Running	Hybrid	Multi-Tier	Conventional database and DLT	Domestic and semi-international	Both	semi-account-based	connecting with existing payment system	High	Low	Moderate
E-euro	ECB	Research	Hybrid	Multi-Tier	DLT, Corda	Domestic and International	Retail	Both	ND	High	High	Very High
E-krona	Sweden	Pilot	Hybrid	Multi-Tier	DLT, Corda	Domestic	Wholesale	Both	digital complement to cash	Moderate	High	Moderate
Digital Fiat Currency	Brazil	Research	Hybrid	Multi-Tier	DLT	Domestic	Retail	token-based	ND	Moderate	High	Moderate
E-pound	United Kingdom	Research	Hybrid	Multi-Tier	DLT	Domestic	Retail	account-based	ND	High	Low	ND
E-hryvnia	Cambodia	Pilot	Direct	Single-Tier	DLT	Domestic	Retail	account-based	ND	ND	Low	ND
Bakong	Ukraine	Research	Hybrid	Multi-Tier	Conventional database and DLT	Domestic	Both	account-based	Issued the limited volume	Moderate	Moderate	Moderate
E-euro	France	Research	Direct	Single-Tier	DLT	Domestic	Retail	token-based	ND	High	High	Moderate
E-ruggit	Malaysia	Research	Direct	Single-Tier	DLT	Domestic	Both	account-based	ND	ND	Low	ND
E-rouble	Russia	Research	ND	Multi-Tier	Multi-Level	Domestic	Both	account-based	ND	High	Low	ND
E-AUD	Australia	Research	Direct	Single-Tier	Self-Regulated Blockchain	Domestic	Wholesale	token-based	Compatible with EU Member State	High	High	ND
Digital-Yen	Japan	Research	Indirect	Multi-Tier	ND	Domestic	Retail	account-based	Private and central bank	High	Low	ND

Built on the DLT, the E-euro uses a simplified form of the proof-of-concept environment. Here the users' privacy and security are taken into account while simultaneously enforcing the AML/CFT regulations [24]. Rafkróna is made on Jasper, which is based on the DLT developed by the central bank of Iceland [25]. The digital yuan is built with the DLT in mind and follows the tiered approach where the PROC issues the CBDC and PSP is responsible for the users [23]. Sand Dollar uses the DLT but maintains a centralized Know Your Customer (KYC) infrastructure so that the customer transaction can be validated. Consequently, it does not offer anonymity since it uses the transactional data from this KYC infrastructure [26].

Concordia is the DLT platform used by E-euro, that is responsible for the transaction remaining the same throughout the ledger. Concordia updates the information in the system and ensures the information is not shared with others [24]. The E-euro has four entities the central bank, two intermediaries, and the AML authority to ensure the regulations of AML/CFT are being followed [24]. Rafkróna can be transacted in the same way as physical cash would be stored in a card or wallet, and if that is stolen, it would be the same as losing one's conventional wallet, effectively meaning that Rafkróna will be lost [25]. The approach followed by the digital yuan is tiered; hence the PBC is mainly concerned with the issuance of the digital yuan, while the PSP is responsible for the provisioning of digital yuan to the user [23]. Sand Dollar is made with the intention of inclusion of everybody in the system. As such, anyone can open an account with their mobile wallets with no need for bank accounts. However, no interest will be offered on the deposit in this digital currency [26].

5.2. Security and Privacy Aspect

The E-euro is made in compliance with the Anti-Money Laundering/Combating the Financing of Terrorism (AML/CFT). The transactions performed offer not only privacy to the user, but they effectively offer a solution to the AML/CFT problem faced in digital currency [24]. To do this, the E-euro offers anonymity vouchers so that the users can perform the transactions anonymously, as seen in the case of physical money. However, this transaction is limited by the amount and the number of vouchers a user has. Only a limited number of vouchers will be issued per year. Therefore, limiting the E-euros in the use of AML/CFT [24]. The privacy offered by Rafkróna is high since both intermediaries involved have pseudonymous identities, which ensure anonymity and use network address for CBDC payments [25]. The digital yuan is centralized; hence anonymity of the user is not possible which the AM/VFT are appropriately addressed [23]. Sand Dollar does not offer anonymity to the user, but it guarantees that the privacy and security of the user are safeguarded [26]. Sand Dollars use a secure tokenized environment to perform payments through mobile phone, sales, or business [26].

5.3. Performance and Scalability Aspect

The performance of the E-euro has not been tested in a realistic environment and is just theoretical research undertaken by the EUROchain research network. From their research, it can be seen that if launched as a CBDC, it will nevertheless perform better than some of the projects discussed, such as the Rafkróna in performance [24]. The growth potential of the E-euro is excellent since it follows the two-tier models, including PSP in their CBDC system, while enforcing the AML/CFT protocols [24]. Jasper, used by the Rafkróna, is known to have a negative score on the security side as it has operational risk and monetary settlement [25]. Therefore, its performance and scalability are low since it has glaring issues in the model with which it is implemented. Unless a solution to these issues is raised, the Rafkróna will not be able to be used as a CBDC [25]. Performance of the digital yuan has been outstanding so far and is expected to increase with time. The potential for growth is immense as the PSP providers are offered the ability, albeit slightly, to work with the core ledger by offering the user the services [23]. The growth potential of the Sand Dollar is low since the anonymity feature that the digital currency is being undermined [26].

6. Conclusion

CBDC has many different architectures and frameworks, but from the paper, the indirect approach is the most optimal solution in implementing CBDC. Without involving the PSP, the process of regulating and validating can cause a large amount of financial and workforce drain on the central bank implementing it. Therefore, the case where the PSPs is included in the CBDC makes this burden minimal for the central bank. They need only to enforce regulations such as AML/CFT and validate the payments. Similarly, the CBDC attributes offered by the central banks vary where some follow the conventional cash as the example, while others model CBDC to be an effective substitute when cash is unavailable.

The cost and impact of the CBDC depend on the architecture and the framework chosen and whether the CBDC is following the properties of conventional cash, or is an alternative to cash, and being offered alongside it while having lesser features. From the evaluation of the projects, it can be seen that the CBDC issued by different central banks varies widely and is and differs depending on respective country-specific factors.

This paper offers a comprehensive analysis of the current projects pursued by the various central banks, some of which are just researches but some have already begun testing. Analyzing them has shown us that CBDC pursues the qualities provided by conventional cash in digital currency but implementing them has been a challenge for the central banks while enforcing the AML/CFT requirements leading to a difference in approach by the central banks, which has given rise to the sCBDC which shows us that CBDC may result in different end results as implementing physical cash properties in CBDC is a considerable challenge, and this will need to be researched further before it can be implemented like cash. However, it can be an excellent substitute for when cash is not available since its distribution is straightforward by the central banks.

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